THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1908.

PARTS 3–4.

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1908.

Parts 3-4.

The Institution of Mechanical Engineers.

PAST-PRESIDENTS.

GEORGE STEPHENSON, 1847–48. (*Deceased* 1848.)

ROBERT STEPHENSON, F.R.S., 1849–53. (*Deceased* 1859.)

SIR WILLIAM FAIRBAIRN, BART., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

JOHN PENN, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

JAMES KENNEDY, 1860. (*Deceased* 1886.)

THE RIGHT HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869. (*Deceased* 1900.)

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JOHN RAMSBOTTOM, 1870–71. (*Deceased* 1897.)

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JOHN ROBINSON, 1878–79. (*Deceased* 1902.)

EDWARD A. COWPER, 1880–81. (*Deceased* 1893.)

PERCY G. B. WESTMACOTT, 1882–83.

SIR LOWTHIAN BELL, BART., LL.D., F.R.S., 1884. (*Deceased* 1904.)

JEREMIAH HEAD, 1885–86. (*Deceased* 1899.)

SIR EDWARD H. CARBUTT, BART., 1887–88. (*Deceased* 1905.)

CHARLES COCHRANE, 1889. (*Deceased* 1898.)

JOSEPH TOMLINSON, 1890–91. (*Deceased* 1894.)

SIR WILLIAM ANDERSON, K.C.B., D.C.L., F.R.S., 1892–93. (*Deceased* 1898.)

SIR ALEXANDER B. W. KENNEDY, LL.D., F.R.S., 1894-95.

E. WINDSOR RICHARDS, 1896–97.

SAMUEL WAITE JOHNSON, 1898.

SIR WILLIAM H. WHITE, K.C.B., LL.D., D.Sc., F.R.S., 1899–1900.

WILLIAM H. MAW, 1901–02.

J. HARTLEY WICKSTEED, 1903–04.

EDWARD P. MARTIN, 1905–06.

The Institution of Mechanical Engineers.

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1908.

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SECRETARY.

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The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, Westminster, S.W.
Telegraphic Address :—*Mech, London.* Telephone :—*Westminster*, 264.

The Institution of Mechanical Engineers.

PROCEEDINGS.

July 1908.

The Summer Meeting of the Institution was held in Bristol, commencing on Tuesday, 28th July 1908, at Ten o'clock a.m.; T. Hurry Riches, Esq., President, took the chair in the Hall of University College, Bristol, after a Reception by the Right Hon. the Lord Mayor, Alderman Sir Edward B. James; the Sheriff of Bristol, Colonel H. G. Cary Batten; Professor C. Lloyd Morgan, Principal of University College; and J. Weston-Stevens, Esq., Chairman, and the Members of the Reception Committee.

The Lord Mayor said he was glad to be able to be present to extend a warm welcome to the members of the Institution. England's prosperity was in a large measure due to her engineers. The Civil Engineer constructed their docks and waterways, made their railways, was responsible for their water supplies and excellent sanitary system, but it was the Mechanical Engineer who invented the splendid machinery which enabled those great works to be carried out. Our marked superiority on the seas, which made England the greatest ocean carrier in the world, was due to the magnificent fleet of steamers constructed by the great mechanical engineers of this country, and he was glad that day to receive them in the ancient and historic city which built the pioneer of that great fleet and sent it first across the Atlantic Ocean. The cotton spinner, cloth weaver, and silk worker owed their existence to the perfection

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(The Lord Mayor.)

of the machinery which enabled the manufacturer of this country to compete with the other nations of the world. And not only was that the case with textile fabrics, but in the building up of every great industry in their midst the mechanical engineer played a decisive part. An Institution which fostered and encouraged the interests of such an important class in the community as the mechanical engineers was worthy of the support and recognition of every great manufacturing centre, and he had the greatest pleasure that day, in the name of his fellow-citizens as well as himself, to extend to the President, Council, and Members of the Institution of Mechanical Engineers a most hearty welcome to the City. His pleasure was enhanced by the fact that the father of the Lady Mayoress, the late Sir George Edwards, thirty-one years ago performed the same pleasing duty as Chief Magistrate of the City. There was another interesting coincidence in connection with this year's visit. The Chief Magistrate in 1877 said (and he quoted from a local paper dated 26th July of that year), "the inhabitants had lately been turning their attention to various matters, and in the course of his year of office they had opened a large dock at the mouth of the river, by means of which they could now receive any ship afloat," and in 1908 the Chief Magistrate of that day might use exactly the same words of the Royal Edward Dock, so recently opened by His Majesty the King, and which he trusted the members would all visit.

In looking over the programme, he noticed that while business was kept well to the fore, there were social functions arranged, and excursions to places of interest in their beautiful neighbourhood, not only for themselves, but also for the many ladies who accompanied them, and to whom he extended, on behalf of the Lady Mayoress and himself, a most cordial welcome. The Institution had come to no mean city, and there were few manufacturing centres where there was such a happy combination of the practical and the beautiful. He trusted they would all make time—especially those who had not been there before—to become acquainted with the City, a City renowned for maritime activity and discovery, with many objects of architectural interest, a City, as it had justly been called, of Churches, many of which were of pre-eminent beauty, and while retaining so much that was old and picturesque, a present-day city with the most modern improvements. He trusted that when they had seen the Avon Gorge, the Downs, and the suburbs, and the beauty of the scenery in the immediate neighbourhood, they would say they were worthy of the visit, and feel also that as citizens they should be justly proud of Old Bristol. Once more he desired to say he was delighted to welcome them, and trusted the Institution would not allow thirty-one years to elapse before they honoured the City with another visit, but would give the citizens of Bristol an opportunity of welcoming the members of the Institution long before that period had expired.

Principal C. LLOYD MORGAN, LL.D., F.R.S., said he was exceedingly sorry that Mr. Lewis Fry, the Chairman of the Council of the University College, who fully intended to be present and extend to the members, in company with the Lord Mayor, a hearty welcome to the College and to the City, had written to say that he was unable to leave his house; and it therefore fell upon his (Principal Lloyd Morgan's) shoulders to say a few words in support of what the Lord Mayor had already put so well. The University College welcomed the Institution most heartily to the building, and hoped they would find it convenient for their purposes. It had fallen to his lot to propose to the Council of the College that the Hall and the adjoining offices should be placed at the disposal of the Institution, and the Council at once said that every facility that he and his colleagues could afford to the Institution should, as a matter of course, be rendered. He therefore welcomed the members most heartily to the College as part of the City. For many years in connection with the University College, and elsewhere in the City, education in the matter of engineering had not by any means been neglected; and, as the members might be aware, the hope was cherished that ere very long the College in which they were met would become only a part of a larger whole in the City of Bristol, which would be called the University of Bristol; and he

(Principal C. Lloyd Morgan, LL.D., F.R.S.)
thought there was no doubt that in that University ample provision would be made to continue at, it was hoped, a yet higher level the engineering education which had been carried on there and elsewhere in Bristol for a good many years.

He rejoiced to see such a goodly attendance, and also the brilliant sky overhead. He hoped the meeting would be in every way a success, not only in the matter of the Papers read, but also in the facilities afforded for the enjoyment of the beautiful country around, and in that which always seemed to him one of the most important features of such a gathering, namely, in the opportunities for coming into personal contact with those who followed the same lines of thought as themselves; because it seemed to him that it was not merely in the formal Papers, in the pleasant gatherings, the good hospitality and so on which they experienced, but also in the friendly converse with those who were engaged in the same great pursuits that the success of such a gathering mainly lay. Therefore, without further words, he ventured to support what the Lord Mayor had said in welcoming the members to the City of Bristol, and to assure them that Mr. Fry, had he been present, would have welcomed them most heartily to the University College of Bristol.

The PRESIDENT, in acknowledging the welcome, said that the Lord Mayor in the remarks he had made had raised up old memories in his (the President's) mind of the visit which the Institution last paid to the City. On that occasion, thirty-one years ago, he was more or less a young man, as the members would readily conceive, and he then had the honour of presenting to the meeting a Paper, which at the time created a great deal of interest, on the rescue of entombed Welsh miners.* He remembered, as the Lord Mayor had been good enough to remind them, the kindly welcome which was extended to the Institution by the then Mayor of the City, and they were also cordially welcomed by the Master of the Society of

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* *Paper* on "The Tynewydd Colliery Inundation, with particulars of the appliances used for rescuing the miners and recovering the workings." Proceedings 1877, page 221.

Merchant Venturers. He also remembered with a great deal of pleasure, not untouched by regret, that his old friend, Mr. Thomas Hawksley, whose son he was pleased to see in front of him at the present meeting, was the President of the Institution, and extended to him and to all the young men of the Institution very cordial sympathy and encouragement to go on and do better. The present was not the occasion for him to attempt to make anything like a long speech; but he was sure the members would join with him, as was customary on such occasions, in most cordially thanking his Lordship and the ladies and gentlemen of Bristol for their very kind extension of welcome that morning, and for the delightful programme which the Local Committee had been good enough to provide for their entertainment during the week. He hoped most sincerely that the suggestions of Principal Lloyd Morgan might be fully realised, and that Bristol ere long would have its own University. There was certainly no body of men who more heartily supported every movement for the higher technical education of the people than the members of the Institution of Mechanical Engineers. It was of vital importance that the engineers of the future should be educated to the highest possible degree. But whilst that was necessary it was also advisable, indeed imperative, that they should have a thorough knowledge of the practical workshop details of their profession. Theory was most useful, but so was practice, and unless the two were combined they could not hope to make an efficient engineer.

His Lordship had been good enough to call attention to the work of mechanical engineers. He himself remembered in the early stages of his life being taken round by his father to the old shipbuilding yards of Messrs. Hill and Sons, alongside the Floating Harbour. At that time a number of gun-boats were being built in those yards for the English Government during the Crimean War. It occurred to him as strange that Bristol, which had sent out the first steamer across the Atlantic, and had built some of the first-class ships in the early days of steam navigation, did not today quite hold its own in that direction. Why was that the case? Bristol certainly had a great many advantages. It was close to the sources of coal and

(The President.)

steel, and could get all the parts and details of shipbuilding readily, while it certainly had plenty of money with which to transact such a business. Why did not the people of Bristol recover that old industry, and build at least for the requirements of the Bristol Channel? He was sure his friends of the North would not find fault with what he said. As a Bristol Channel man he often felt that, with all the money which was sent out by the owners and capitalists of the district, Bristol as well as Cardiff ought to see that some of the money was spent in their own localities. His Majesty said to them the other day that Bristol stood at the gates of the Western Ocean. So it had always been, and it was for many years absolutely the leading port dealing with the African and many other trades. He remembered the "Guineaman" coming home; he remembered the fruit vessels, the "Bluejacket" and the "Redjacket," which used to run to St. Michael's. Bristol was then pre-eminently the greatest ship-owning port of the Bristol Channel, and did far and away the biggest trade. Bristol was still the headquarters of the import trade of the Bristol Channel, but it had not the quantity of exports that some of the neighbouring ports had. It was so closely allied and associated, however, with the ports on the other side of the Channel that he felt they ought collectively to command a vast amount of the maritime and commercial work of the country. He hoped that Bristol in the future would wake up to the fact that things were possible to her which at present she did not appear to care for. It was to be hoped that Bristol and the Bristol Channel ports would always hold a pre-eminent place amongst the great ports of the Kingdom, and that Bristol, the oldest and proudest city of the Bristol Channel would be, as it deserved to be, the leading port, and furnish, as it must do, a vast amount of the capital required for keeping commercial prosperity in this part of the Kingdom. He thanked the Lord Mayor and the ladies and gentleman present for giving him the opportunity of saying those few words; and perhaps on another occasion he might have the opportunity of being a little more reminiscent of his memories with regard to Old Bristol.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following one hundred and one candidates were found to be duly elected:—

MEMBERS.

ADLAM, EDWIN GEORGE,	Bristol.
BALL, RALPH HILL CODRINGTON, Engineer Comm., R.N.,	Manchester.
BECHER, ROBERT ARNOLDS,	Goa, India.
BÉLIARD, HENRI JEAN PIERRE,	Antwerp.
BISHOP, WILLIAM GEORGE,	Uitenhage.
BURNET, CHARLES DOUGLAS,	Carlisle.
DAMANT, WALTER SANCROFT, Engineer Lieut., R.N.,	Portsmouth.
DAVY, BERNARD JOSEPH,	Sheffield.
GERBBIATEFF, JOHN THEODORE, Colonel, I.R.A.,	St. Petersburg.
HARDY, WILLIAM EDWARD,	Vienna.
HOLMES, JOSEPH CORNELIUS,	London.
KLOPP, GEORGE ONNO HOMFELD,	London.
KOZIELL, JOSEPH POKLEWSKI, Engineer Capt., I.R.N.,	London.
KROTO, GEORGE,	Tokyo.
METCALFE, ARTHUR WHARTON,	Cheddar.
MORRISON, FREDERICK THOMAS,	Cape Town.
ROGERSON, ALBERT CHORLEY,	Manchester.
ROOKE, WILLIAM MASON,	Yokohama.
TOMPKINS, ALBERT EDWARD, Engineer Comm., R.N.,	Portsmouth.

ASSOCIATE MEMBERS.

ABRAHAM, GRIFFITH,	Cardiff.
BAIN, DAVID BALFOUR,	London.
BERNER, CORRÈZE AAGE OSCAR,	London.

BORNER, OTTO LEO,	London.
BROWN, CLEMENT,	Birmingham.
BROWN, ROBERT HARRY,	Birkenhead.
BURCHALL, WILLIAM BALLANTYNE,	Stockport.
BURT, LESLIE NEWMAN,	London.
CACHEMAILLE, EUGENE DÉSIRÉ,	Wellington, N.Z.
CARR-GOMM, MARK CULLING,	London.
CARTER, EVERSHED,	Stamford.
CARTER, FRANK,	Stamford.
CARTER, HAROLD THOMAS,	Calcutta.
CLARKSON, WILLIAM ALAN,	Valparaiso.
COOK, GEORGE HENRY,	London.
CRAWFORD, JAMES FORRESTER,	Glasgow.
CUMMING, WILLIAM MILLIGAN,	Yokohama.
CURRIE, RICHARD SEDGWICK,	London.
DADABHOY, HORMASJEE RATANSHAW,	London.
DIXON, WILLIAM,	Leeds.
FOWLER, HAROLD,	Manchester.
GILL, RICHARD DUNCAN,	Camborne.
GOODCHILD, GEORGE WILLIAM PEPYS,	London.
HAMILTON, BELTON TATTNALL,	London.
HAY, ALEXANDER STANLEY,	Yokohama.
HEMER, WILLIAM HENRY,	Birmingham.
HENDRY, CHARLES ARTHUR JOHN,	Calcutta.
HICK, CHARLES,	Cardiff.
HOLL, WILLIAM ESPLIN,	Bombay.
HUNTER, JOSEPH MOORE,	London.
ILIFFE, REGINALD JOSEPH,	Liverpool.
JOHNSON, FRANCIS WILLIAM,	Cambridge.
KERR, NORMAN,	Glasgow.
KNIGHTS, HENRY NEWTON,	London.
LANDER, CECIL HOWARD,	Manchester.
LE MASURIER, JAMES,	Singapore.
LITTLEJOHN, WILLIAM JOHN,	Subiaco, W.A.
LIVERMORE, ALFRED ERNEST,	Bristol.
MACKIE, RONALD HASTINGS,	Insein, Burma.

Matthews, James,	Wolverhampton.
McPherson, John,	Calcutta.
Methuen, James Allin,	Umtali, Rhodesia.
Miaskowski, Paul August Herrmann v.,	London.
Millington, William Ernest Wyatt,	Manchester.
Page, John Henry,	London.
Pearson, George Armstrong,	Hull.
Peck, Herbert Horace,	Henley-on-Thames.
Pemberton, Alfred,	Erith.
Redfern, Charles Julian,	London.
Seagrief, Charles William,	London.
Shearer, William,	Edinburgh.
Spalding, Edmund William,	Lincoln.
Stewart, Charles John,	London.
Swain, Edward Henry,	Pontypridd.
Thomas, Adolphus Henry,	London.
Waite, William Vincent,	Edinburgh.
Walker, Frank Egerton,	London.
Ware, Edward Samuel,	Manchester.
Watson, Francis Renton Barry,	Bristol.
Watts, Richard Edward,	Stamford.
Wilcocks, William John Richard,	London.
Wimbush, Henry Lawrence,	Johannesburg.

GRADUATES.

Armitage, Herbert Cyril,	Grantham.
Bird, Percy Carr,	Fraserburgh.
Dowling, William,	Glasgow.
Essery, Thomas Henry,	Birmingham.
Godfrey, Henry Ronald,	London.
Goodall, Harry David Ernest,	Reading.
Hayes, Morgan Wilfrid,	Portsmouth.
Hooper, William Frederick,	London.
Jones, Edgar Price,	Crewe.
Langdon, Douglas Eckley,	Junin, Arg. Rep.
Leese, John Scurr,	London.

MATTHEWS, ERNEST, ...	Eccles.
MOORE, EARLE SIDNEY CHARLES, . .	London.
PEARSON, VERNON, ...	St. Leonard's-on-Sea.
QUINTON, WALTER RICHARD, . . .	London.
SIBETH, EDWARD FRANCIS, . . .	Penzance.
STEPHENS, CHARLES VIVIAN, . . .	London.
STRANGWAYS, GUY ERNEST ALAN, . .	London.
WARING, HORACE, ...	Leeds.
WOODS, EDMOND WILLIAM, . . .	Bishop's Waltham.

The PRESIDENT announced that the following twelve Transferences had been made by the Council:—

Associate Members to Members.

ALDERSON, CHARLES ALBERT HESELTON, .	Alexandria.
ALDERSON, GEORGE ALEXANDER, . . .	Alexandria.
BELL, CHARLES SEVER, ...	London.
BRITTON, SYDNEY ERNEST, ...	Chester.
GIBB, MAURICE SYLVESTER, . . .	West Hartlepool.
HEYWOOD, THOMAS EDWARD HETT, . .	Penarth Dock.
LIMPUS, ARTHUR EDWARD JEWERS, . .	Calcutta.
LONGLEY, REGINALD, ...	London.
McDONALD, WILLIAM, R.N.R., . . .	Singapore.
MILLER, WILLIAM THOMAS WARD, . .	Sheffield.
SILLAR, ALFRED RICHMOND, . . .	Colchester.
STANIER, WILLIAM ARTHUR, . . .	Swindon.

The following Papers were then read and discussed:—

"Inclined Retort Coal- and Coke-handling Plant at Bristol"; by Mr. WILLIAM STAGG, *Member*, of Bristol.

"Forced Lubrication for Axle-boxes"; by Mr. T. HURRY RICHES, *President*, and Mr. BERTIE REYNOLDS, of the Taff Vale Railway, Cardiff.

At a Quarter to One o'clock p.m. the Meeting was adjourned to the following morning.

The Adjourned Meeting was held in the Hall of University College, Bristol, on Wednesday, 29th July 1908, at Ten o'clock a.m.; T. Hurry Riches, Esq., President, in the chair.

The following Papers were then read and discussed:—

"The direct Production of Copper Tubes, Sheets, and Wire"; by Mr. Sherard O. Cowper-Coles, *Member*, of London.

"The Evolution and Methods of Manufacture of Spur-Gearing"; by Mr. Thomas Humpage, *Member*, of Bristol.

"A Method of detecting the Bending of Columns, including a description of the Sphingometer"; by Professor C. A. M. Smith, B.Sc., *Associate Member*, of London.

The President, before proposing the formal votes of thanks, thought he ought to say a few words of a less formal character. In the first place, he was sure the members would agree the Institution owed the Lord Mayor of Bristol a very considerable debt of gratitude for remaining in the City for the purpose of welcoming them after the exceedingly arduous duties he had recently had to perform in connection with the visit of His Majesty the King. He therefore made the proposition that a cordial vote of thanks should be passed to him in less formal words than the ordinary routine vote of thanks.

The resolution was carried by acclamation.

The PRESIDENT, in proposing the following resolution of thanks, assured all the friends in Bristol who had been good enough to show to the members so much kindness and to watch over their comforts and pleasures during their visit to Bristol, Bath and the neighbourhood, that the members owed them a deep debt of gratitude for all they had done for them. It gave him much pleasure to move, "That the best thanks of the Members of the Institution of Mechanical Engineers in this Meeting assembled be given":—

To the Right Hon. the Lord Mayor of Bristol, Alderman Sir EDWARD B. JAMES, and the Sheriff, Colonel H. G. CARY BATTEN; to the Chairman of the Council of University College, the Right Hon. LEWIS FRY, P.C., D.L., and the Principal, Professor C. LLOYD MORGAN, LL.D., F.R.S.; for welcoming the President, Council, and Members of the Institution to the City of Bristol.

To the Members of the Ladies' Committee for so kindly entertaining the Lady Visitors.

To the Council of University College, for the loan of their large Lecture Hall, in which the Meetings have been held, and for other facilities connected with the Meetings. The Meeting also desires to record its best wishes for the success of the present Petition to His Majesty's Privy Council in favour of the establishment of a University in Bristol.

To the Chairman, Mr. J. WESTON-STEVENS, and the Vice-Chairman, Honorary Treasurer and Members of the Bristol Reception Committee, for the presentation of a specially-prepared Guide Book, and for the many arrangements they have made for the entertainment of the Members; also for their kind invitations to a Conversazione in the Museum and Art Gallery Buildings and to an Illuminated Garden Party in the Zoological Gardens; also for their hospitality at Avonmouth.

To His Worship the Mayor of Bath, Councillor T. H. MILLER, for presenting a specially-prepared Guide Book of Bath, and for entertaining the Members and Ladies at Luncheon and Tea in the Guildhall, Bath; also to Mr. T. STURGE COTTERELL and Mr. WALTER PITT, for their kind arrangements for the day in Bath.

To the Most Hon. the Marquess of Bath, for kindly granting permission to visit Longleat House and for other facilities at Shear Water.

To the Corporation of Bristol and their Chief Dock Engineer, Mr. W. W. Squire, for the visit to the new Royal Edward Dock at Avonmouth.

To the Bristol Water Works Company and their Chief Engineer, Mr. J. A. McPherson, for the visit to the Barrow Gurney and the Blagdon Reservoirs.

To the Right Hon. Lord Winterstoke of Blagdon, for kindly inviting the Members and Ladies to Luncheon in his Pavilion near the Combe.

To Mr. A. Wharton Metcalfe, for his hospitality to the Members and Ladies at The Hall, Cheddar.

To the Chairman and Directors of the Bath Stone Firms, Messrs. Spencer and Company, Messrs. Saxby and Farmer, Messrs. Stothert and Pitt, and the numerous Proprietors of Places of Engineering Interest in Bristol and Bath, for their kindness in throwing open their Works for the Visits of Members; also to five Clubs in Bristol for the extension of hospitable facilities.

To the Great Western Railway Company and Mr. G. J. Churchward, for their invitation to visit their Locomotive, Carriage, and Wagon Works, and for the entertainment of the Members and Ladies at Swindon.

To the Great Western and the other Railway Companies of the United Kingdom, for special travelling facilities in connection with the Meeting.

To the Right Rev. the Lord Bishop of Bath and Wells, for permission to visit the Palace at Wells; to Prebendary S. A. Boyd, M.A., for conducting the Members and Ladies over Bath Abbey; and to the Rev. Canon C. M. Church, M.A., for receiving the Members at Wells Cathedral.

To the Honorary Local Secretary, Mr. Bernard de Soyres, for planning numerous Visits to places of interest in Bristol and neighbourhood, and for the admirable arrangements which his forethought and energy have provided for each day of the Meeting.

The resolutions were then put, and carried with applause.

The Meeting then terminated shortly before One o'clock. The attendance was 277 Members, a number of Ladies accompanying them, and 49 Visitors.

INCLINED RETORT COAL- AND COKE- HANDLING PLANT AT BRISTOL.

BY MR. WILLIAM STAGG, *Member*, OF BRISTOL.

It is estimated that fifteen million tons of coal are carbonized annually in gasworks in this country. It will be readily understood that the economical handling of this large quantity of material and of its principal by-product is of vital importance in gas undertakings, and it is hoped will afford a subject of interest to Members of the Institution. In Bristol, which was amongst the first of the provincial cities to light its streets by gas, last year nearly half-a-million tons of coal and coke were handled. The oldest works are at Avon Street, where there may still be seen a very interesting series of ten retort-houses built nearly a hundred years ago. In plan they present the form of a horse-shoe, with a large covered coal-store occupying a central position and opening into each of the retort-houses—all admirably adapted to the requirements of those days. They are a standing monument to the foresight and enterprise of the pioneers of the gas industry in Bristol.

For the greater part of the century that has passed since the introduction of gas-lighting, little was done to introduce strictly mechanical methods in the handling of materials. However, of late, various forms of machines for charging and discharging horizontal retorts, with their auxiliary coal- and coke-handling plants, have gradually come into use.

Charging and Discharging Machines.—The essential feature of the earlier charging machines is a long trough or scoop, which having been filled with coal is pushed into the retort, turned over and withdrawn; to put in the full charge the scoop makes two or more excursions into each retort. A machine is required on each side of the bench. The spent charges are withdrawn by separate machines which operate by means of either a rake or a ram; these stoking machines, as they are called, are operated either by hand, hydraulically, or by compressed air.

Projectors.—There are later types of machines which project the coal into the retort without any part of the apparatus entering the hot retort, and work from one side only of the bench.

In the De Brouwer projector, the machine is brought up to the front of the retort and the charge of coal allowed to fall upon a horizontal rubber-band moving rapidly towards the retort in the direction of its long axis; the coal is thrown off the band into the retort by its acquired momentum, the speed of the band being gradually reduced as the retort fills.

In West's projector machine the coal falls upon the blades of a revolving device and is projected into the retort by centrifugal force; the spent charges are pushed out by a ram, usually carried upon a separate frame.

Ram-Dischargers.—In these machines the ram consists of a cast-steel rack, in two or more sections, actuated by a sprocket-wheel. The first section to emerge beyond the frame of the machine is a rigid rack-bar; those that follow are flexible and held rigidly in a straight line by being sheathed in channel guides which telescope into each other; the flexible sections are constructed of short links.

In entering the retort, the head of the discharging ram slides along the floor of the retort, and when the first (rigid) section is fully extended it draws forward the next section, and this in turn the following section. In withdrawing the ram, the sheaths telescope into each other and the flexible tail of the rack coils back upon itself, in an easy curve, thus considerably economising space and length of frame required. A constant stream of water is directed upon the ram to keep down the temperature of those parts entering the hot retort.

Combined Charging and Discharging Machine.—In the Fiddes-Aldridge machine, the two operations of charging and discharging are carried on simultaneously; the ram which removes the spent charge carries in the fresh charge of coal by the same movement.

Projectors, ram-dischargers, and the Fiddes-Aldridge machine are all electrically driven. The former may be seen at work at the Stapleton Road Works and the latter at the Canons' Marsh Works of the Bristol Gas Company.

Inclined Retorts.—Another method of charging and discharging retorts avails itself of the force of gravity. In this system, which is characterized by extreme simplicity, the retorts are inclined at an angle to the horizon, and the coal from continuous hoppers is dropped directly into the retorts through portable charging-shoots. The recent introduction of coal-projecting machines in conjunction with ram-dischargers has to a large extent checked the progress, for the time being, of the inclined-rotort system, because with machines of this class retorts can be charged and discharged by the employment of a machine at one side only of the retort-house; this offers considerable advantage compared with the older forms of stoking machines, which work from both sides of the retort.

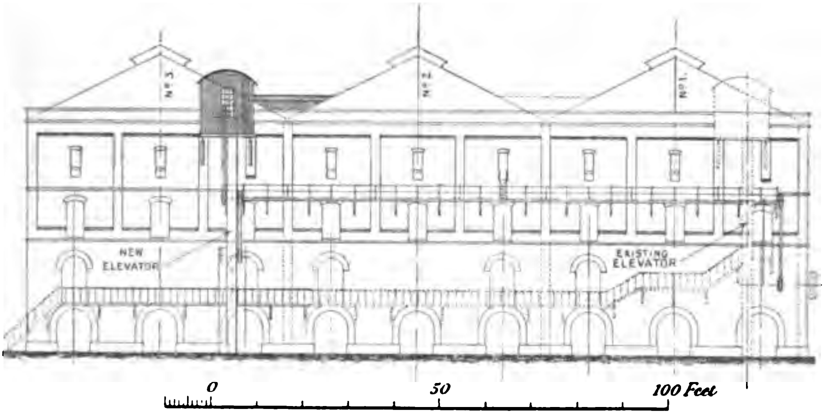
Inclined retorts were used at the beginning of last century by William Murdock, of Messrs. Boulton and Watt, Soho Foundry, Watt's right-hand man, as he has been called. An arrangement of inclined retorts was devised by Mons. Andrè Cozè, in France, and worked on a small scale in Rheims about twenty years ago. In the French plan the retorts were arranged in pairs with a single cast-iron mouthpiece joining their upper ends buried in the brickwork of the setting. About 1889 the system was revived in England; even at Bristol there are memories at the Avon Street Works of a primitive installation of inclined retorts dating back fifty years. Here, in England, the single straight-through retort was adopted, which immensely simplified the system, compared with the French plan, and assured its success.

Where the work is continuous, as in retort-houses, machines must be of the simplest, strongest and most durable character to avoid the risk of breakdowns, and considering the conditions prevailing in which they are expected to work—the great heat and the cutting action of coke upon wearing parts—it may be wondered why any other method than the inclined-retort system should be employed

FIG. 1.

Avon Street Gasworks, Bristol.

Front Elevation of Buildings showing the two Coal-Elevators.



for charging retorts. However, greater care is necessary in the selection of suitable coal, and the success of the system depends, in a measure, upon the type of coals from day to day being fairly uniform. Some gas-coals have a tendency to slip during the earlier stages of carbonization in inclined retorts, and in doing so, a downward creeping movement readily sets in, leading to a thickening of the charge of coal at the lower end of the retort, thus rendering efficient carbonization difficult. Avoiding these slipping coals, the system is as near perfection as can be attained by any method. The slipping is due to the coal swelling during the earlier stages of carbonization.

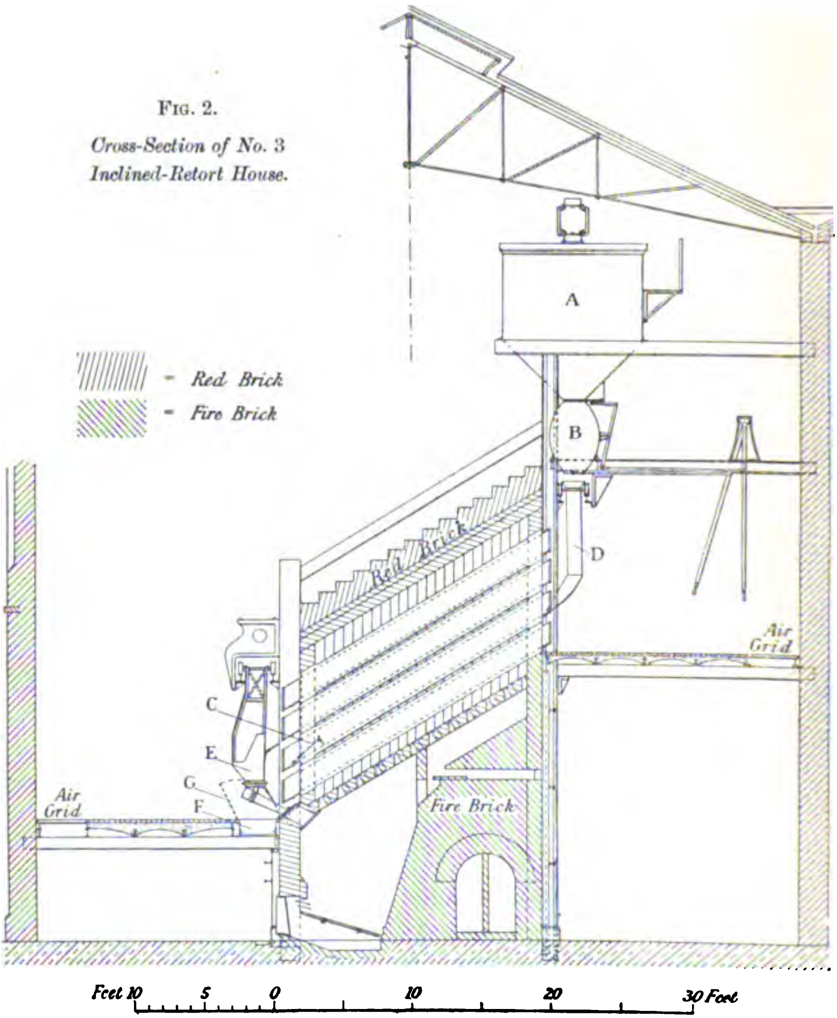
An Installation of Inclined Retorts at Avon Street Works, Figs. 1–4, and Plate 15.—On the "New Side" of the works at Avon Street three very substantial retort-houses adjacent to the harbour were erected in 1860. In order to make the most of these buildings it was decided in 1900 to raise the roofs; the height of the walls was doubled and by this means accommodation afforded for inclined retorts. The dimensions of the houses and the general surroundings lend themselves admirably to this method of carbonization. The work was designed and carried out by, and under the personal superintendence of, the Company's Chief Engineer, Mr. Daniel Irving, and the work executed by the Gas Company's own staff and workmen. The coal can be lifted from the hold of the steamboat lying alongside the Quay, weighed, broken, elevated, conveyed to any part of either three retort-houses, charged into the retorts, and when carbonized discharged from the retorts directly on to coke-conveyors, cooled, conveyed into the yard, screened, stored, and loaded into carts or trucks without the material being once handled.

The plant is divided into two sections—for coal-handling and for coke. The power required is supplied by gas-engines provided in duplicate for each section. The coal-breakers and elevators are also provided in duplicate, and the coal can be placed in any part of the coal-hoppers of the three retort-houses from either breaker. The coal-handling plant is designed to do its work, as far as possible, during the hours of daylight, 300 tons per day being required of it.

Inclination of the Retort.—The determination of the angle of the retort, as might be expected, is a critical question. The ideal coal for working with is "Nuts," such as will pass through a screen of 1¼-inch mesh; compared with this "lively type," small coal requires a steeper angle, especially if damp, and larger coal a less angle. An angle that would serve well in a newly-built bench would be less suitable as the retorts become worn, in consequence of the formation in the retorts of irregularities in the inner surface and of ridges at the joints, which impede the descent of the coal; and generally a steeper angle might be employed for discharging than would be suitable for charging. For a slipping coal, a less angle would be more

FIG. 2.

Cross-Section of No. 3 Inclined-Retort House.



serviceable. Lastly, the amount of vertical drop of the coal from the measuring chamber to the charging mouthpiece of the retort varies for each horizontal line of retorts, and introduces another disturbing factor, which requires some compensation and which is provided for by introducing baffles and checks in the charging-shoot. Obviously then, a compromise in the angle is necessary to satisfy these conflicting claims, and the angle decided upon is 31°.

Fig. 2 (page 570) shows a cross-section of the retort-house; it will be noticed that the charging floor is placed upon a higher level than the discharging floor, allowing of this angle of 31° as the inclination of the retorts. High up over the retort mouthpieces on the charging side is a continuous coal-hopper A, supported partly from the bracing of the retort bench and on cross-joists resting on the walls of the retort-house: over each vertical line of four retorts a measuring chamber B, for the charge of coal, depends from the hoppers—twenty in all. These measuring chambers are shown in detail, Fig. 3 (page 572); there is a slide at the top for filling it from the hopper and another at the bottom for discharging, each worked from the charging floor of the retort-house by a separate lever. The full capacity of the chamber is 7 cwt. This may be reduced by pushing in a flap-plate, which hangs hinged inside the chamber, held in position by a quadrant which passes through the back of the chamber, and fixed by a pin. The weight of the charge of coal can by this means be adjusted to suit the prevailing conditions.

The method of charging the retorts is as follows:—A portable stop-plate C, Fig. 2 (page 570), is placed in the retort at its bottom end in order to prevent the charge of coal from resting upon the relatively cold iron mouthpiece and from pressing against the retort lid; this remains in the retort during the period of carbonization. On the charging side are four shoots D, one for each horizontal line of retorts; the lower hinged end of one of these shoots is placed in a retort, and the contents of the measuring chamber are discharged into it by pulling a lever, Fig. 5, Plate 15, the coal forming an even layer along the bottom of the retort about 6 inches thick from the stop-plate to the upper end of the retort. These charging shoots, Fig. 4 (page 573), are provided with adjustable baffles

Fig. 3.—*Measuring Chamber for Coal.*

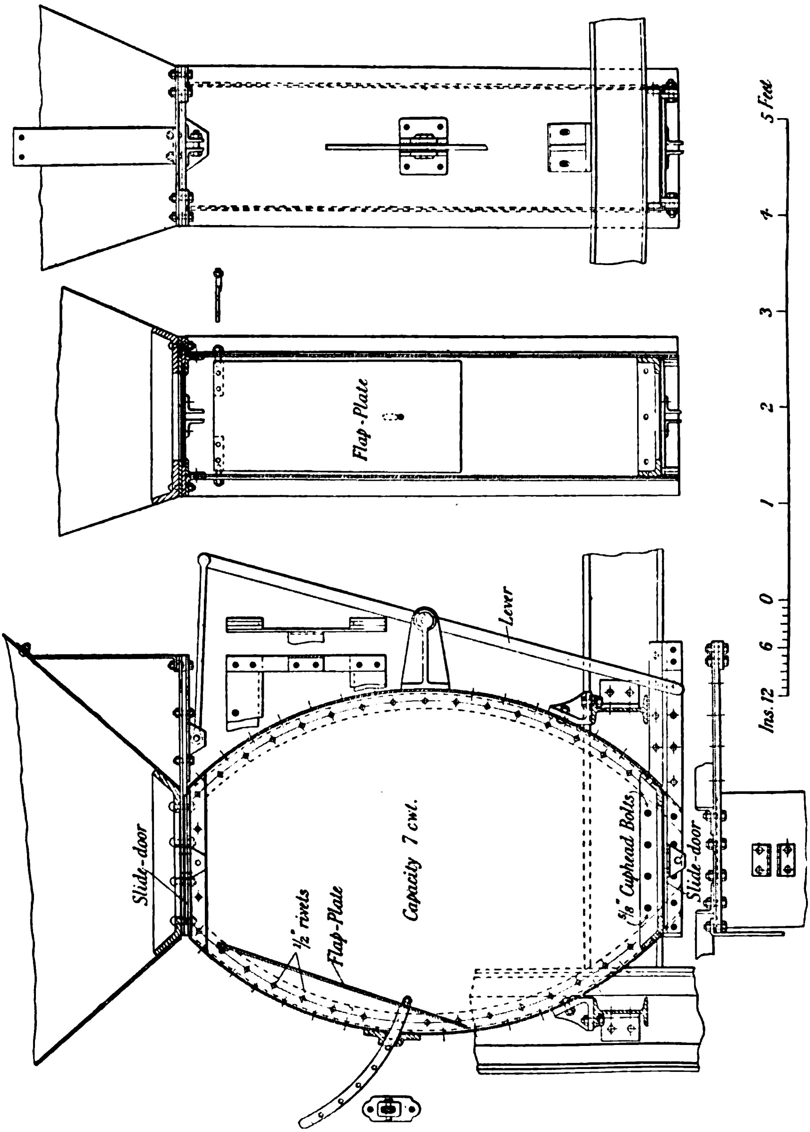
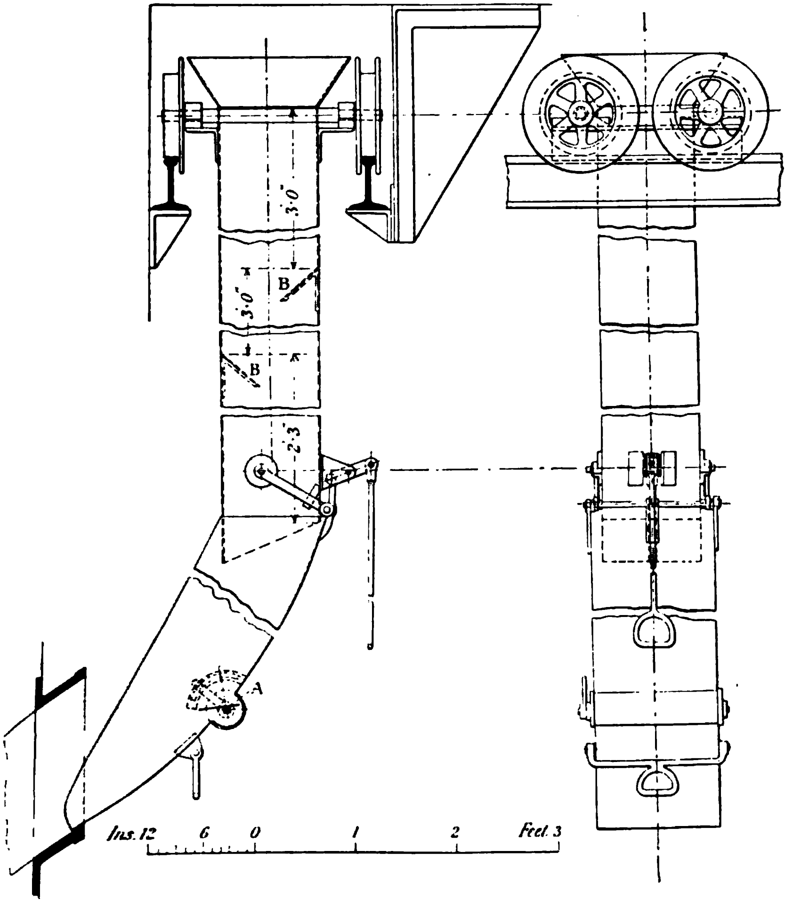


FIG. 4.

Shoot for Charging Coal.



A, and in the longer shoots fixed baffles also BB, for regulating the speed of the descent of the charge of coal, thus aiding the operator who has the chief control. The weight of the charge is from 6½ to 7 cwts., and twenty retorts can be drawn and charged in twenty-five minutes.

The retort-lids and the face against which they close are machined, the retort being sealed by pressure from a lever with an eccentric shank.

The retorts are tapered, increasing in width towards the bottom end, to facilitate the discharge of the coke. In this installation they are arranged in sets of eight, two vertical lines of four retorts under each of the ten arches, each set being independently heated by producer-gas on the regenerative system. A fraction of the hot coke as it is discharged from the top line of retorts is directed through a portable shoot hung on rails, into the producer E, Fig. 2 (page 570), the only manual labour necessary being to push it back in order to maintain an even thickness in the depth of the fire, Fig. 6, Plate 15. The clinkering is done from the ground-floor stage below. Owing to the regular heating possible in this system, the life of the retorts and of the setting is prolonged. A bench is still in action at the Avon Street Works in which the heats have not been once let down since August 1904, having done continuous work for nearly four years.

Coal Plant.—Water-borne coal is unloaded by means of a steam-crane and a Hone's grab. The grab of 15-cwt. capacity discharges into a hopper weighing-machine, in which the weight of the coal is indicated by a pointer on a scale of hundredweights. This arrangement permits of rapid weighings, as the shifting of the counterpoise is unnecessary. From the weighing-machine it is discharged by a lever into the hopper of the breaker, together with coal received by cartage, and there reduced to a uniform and suitable size.

The breaker A, Fig. 8 (page 577), is a powerful machine, capable of dealing with 30 tons of Cannel per hour, Cannel being the hardest variety of coal carbonized. The coal is fed in automatically by a shuffle-plate to two double lines of steel claws on square shafts, suitably enclosed. The breaking is done in two stages; the coal falls from the second pair of claws into the boot of the elevator. During its six-and-a-half years' continuous work it has dealt with 360,000 tons of coal without having been once taken apart for repairs, notwithstanding the rough usage it has sustained from stray tram-coupling links, axle-bearings, and stones which occasionally find their way in with the coal.

The steel elevators, Figs. 7 and 8 (pages 576–577), are constructed of a central roller-chain upon which buckets of 28 lbs. capacity are fixed, 18 inches apart. They are driven from the top end by a sprocket-wheel which engages the connecting-chain. Projecting arms, fixed on each side of the buckets, slide on angle-iron bars which serve as guides. The coal is elevated to the full height of the lofty retort-house walls, a total lift of 70 feet, and there delivered into the conveyors for distribution.

The general arrangement of coal-conveyors A is shown on Fig. 9 (page 578) and details on Fig. 10 (page 579), from which it will be seen that each of the three retort-benches is served by its own conveyor, fixed on cross-joists above the continuous hopper, and a fourth conveyor at right angles to these stretches from one elevator head to the other; this cross-conveyor is fitted with reversing gear and clutches, Fig. 11 (page 580), and so arranged that coal from either elevator can be delivered on to each of the hopper-conveyors, and thus serve all three benches in turn. These conveyors are driven from the elevator head by chain-drives; the coal from the elevator is directed by a shoot into the trough of one of the conveyors; along this the coal is swept by a continuous chain of push-plates to the first open slide, where it falls either into the cross-conveyor or into one of the compartments of the coal-hopper.

Referring to Fig. 12 (page 581), it will be noticed that the section of the trough of one of the conveyors is semi-elliptical. In this conveyor every third push-plate is provided with wheels and axle, and the whole connected up by a chain of the roller type, driven by a sprocket-wheel at one end, which engages the rollers on the links of this chain; at the opposite end of the conveyor, a screw tension-gear is provided which acts through a second sprocket-wheel. The

(*Continued on page* 582.)

Fig. 7.—*Upper End of Coal-Elevator.*

(Continued on next page.)

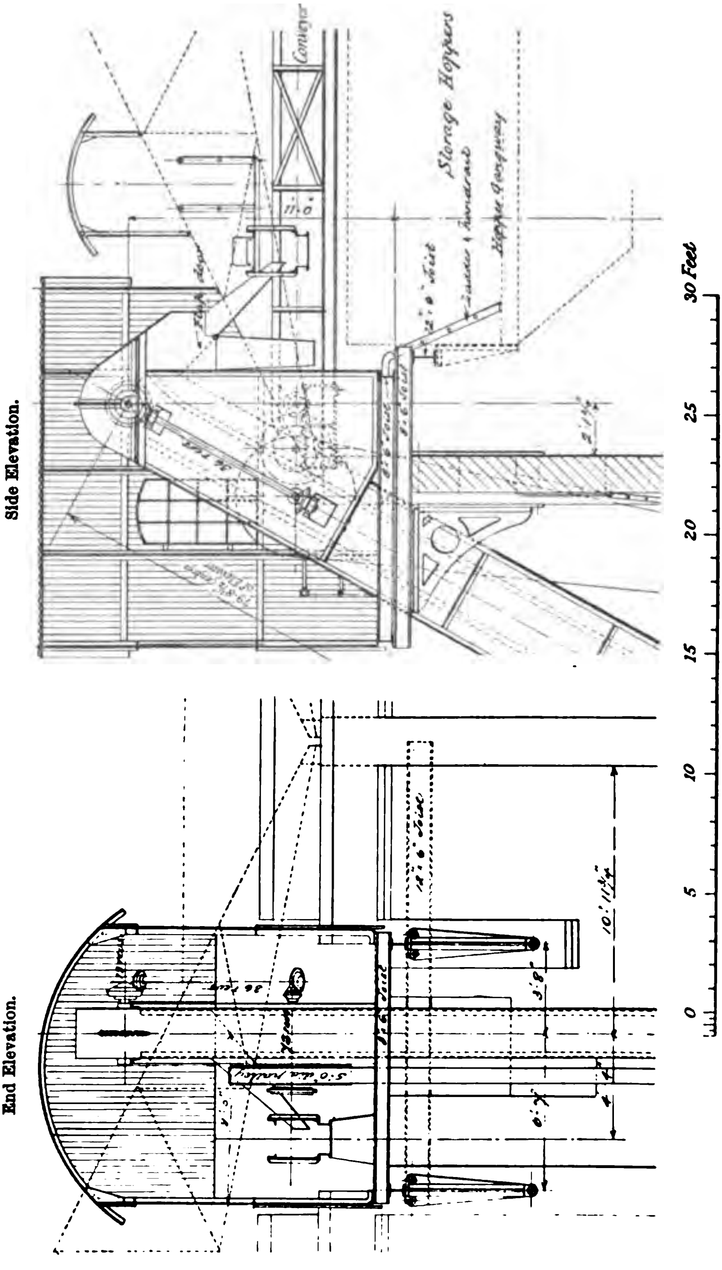


FIG. 8.—*Lower End of Coal Elevator.*

(Continued from above.)

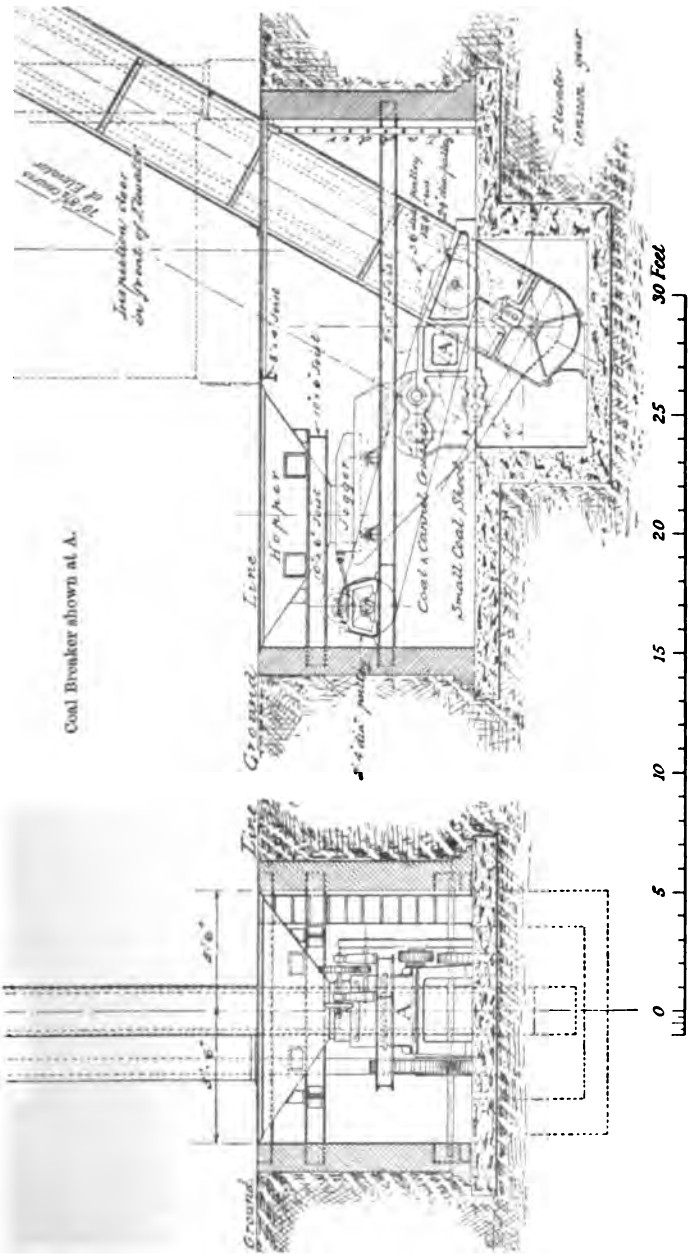
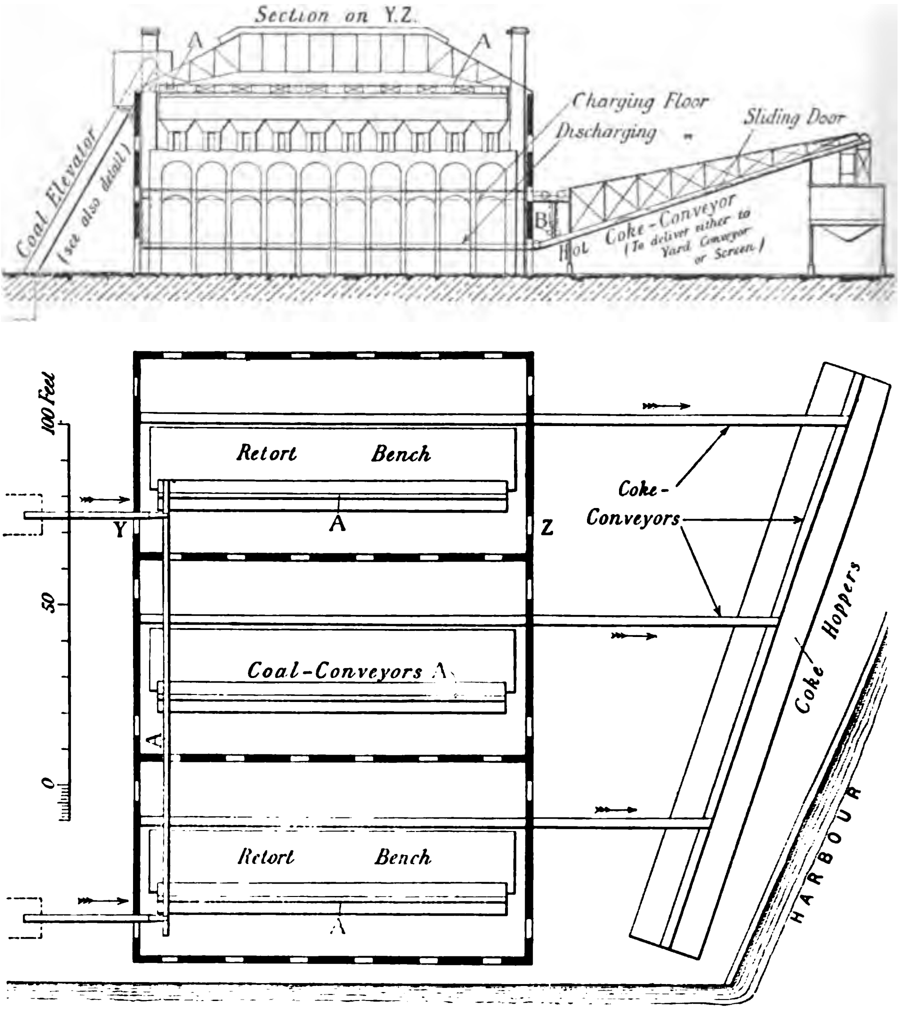


FIG. 9.

General Arrangement showing Hot Coke-Conveyors and Hoppers.



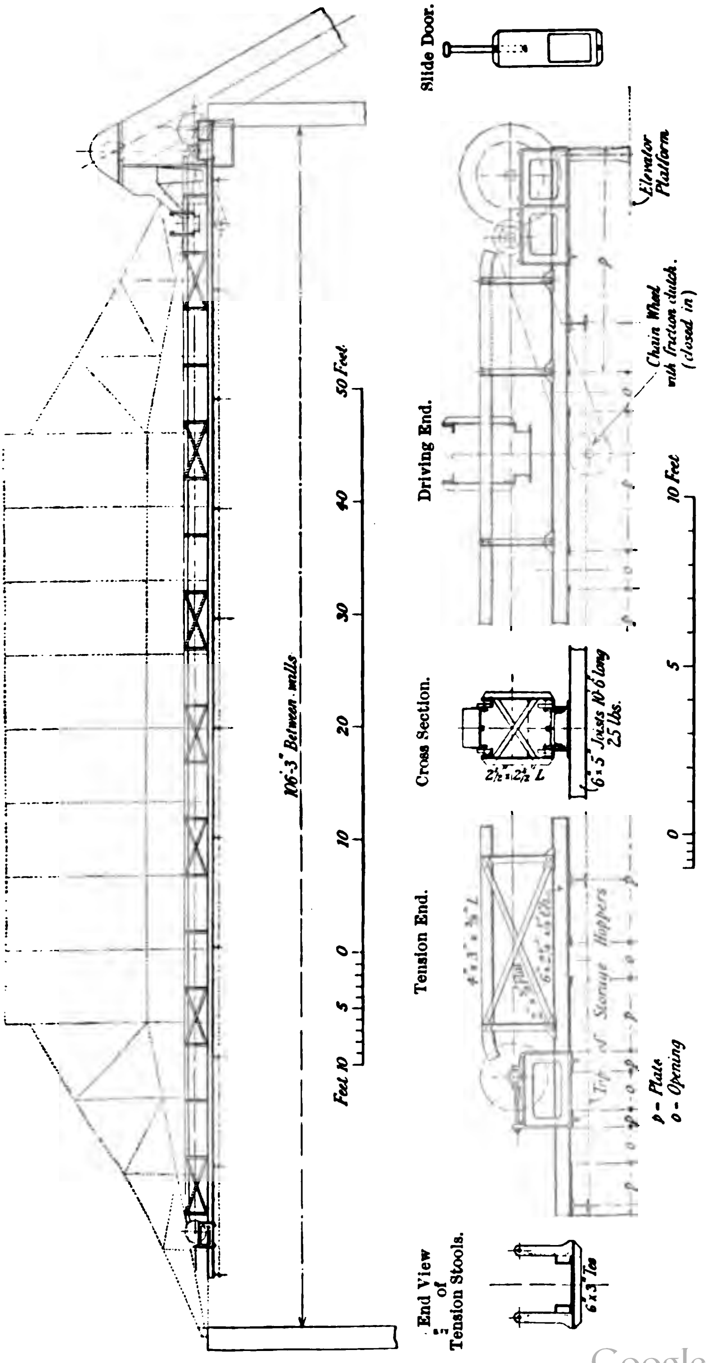


FIG. 10.—*Longitudinal Coal-Conveyor.*

FIG. 11.—*Cross Coal-Conveyor.*

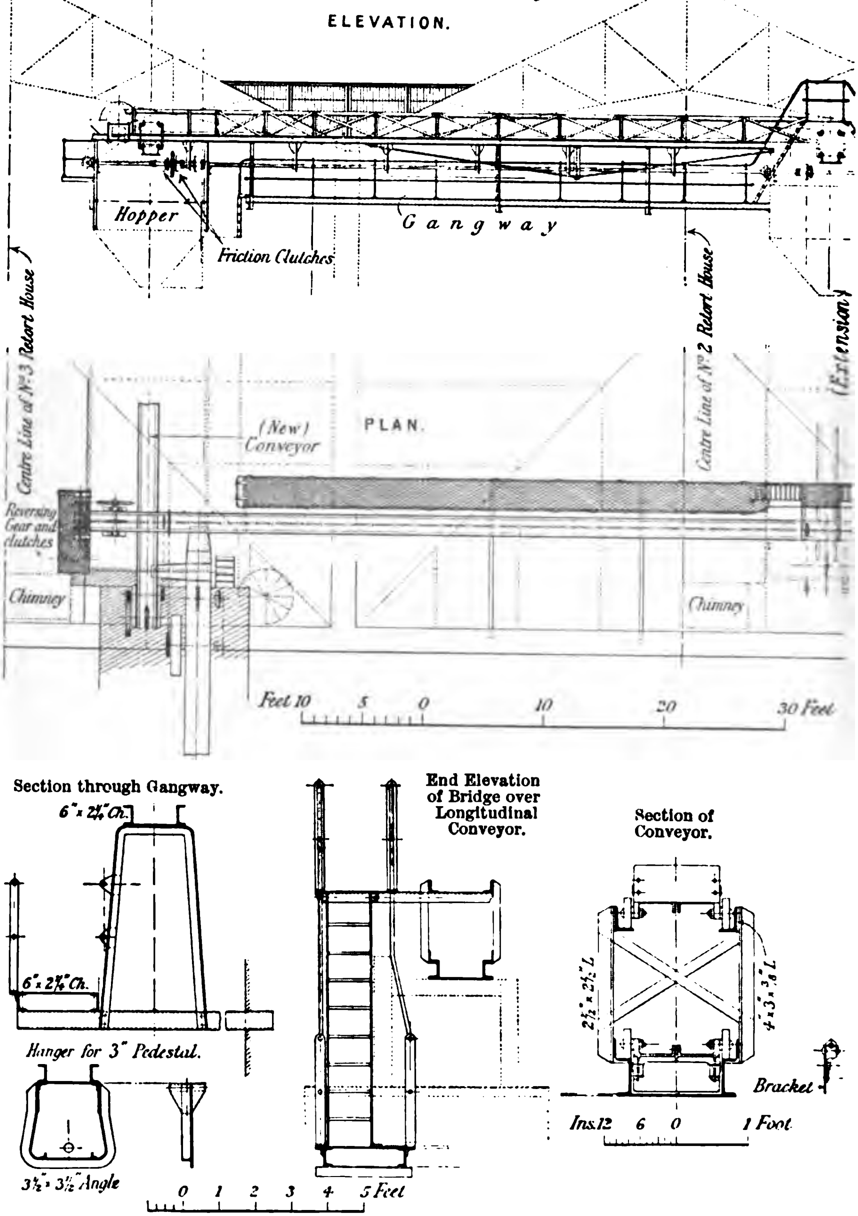
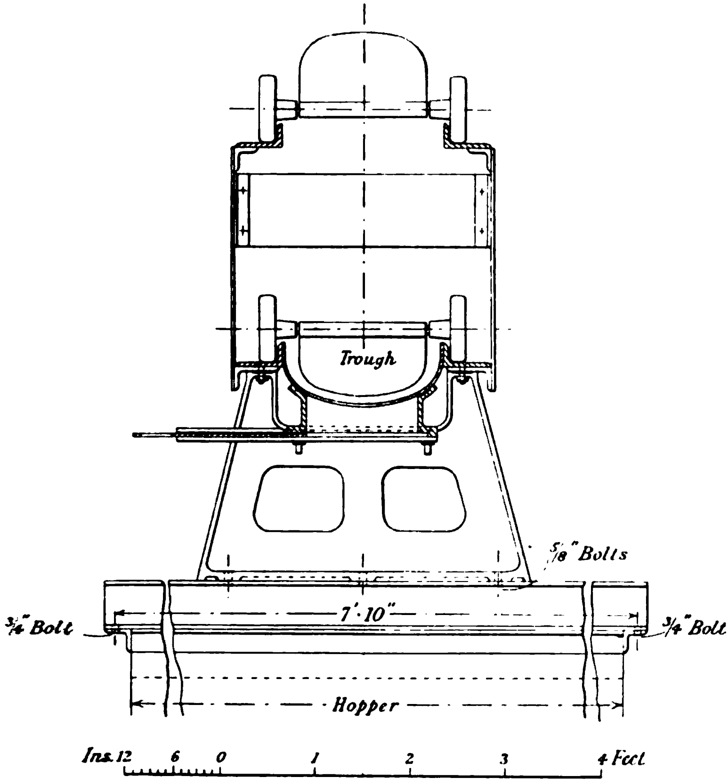


FIG. 12.

Section of Semi-elliptical Coal-Conveyor.



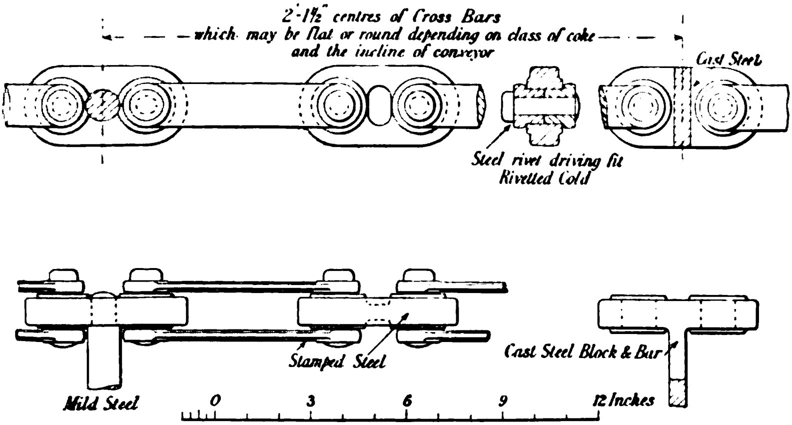
wheels carrying the push-plates run upon angle-irons fixed at each side of the trough. A more efficient conveyor could scarcely be devised; it requires very little attention, and owing to the slippery character of the coal requires very little lubrication. During its six years' work it has transported 220,000 tons of coal. Such ample bearing surfaces have been provided, that, excepting the bottom of the trough where the coal falls upon it, the amount of wear is proved to be insignificant.

In all the other conveyors the section of the trough is rectangular, and every push-plate provided with its wheels and axle, Fig. 11 (page 580). The coal moves along at the rate of 100 feet per minute. To drive the whole plant—2 breakers, 2 elevators, 2 hopper-conveyors and 1 cross-conveyor—when running light requires 35·89 I.H.P., and 35 per cent. more when dealing with coal, nearly 50 I.H.P.

Coke Plant.—The coke-handling plant is shown in Fig. 9 (page 578). Along the front of the retort-bench, below the bottom line of retorts and below floor-level, is a rectangular trough F, Fig. 2 (page 570), constructed of steel plates and angles, with cast-iron renewable bottom wearing plates. This trough F is covered down with ⅜-inch plates with a hinged section G in front of each vertical line of retorts. The plates serve to confine the heat and steam to the trough as the coke is conveyed through the house, and when raised for discharging the retorts they serve as shields to protect the workmen from the falling hot coke. Beyond the house, the conveyor-trough is bent upwards at a considerable angle, becoming an elevator; this portion being entirely enclosed acts as a flue and draws the steam from the retort-house, discharging it at the top end, entirely clear of all workmen. Along the walls of the retort-house a line of wrought-iron gratings takes the place of the ordinary brick floor, allowing a plentiful circulation of cool air in the retort-house.

The coke and breeze storage-hoppers rest upon pillars, and are raised sufficiently to allow carts to stand underneath the hoppers, Fig. 9 (page 578). They are divided into sections by bulkhead plates, corresponding with the screens, and below each pair of screens the hopper is partitioned off for breeze. Above and along the entire length of the hoppers, carried upon a lattice framing, there is a conveyor for distributing the coke. As the coke leaves the retort-house it is quenched, and on reaching the top of the coke-elevator it is discharged into the trough of the distributing or hopper-conveyor, and either falls directly on to screens through the open slide beneath, or is carried to the next set of screens, where the coke is separated from the breeze, and each falls into the section of the hopper set apart for it. To save the coke from

FIG. 13.—*Hot Coke Chain-Conveyor* (De Brouwer).

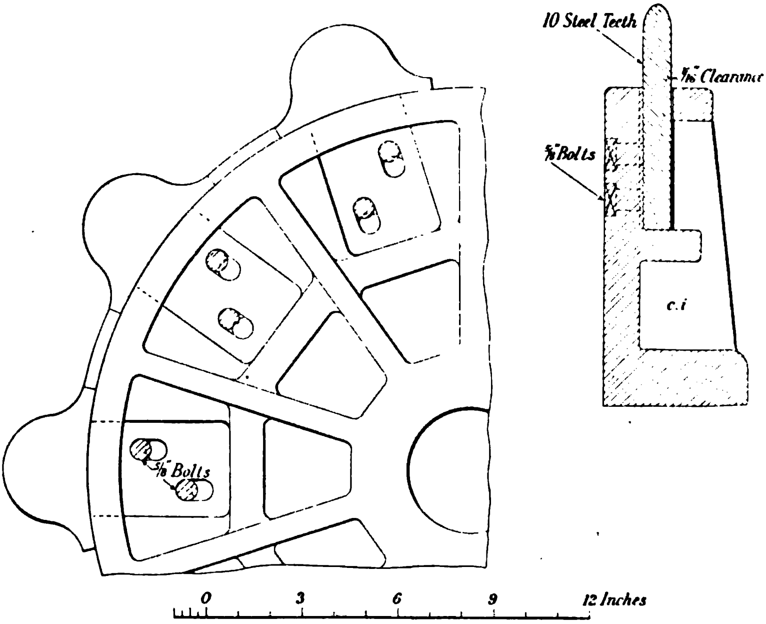


breakage in falling into the hoppers, portable shoots are placed when required at the foot of the screens. The carts are filled by operating a lever from the ground-level.

The form of conveyor chain adopted for the coke plant is the De Brouwer, Fig. 13 (above), which resembles a flexible ladder with cross-bars of round and flat steel. M. De Brouwer is the engineer of the gasworks at Bruges, where it was first used towards the end of 1895. The whole of it consists of mild forgings stamped to shape under a drop-hammer. All parts are machined and the rivet-holes are rimered, the rivets being driven in cold and riveted cold. Where the coke has to be taken up inclines, flat bars are introduced at regular intervals in place of the round bar. The conveyor when new moves along at the rate of 50 feet per minute. This speed is increased as the wear of the chain necessitates an increase in the diameter of the pitch circle of the driving sprockets.

In discharging the retort, the coke slides down the inclined retort into the trough in front of the bench and is carried forward,

FIG. 14.—*Sprocket-Wheel for Hot Coke Chain-Conveyor* (De Brouwer).



sliding along the bottom plates. A little water lies in the bottom of the trough to keep things cool, and this helps to quench the coke as it travels along. In spite of the trying conditions under which it has to work, and of the cutting and grinding action of coke, a chain may be made to last more than three years, working day and night, and to transport 70,000 tons of coke during its life. The new chain weighs 50 lbs. per yard; an old one removed to the scrap heap weighs 32 lbs. per yard, showing a loss in wear of 36 per cent. by weight.

The chain of the conveyor is driven by a pair of sprocket-wheels, Fig. 14, engaged for ninety degrees of the pitch circle; the slack chain is payed directly on to guide-wheels which maintain it in constant tension by a balance-weight B, Fig. 9 (page 578). The chain of the hopper distributing-conveyor is kept taut by tension screws instead of the usual balance-weight arrangement, which cannot be well applied where the conveyor has to be reversed; in this case the chain has a trick of increasing in length more on one side than on the other; sections of the chain have frequently to be turned over to counteract this unequal wear and consequent difference in the pitch of the two sides. Judging from what takes place at the Avon Street Works one would be inclined to think that the introduction of a balance-weight in place of the tension-screw would overcome the difficulty, but the experience at other works renders this doubtful.

It will be noticed that, as the parts wear, the pitch of the chain increases and demands a readjustment of the pitch of the sprockets; this is met by increasing the radius of the pitch circle, the sprockets being drawn further out from the centre of the sprocket-wheel as the wear increases. This extension of the length of the chain is considerable, and where in a new chain the pitch is 8½ inches, when nearly worn out it is found to have increased to nearly 9½ inches, equivalent to an extension of 10 per cent. in the pitch of the chain.

The amount of power required for these conveyors is surprisingly small, and is supplied by a gas-engine. 1,540 feet of conveyor-chain requires, when light, only 25·16 I.H.P., including two line-shafts, belts, and driving-gear, and 12 per cent. more when fully loaded. So thoroughly reliable are gas-engines that for nearly three years work was proceeding day and night, year in and year out, with a single gas-engine. The rapidity and ease with which hot coke is removed from the retort-house by conveyors adds much to the convenience and comfort of the workmen and to the general economy of the system.

The Paper is illustrated by Plate 15 and 12 Figs. in the letterpress.

Discussion.

On the motion of the PRESIDENT, a hearty vote of thanks was accorded to Mr. Stagg for his interesting Paper.

Mr. W. H. ATHERTON, in opening the discussion, remarked that the author pointed out (page 567) that the introduction of coal-projecting machines and ram-dischargers had checked the progress of the inclined-retort system, because they enabled retorts to be charged and discharged by machinery working on one side only of the retort house. While that was true enough, it was not the sole reason why projectors had come so much to the fore in recent years. It must be remembered that most gasworks of moderate size were already equipped with hand-charged horizontal retorts, and the adoption of projectors enabled the old settings to be utilised, thus permitting the introduction of labour-saving appliances at a minimum of first cost and without interruption of working. Their use also permitted a rather freer hand in the choice of coal, as was pointed out on page 568. It must be admitted, however, that projectors were very dirty machines in operation, clouds of coal dust and thick smoke being evolved from the retorts during the process of charging. In this respect the Fiddes-Aldridge machine was an improvement, but smaller charges had to be used than were possible with projectors for a given size of retort. In the course of another decade he was hopeful of seeing both horizontal and inclined retorts displaced by vertical retorts.

He hoped the author would favour the members with a rough idea of the comparative cost of two new retort-houses of equal capacity, the one being equipped with inclined and the other with horizontal retorts, and the usual labour-saving machines. He did not ask for actual, but only relative costs. The author gave high praise to the inclined retorts in saying (page 568) that "The system is as near perfection as can be attained by any method." The ideal system in principle, though not yet in practice, seemed to be the vertical retort, as in the Woodall-Duckham system, where the coal was fed by a conveyor continuously into the top of the retorts and discharged either continuously or intermittently at the bottom, precautions being taken to seal both ends. That system was being tried on a small scale at three English gasworks, though a full measure of success had not yet been achieved. In Germany he understood that "Dessau" vertical retorts, fed and discharged intermittently, were in successful operation on a large scale.

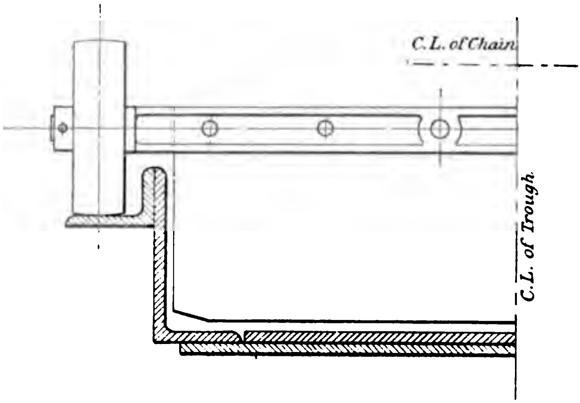
With regard to the details of the coal-handling plant, he noticed that the receiving hopper below the ground level was shown in Fig. 8 (page 577) unusually shallow, the inclination of the sides being about 35° only. Did the author find that the coal flowed freely from that hopper without hanging up at the sides? The method of feeding the coal-breaker by means of a jigger or reciprocating shoot was certainly an improvement on the ordinary sliding door, and ought to be adopted generally, in spite of the extra first cost and space occupied. Only in that way could a regular feed be obtained with variable and lumpy material, without the necessity of frequent adjustment by hand. Apparently the small coal fell through holes in the bottom of the jigger, and was by-passed to the elevator boot without passing through the breaker.

Roller chains were successful if kept lubricated, but, as that was hardly feasible in elevator work, it was found in practice that better results were obtained by the use of a rollerless chain of the Ley type, with a hardened steel renewable bush, the latter being subjected to external wear by the action of the sprocket-wheel teeth, as well as to internal wear due to the pull of the pins. The elevator top shaft in Fig. 7 (page 576) was shown driven through two pairs of bevel wheels and a side shaft. Personally, he preferred a chain drive, which was more flexible and required fewer bearings. In large elevators the top shaft was commonly driven through a pair of spur wheels and a short countershaft, itself chain-driven. In light elevators the countershaft could be dispensed with and a direct chain-drive used. In the case of an elevator to handle 50 tons of coal per hour now being made for a retort-house by the Chain-Belt Engineering Co., Derby, he had ventured to adopt a frictional or grip chain-drive, by which a large reduction ratio could be

(Mr. W. H. Atherton.)

conveniently realised, even with short centres. In that case the driving sprocket-wheel was about 12 inches diameter, and the driven wheel keyed to the top shaft was 60 inches diameter with a plain grooved rim, thus avoiding all trouble due to variation of chain pitch. Owing to the wedge action of the grip chain on the tapered sides of the groove, the drive was more positive than a belt, while in case of a total jam there was still the possibility of slipping. In that 50-ton coal elevator the top shaft was carried on roller bearings. The buckets were also fitted with bushed rollers, and were bolted to a chain of the Ley bushed type.

FIG. 15.—*Section of Scraper Conveyor Trough.*



The three types of coal conveyor used in retort-houses were the scraper or push plate, the rubber and canvas band, and the gravity or tipping bucket. Each of those types was capable of good service. Probably the scraper type (page 579) was the most convenient and durable form for retort-house duty, where coal was required to be deposited at a large number of points. The particular design shown in the Paper was capable of improvement, the projection of the acting edge of the scrapers beyond the rollers being too great, and thus the head room required by the conveyor was excessive. A convenient form of section he had used with success was indicated in Fig. 15. The bottom of the trough was fitted with renewable lining plates, and the rollers were bushed.

Mr. J. HERBERT CANNING, of Newport (Mon.) Gas Works, most heartily congratulated the author upon his comprehensive and detailed Paper. He was specially interested in it, because a few years ago through the kindness of Mr. Daniel Irving he had the opportunity of seeing the excellent installation in operation at the Avon Street Works, and nothing could exceed the smoothness and efficiency with which every department worked. The portion of the Paper which interested him particularly was that dealing with the coke-handling plant. At the gas works with which he had the honour of being connected, the directors some years ago decided to carry out a considerable installation for the mechanical handling of the coal and coke. For that purpose they used gas-engines as prime movers; and he could bear witness to what the author said, that nothing could exceed the excellence with which those engines had worked under trying conditions. At Newport the work was spread over a considerable area, and in consequence an electrical system of distributing the power was installed, which had worked very efficiently. They had capstans and a tipping crane at the sidings which were elevated about 25 feet above the yard level. The coal was tipped from the wagons into a hopper, which discharged into a breaker, the remainder of the coal-handling installation being very similar to that described by the author, with the exception that horizontal (not inclined) retort benches were used.

With regard to the power required to drive a coal breaker, at Newport this was driven by a separate motor; and as it was driven electrically one was enabled to measure the varying load with some approach to accuracy. The variations in load were somewhat extraordinary and were very sudden, and there was a continual variation due to the size and hardness of the coal. Tests which he had made indicated that, using ordinary coal, the power required was from 8 to 12 E.H.P. A deduction would have to be made from that for the efficiency of the motor; those were gross figures. Occasionally, however, a momentary rise to 20 E.H.P. was obtained. The diagram, Fig. 16, Plate 15, from a recording ammeter gave some idea of the variations in the load.

(Mr. J. Herbert Canning.)

In breaking Cannel coal, which was much harder, the usual load was from 9 to 15 E.H.P., with sudden momentary rises to as high as 23 E.H.P., and 30 tons could be broken per hour. Owing to that variation in load, he considered a gas-engine was admirably adapted for the purpose of driving such a plant.

With regard to coke-handling, the conditions at Newport being different, a coke conveyor of the type used at the Avon Street Works, Bristol, had not been installed. It was necessary at Newport, owing to the height of the sidings above the yard level, to instal a coke-handling plant which at one and the same time would either deliver the coke at the yard and stack it, or load the coke into wagons on the sidings. For that purpose a telpherage system was put in. The telpher ran upon an elevated track, with an up gradient of about 1 in 22, and at the siding end it was about 40 feet above the yard level. The coke was dropped from the retorts into openwork wagons, specially devised to prevent the buckling of the wagons by the expansion and contraction caused by the hot coke. For that purpose the bars of which the wagons were built were riveted at one end only, and were free to expand and contract at the other end. The wagons were taken from the retort house, elevated by the telpher and carried to the point in the coke heap, or to the wagon on the siding where they were to be discharged and tipped. The telpher elevated a ton of coke in each wagon at the rate of 60 feet per minute, and travelled along the track at 200 feet per minute. The power absorbed was very slight. Hoisting the empty tram only absorbed about 3 E.H.P.; hoisting a full tram absorbed about 7 E.H.P.; running light upon the gradient took 4½ E.H.P.; and running full 7½ E.H.P. There was a considerable advantage also in the use of a telpher, in that there was no portion of the machinery which came into actual frictional contact with the coke. Some transformation took place in the carbon of coal when it was converted into coke, which changed it from what might be called the graphitoid state in which it existed in the coal, into a hard, gritty substance, having very much the same effect as emery upon everything with which it came in contact, so that there was a great deal of advantage in a machine which obviated frictional contact with such a material.

It was mentioned in the Paper that the total extension of the chain of the coke-conveyor amounted to about 10 per cent., but the author did not mention whether that was due to wearing at the joints entirely, or to absolute extension of the links under tensional stress, or to both causes combined. It would be of interest if the author would state which cause produced the effect.

Mr. Daniel Irving said he thought nothing indicated more clearly the progress mechanical engineering was making, not only in the gas industry but generally, than the fact that the plant, which the author had so ably described in his Paper, had practically in eight years become antiquated. Mr. Atherton had contrasted the carbonising of coal in what was known as the inclined-retort system with that of the horizontal, or the old-fashioned system. There could be no doubt that the projector machine lent itself very readily to existing old-fashioned retort-houses, and enabled the work to be done with great economy. The tendency of gasworks practice was still further to incline the retort. Instead of an angle of 31°, 45° had been adopted; and the angle had even been abandoned altogether, and the retort set upon end. The vertical retort was now being generally used in Germany. The most advanced and complete vertical system at present in use was at Bournemouth, namely, the Woodall-Duckham system, where the coal was continuously and automatically fed in at the top of the retort, and the coke periodically removed from the bottom of a vertical retort. All practical men would at once see that this arrangement must result in great economy in the handling of coal for gas-making.

He hesitated in giving figures with regard to his own works; but he might state for the information of members that the labour costs had practically been reduced to nearly one-third. On the old system it practically cost 5*d.* per ton to place the coal in the retort house; at the present time the cost of handling coal with the plant that had been described was something under 1*d.* per ton. With the old arrangements coke cost practically 5*d.* per ton of coal for wheeling, cooling and stocking, while the labour involved in doing the same work with this plant was something under 1¾*d.* Coke was a much

(Mr. Daniel Irving.)
more difficult article to deal with than coal. The plant the author had described had worked remarkably well, and the whole system had worked very smoothly ever since it was introduced; the fact that Mr. Stagg, who had the most intimate knowledge of the plant of any member of the staff, was the most enthusiastic with regard to it, spoke greatly in its favour. The cost of maintenance had not in any case exceeded the original estimate. The system had been of great help to the men employed, and the work was much easier and more comfortable. He did not for one moment suggest that the plant was introduced simply to lighten the labour of the work; it was introduced by the directors to enable them to meet their great responsibility in providing light and power in the important city of Bristol at the least possible cost, and so far there was every reason to be well satisfied with the results that had been secured.

Mr. F. G. Wright, after asking the author if he could give the members any information with regard to vertical retorts, said he happened to be a director of the gasworks at Swindon; and was interested in the subject. The Great Western Railway Co. had gasworks, and any of the members who intended visiting Swindon by the Institution Excursion on the Friday would be welcome to inspect the works there, which were of a modern nature, although not so large as those connected with Bristol.

Mr. A. T. Tannett-Walker, Vice-President, thanked the author for his able Paper and for calling attention to the fact that William Murdock, who was the inventor of the slide-valve, was the first to use inclined retorts in this country. Under the heading of coal plant (page 574) the author said that "water-borne coal is unloaded by means of a steam-crane and a Hone's grab." His own experience, which was a fairly considerable one, was entirely in favour of unloading coal from boats by means of cranes and grabs, and he had been present at tests when as much as 70 tons of coal were pulled out of a boat in an hour at, he should think, 200 per cent. less cost in mechanical work compared with the previous plant. From actual experience he knew that the grab was a cheap, economical, and simple means of unloading coal from a boat. His firm had a problem to deal with at the present time which related to the handling of something like a million tons of coal per year. The coal was sea-borne; and after experience on the River Thames and in various other places, where marvellous results had been obtained so far as simplicity and economy were concerned, they had decided to adopt grabs. The ingenious sprocket pulley-chain depicted in Fig. 14 (page 584) was invented by a Welshman, who ought to receive every credit for his work. It was a wonderful contrivance, and the French honoured the country to this day by calling it "Chaine de Galles," which showed that they admitted that the chain was invented in Wales. It was of interest to have new things brought before their notice, and he was therefore much indebted to the author for his description of the De Brouwer wheel.

Mr. CHARLES HAWKSLEY said it had been foreshadowed that certain particulars would be given with regard to costs, and he therefore wished to utter the warning that costs were very illusory unless they included every item, that is, the capital cost, and the cost of up-keep, including replacement so as to maintain the machine or structure in perpetuity. Then, on the other hand, in arriving at the cost of labour it was amongst other things necessary to remember the expense of ensuring the workmen against accidents. All items of whatever kind ought to be brought into account before comparing the cost of handling coal or other articles by one method with the cost by another method. He therefore hoped that, in any costs which might be given, everything of that kind would be included.

Mr. ALFRED SAXON, in referring to the question of the lengthening of the pitch of the chain, said it was his experience that driving chains for motors lengthened somewhat under ordinary working conditions in addition to the wear in the holes and the pins, and he thought it not unlikely in the particular case under discussion that, owing to the heat under which the chains worked, they had also stretched as well as worn.

Mr. WILLIAM STAGG, in reply to Mr. Atherton's request for particulars of costs, desired to refer the answer to that request to Mr. Irving. Mr. Atherton also referred to the angle of the slope of the breaker being too flat. As a matter of fact the coal fell down almost vertically on to the lines of steel claws. There was a by-pass for coal which did not require breaking, but he was bound to admit it was not working well, and was really out of use, so that its angle did not matter under those circumstances. With regard to the chain-drive at the elevator head, a chain driven from the elevator head was used to drive the conveyor itself, and he had nothing to complain of whatever in the vertical shaft for the main drive. There was less friction with a pair of wheels than with a chain-drive. Mr. Atherton illustrated a section of the coal-conveyor he favoured. If a reference were made to the two sections given in the Paper, it would be seen that one was semi-elliptical and the other rectangular, and the one Mr. Atherton sketched was exactly like the rectangular section shown in the Paper. From practical experience in working, he preferred the semi-elliptical pattern as shown in Fig. 12 (page 581), the wear and tear being much less than with the rectangular form. The rectangular coal-conveyor referred to by Mr. Atherton was also in the Paper, and was shown on page 580.

Reference had been made by Mr. Canning (page 589) to the amount of electrical power required for driving a plant. There was no electrical installation at the Avon Street Works, although there was at Stapleton and Canon's Marsh, where all the work was driven electrically. He was very interested in the statements of the variation of power required for breaking, and they quite bore out his own estimates. There must be a great variation, owing to varieties in the hardness of the coal, the foreign matter which inevitably got in, and the small coal jamming itself. He was afraid he could not give the information asked for with regard to vertical retorts; he had given in the Paper the result of first hand experience. Grabs were splendid things for small coal, but they were of no use for large coal.

Mr. A. T. TANNETT-WALKER, Vice-President, stated that his firm used the grabs for large coal.

Mr. STAGG, continuing, said that the sprocket-wheel which was referred to was designed by Mr. W. J. Jenkins, of Retford. After seven years' experience of the plant, he would not go back to the old style of work. It was quite likely, as had been suggested by Mr. Saxon (page 593), that the links of the coke-conveyor chains stretched slightly, but the great wear was in the joints. The coke grit got in the joints and the chains became very slack. A hole that might be 1 inch in diameter was enlarged by wear to nearly 2 inches before the chain was thrown away.

Communications.

Mr. FREDERICK BERRY wrote that he wished to call attention to the power required by the conveyors used. The author stated (page 585) that "the amount of power required for these conveyors is surprisingly small, and is supplied by a gas-engine. 1,540 feet of conveyor-chain requires, when light, only 25·16 I.H.P., including two line-shafts, belts, and driving-gear, and 12 per cent. more when fully loaded." Now 12 per cent. of 25 H.P. was only 3 H.P., and therefore the total power at full load was 28 H.P. The writer inferred therefore that 28 H.P. was absorbed in giving out a useful output of 3 H.P. only, that is, the difference between full load and light load. This meant an efficiency of only 10·7 per cent., or a wasteful expenditure of power in friction, &c., of nearly 90 per cent. It appeared to him that the power necessary to work these conveyors was rather high, and not "surprisingly small."

Mr. J. R. WILLIAMS wrote that the author stated (page 571) that the measuring chamber was discharged by pulling a lever connected to a slide, and in Fig. 3 (page 572) a section of the measuring chamber was shown. He would like to ask, if any difficulty were found in actuating these slides? If no difficulty were found and they worked easily, he would like to know the nature of the metal

(Mr. J. R. Williams.)

used. At the Tramway Power Station in Sheffield great difficulty had been found in actuating slides, even when using gun-metal; the levers broke off repeatedly and had to be replaced with a rack and pinion fitted with chain and chain-wheel. They also found it difficult to close the slide tight, owing to its not having a clear way through the trunk; whilst if a way were cut through the trunk, it allowed small coal to fall upon the floor. They intended to try toothing the front edge of the slide, about $\frac{3}{4}$-inch deep; when tried experimentally this had overcome the difficulty.

A sketch was shown (page 583) of a chain conveyor, which was riveted up; the writer's experience of riveted-up chains had not been a fortunate one, and in the conveyor in use at Sheffield, which was of the gravity-bucket type, the links were originally riveted up; but the difficulties of repair were so great, that when the chain was renewed, they fitted it with straight steel pins washered at each end and simply fastened with split pins. Their reason for using the straight pins was cheapness of first cost, as these pins could be cut cold from the rolled steel bars and simply required the pin holes to be drilled. The writer now found that any repairs or alterations that might be required, such as fitting new pins, links, &c., or changing over the chain, owing to the unequal stretching, were much more rapidly completed. Instead of having to chip off the rivet-heads, they simply drew out the split pin, and drove out the coupling-pin.

They had also found difficulties due to the unequal stretching of the chain, the usual result being that, the longer chain ran out of the groove in the guide wheel; and this riding tended to stretch the longer chain still further. This defect could be partly remedied by opening out the grooves in the guide-wheel, the sides of the groove being turned at an angle, and also by carrying the leading on guide rail as close to the wheel as possible.

Mr. STAGG wrote, in further reply to Mr. Atherton's question relating to the possibility of coal hanging up at the sides of the hopper (page 587), that no inconvenience arose from this cause, and in practice the angle of the hopper, 35°, had proved itself to be sufficiently steep. The reply given during the discussion referred to the inclination of the surfaces below the shuffler.

With regard to Mr. Herbert Canning's and Mr. Alfred Saxon's enquiries as to whether the lengthening of the chain was in part due to the stretching of the links under tensional stress, careful measurements, since made, of new links and of those worn out showed that the links did not stretch, and therefore the whole of the wear occurred at the joints.

In regard to Mr. F. Berry's communication, the author quite agreed that the mechanical efficiency of the conveyor was low.

In reply to Mr. Williams, no difficulty was experienced in actuating the coal slides of the measuring chambers. These and their guides were of steel. Occasionally coal dust settled in the grooves in sufficient quantity to cause the slide to jam. But with 120 slides in operation they did not get a jam more frequently than once a month. The slide had a clear way through, and a little coal fell in consequence.

The riveting of the coke-conveyor chain-links (De Brouwer) had proved to be a wholly satisfactory method of connecting the links, and no other method could be so well applied to this type of chain.

FORCED LUBRICATION FOR AXLE-BOXES.

BY MR. T. HURRY RICHES, *President*,

AND MR. BERTIE REYNOLDS, OF THE TAFF VALE RAILWAY, CARDIFF.

This Paper describes a system of Forced Lubrication as arranged for the driving axle-boxes of some of the steam-cars of the Taff Vale Railway Company. Before entering into a detailed description of the system used, it will perhaps be advisable to give a few of the more necessary particulars concerning these cars.

The engine is carried on a four-wheeled truck of 9 feet 6 inches wheel base and 2 feet 10 inches diameter wheels, the boiler (of double-ended locomotive type, lying transversely across the frame) being placed immediately over the centre of the leading or driving-axle. The front end of the coach is supported by means of a bogie centre, carried between the frames at a distance of 4 feet from the trailing-axle, or 5 feet 6 inches from the leading-axle. When the car is loaded with its full complement of passengers, the weight on the driving-axle is 15 tons 13 cwts., the weight at the rail being 17 tons 6 cwts. The journals are 6 inches diameter by 9½ inches length; therefore the pressure, taking two-thirds of the projected area of the brass as bearing area, is 466 lbs. per square inch, the number of the revolutions of the journal, at a speed of 30 miles per hour, being practically 300 per minute. With this pressure and high rubbing velocity an undue amount of oil was being used with the ordinary method of lubrication, while cases of the bearings running hot were not infrequent, therefore the following arrangement for lubricating the journals under pressure was adopted.

To a cross-stay in front of the driving-axle, Fig. 1, a small gun-metal tank of rectangular section, Plate 16, is fixed. On the side of this tank, nearer the driving-axle and in connection with the tank, two small rotary pumps—right- and left-handed—are fitted, the one for forward running and the other for backward running. These pumps are driven directly from the driving-axle by means of a belt passing over a flanged pulley carried midway between the pumps, the pulley containing on each side of it a roller-clutch, somewhat similar to a free-wheel arrangement, fixed to the driving-spindle of the pumps. By these means, the one belt drives either pump forward or backward, the other pump being free.

Following the process through, for the lubrication of one of the journals, when the car is in motion, oil is pumped from the tank and forced through a coiled copper pipe to the top of the axle-box, Plate 17. An oil channel, $8\frac{1}{4}$ inches long, $\frac{9}{16}$ inch deep, is cut in the crown of the box, leaving a margin of metal at each side of the channel of $\frac{3}{8}$ inch flat, which is found, when the box is properly bedded to the journal, to be quite sufficient to ensure that it shall be perfectly oil-tight at the pressures attained.

After passing round the journal, the return oil is collected in the axle-box keep, and from there is brought back to the tank by means of a flexible pipe which allows for the rise and fall of the axle-box, care being taken that the reservoir into which the oil is returned is sufficiently below the keep to drain it. At each side of the axle-box keep a half-ring is fitted with bearing area about $\frac{3}{8}$ inch wide. These half-rings are bedded well to the axles, and are supported upon a couple of small coil-springs which hold the rings up to the journal with a fair pressure, and so prevent the escape of oil along the journal on the bottom side. The supply tank is so arranged that the return oil, after draining from the keep into it, shall pass through a filter before being again sent through the pump. Such briefly is a general description of the method adopted.

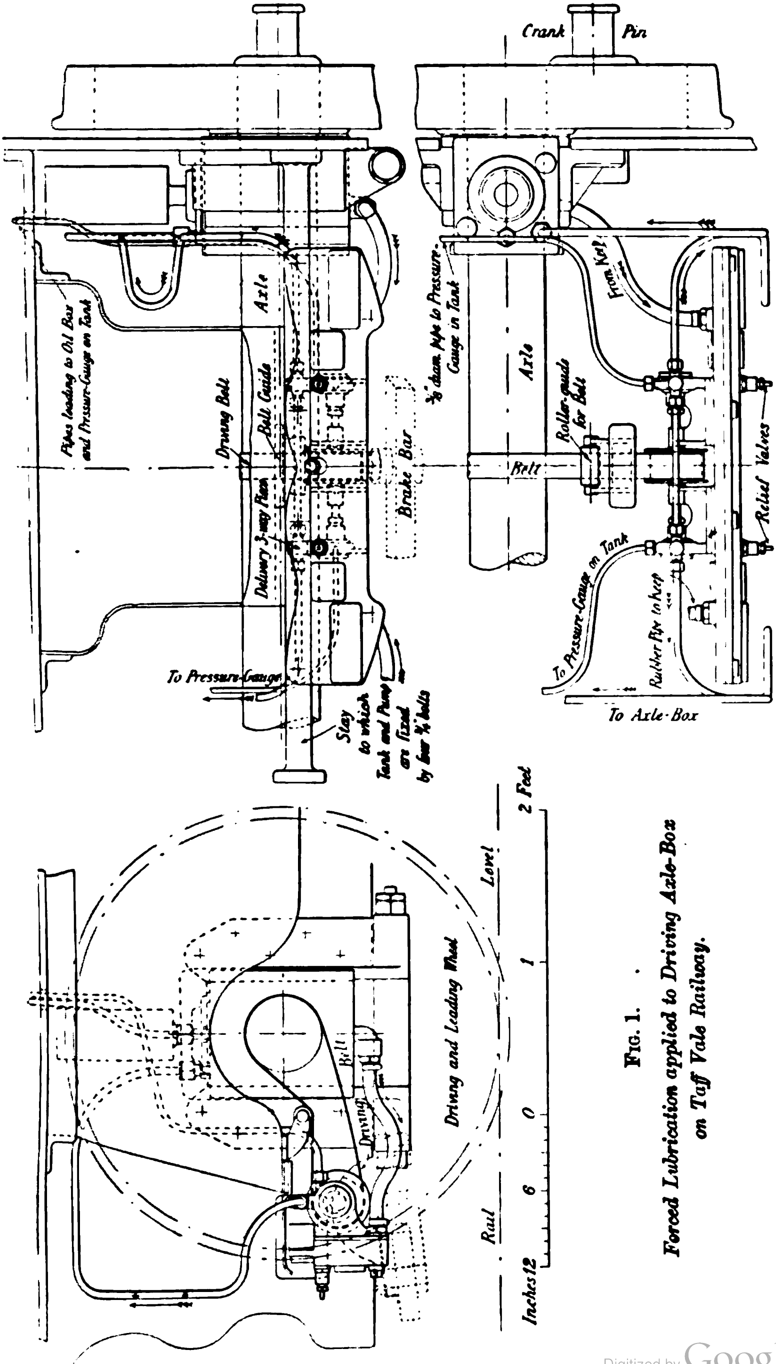


FIG. 1.

Forced Lubrication applied to Driving Axle-Box on Taff Vale Railway.

Many points arise however in regard to the working of the arrangement which it will be well to explain. In the first place, the pumps when running fast (at a speed of 30 miles per hour, the revolutions of the pump are 440 per minute) deal with a greater quantity of oil than can be accommodated in the circuit at a pressure of, say, 20 lbs. per square inch, above which, in practice, it has not been found advisable to work. A relief valve is therefore fitted to each pump with an adjustable spring which enables the pressure at which each pump shall work to be regulated. The excess oil, when pumping, simply passes back into the tank again, through the relief valve against the pressure of the spring. A small pressure-gauge connected to each pump, and fixed in the driver's cab, shows the pressure of the oil pumped on both forward and backward running, whilst also acting as an indicator should failure of either pump occur at any time. Should this happen from any cause, the ordinary system of lubrication, by means of a lubricating-box in the cab, is at hand. This lubricating-box is also necessary, to enable oil to be put into the axle-boxes after the car has been standing for a day or two, and so avoid starting away with dry axle-boxes.

To prevent the oil from the running pump flowing into the other pump and causing it to run backwards, a small ball-valve is placed in the three-way piece leading from each pump to the circuit. The movement of the axle-boxes relatively to the tank and pumps was met in the first instance by trying different sorts of flexible piping, but finally, ordinary coiled copper piping was adopted, both on account of its comparative durability and of its accessibility at any time.

The belt drive for the pumps at once gives a simple method of driving and one which allows for a small relative motion of the axle and pulley. It is apt, however, to soon become saturated with oil, and then slipping occurs. An occasional application of one of the various belting mixtures, however, greatly reduces this slipping. When equal relief-valve springs were put in, it was noticed that the pressure indicated for forward and backward running varied considerably, probably due to the difference in the slip of the belt in each case. The filters in the tank are removable, and are taken out and cleaned at the end of each day's work, the oil being first drawn off through the stop-plug, the thicker part of the oil, after straining, being then replaced by a small supply of fresh oil.

The foregoing description shows one method of dealing with an everyday problem in connection with the running of railway motor-cars, or any rolling stock in which the pressure on the bearings, combined with the rubbing velocity, is excessive. The matter is one of importance to all concerned in the design and care of such stock. This short Paper has been written in the hope that it may be useful to some investigators of this subject.

The Paper is illustrated by Plates 16 and 17 and 1 Fig. in the letterpress.

Discussion.

On the motion of the PRESIDENT, a hearty vote of thanks was accorded to Mr. Bertie Reynolds for his Paper.

Mr. WILLIAM H. ALLEN, Member of Council, in opening the discussion, said he had known the President for the past half-a-century and had never had to find fault with him before, but he did so on the present occasion. The President and his colleague had brought forward a most engrossing theme for discussion, but had stopped short at a description of the drawings, no results being given. He hoped that, in reply to the discussion, the authors would be able to state what results had been achieved, as he believed the present was the first time forced lubrication had been used on rolling stock. His own connection with forced lubrication was rather an interesting one, and the members would, he hoped, forgive him if he told them a little history. Sebastian Z. de Ferranti when he was a boy, in 1881, asked him to make a little force-pump, which he believed was the first time forced lubrication was used in any practical way. Ferranti's employer, Lord Wantage, had asked him

(Mr. William H. Allen.)

to put 3,000 H.P. into a cellar in New Bond Street, London. There were about fifteen engines in the cellar, and everything worked well except the outside bearing of an alternator. No doubt the bearing was too small, or it was not round, or set up, and it caused trouble, and Ferranti proposed a forced lubricating arrangement which acted perfectly. As an instance of how blind fashion was, after that time the outside bearing of nearly every alternator in the kingdom was made with forced lubrication, but to no other bearing was it applied. But why should it be limited to the outside bearing? Messrs. Bellis then took the system up, and adopted it for their connecting-rods; but why should it be limited to connecting-rods? In the end it went all through the engine, and since that day all sorts of machinery had been fitted with forced lubrication.

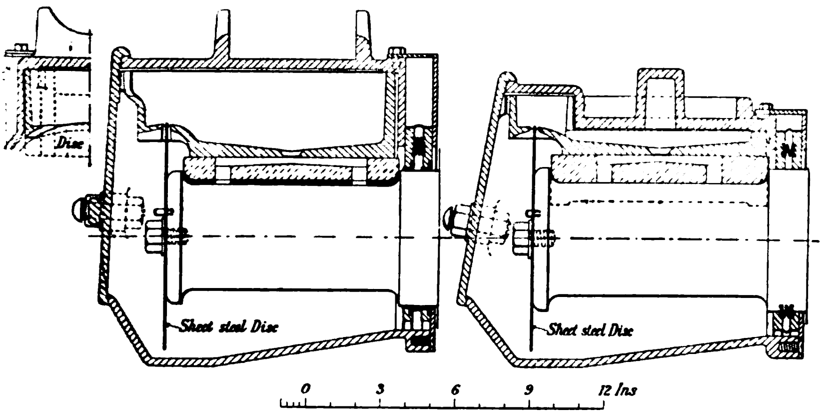
The advantages of forced lubrication were manifest. First of all, the machinery could be run very much faster; practically no oil was wasted because it was filtered regularly; and there was hardly any wear. As an evidence of that, he had in his Works a marvellous crank-shaft which had travelled 340 million revolutions. It was 6 inches in diameter, and was put into an engine made by his firm for Messrs. Harland and Wolff, and it worked for seven years. The engine had to be remodelled, and he thought it worth while to examine the crank-shaft; and, so far as could be measured by the micrometer, there was absolutely no wear on the shaft. No doubt that was the case with every other class of machinery which was working under forced lubrication. He trusted the system would be applied to every class of bearing, and not limited to one alone.

Mr. J. J. Podesta thought it would add to the interest of the meeting if he showed the members something which was being done at the Patent Axle-box and Foundry Co.'s Works, not exactly in regard to forced lubrication, but at any rate with the same object in view, namely, of thoroughly and efficiently lubricating working axles. To illustrate the point, he desired to show two drawings giving particulars of the arrangements adopted. Fig. 4 showed the application to an ordinary wagon-box. On the end of the journal, which was 9 inches by 4½ inches, there was a disc of sheet steel about 9 inches diameter and about 16 S.W. gauge, which was secured by a bolt through the middle, a small dowell preventing any slip. The bottom of the box was filled up nearly to the level of the outside shield opening. There was a shield pressed from underneath, close up against the axle, and also pressed endways to prevent any oil escaping. A few days ago he put his finger to the back of a box which had run with that arrangement, and it was quite dry. People who had had experience knew that the bosses of the wheels generally got splashed

Iracier Axle-box (Wood and Carson).

FIG. 4.—As applied to English Standard 10-ton wagons.

FIG. 5.—As applied to 35-ton Bogie Trucks.



with oil, but in this case there was no trace of oil lost. The disc was all the time dipping in the oil bath, and every revolution it picked up a quantity of oil and carried it up to the key-plate, which was slotted for the purpose. The oil was taken off by both sides of the slot, and was guided by suitable channels cut in the sides of the key-plate, and brought down through a hole in the centre into the bearing.

The bearing he exhibited had been in use about four months; it had only run between 1,000 and 2,000 miles as yet, but it would be noticed that the traverse marks of the boring had not been worn out

(Mr. J. J. Podesta.)
at all, which showed the efficient nature of the lubrication. There were one or two scratches shown, but they were due to the roughness of the journal running in it. He also exhibited an old bearing which had been under the same truck, but with the old system of lubrication, and had been replaced by the new one, in order to show the rough nature of the work it had to do. The bearing which had replaced the former one was made with a white-metal facing, softer than the previous one, but it would be noticed how the hard material had suffered under the usual system of lubrication, while the softer was standing the strain well with the new arrangement adopted. The box had a very deep key-plate, but that was to accommodate the height of the spring seat; it could easily be arranged for lower spring seats.

The second drawing, Fig. 5 (page 605), showed a case in which the spring seat was lower, and the slot could still be obtained in front of the box. It was right out of the way, and did not interfere with any work at all. There was a continuous flood of oil. It might be asked whether the disc would pick up the oil when going at slow speed. Experiments showed that oil was well lifted, even when the truck was being shunted by hand in the yard. At eight miles an hour there was a regular reservoir of oil $\frac{3}{8}$ inch deep on the top, while at higher speeds there was no question of its reliability. A few days ago a wagon came in which had run from Wolverhampton to Hull and back again, and on examination it was found that hardly any oil at all had been lost.

Mr. WILLIAM SISSON thought the members would agree that the Paper described an interesting development in forced lubrication. He did not know what their experience had been, but his idea of forced lubrication had always been its application to those cases where there was an alternation of pressure, where the pressure was periodically applied and relieved. The development the authors had described showed that, at least in rolling stock, it was advantageous to apply forced lubrication to a bearing where the pressure was not entirely relieved periodically, as in the case of a crank-pin of a double-acting engine. He had been wondering whether the same desirable result would be obtained, were it not for the vibration of the axle and the box on the permanent way and the end play, both of which were present in such a bearing as had been described. He wished to ask whether the authors had any results of the application of forced lubrication where the load was not relieved at all, and the oil pressure was not equal to the pressure per square inch between the surfaces.

He spoke with considerable diffidence in regard to what Mr. Allen had said, but he could not help thinking that Mr. Allen must have forgotten, when he stated that forced lubrication began in 1881, that long before that time, footsteps of vertical shafts were lubricated, not by the present system of forced lubrication, or as he thought it should be more properly called assisted lubrication, but by an actual oil pressure which was sufficient to lift the shaft. That was a different thing, the oil being actually forced in, and it might fairly be called forced lubrication.

He had adopted a connection with a flexible pipe in a plan he was now carrying out, not exactly for the same purpose, but for a similar purpose, where he wished to make a very high pressure connection, about 700 or 800 lbs. per square inch on to a part moving at the rate of about 600 strokes a minute, although the motion was small, and therefore he was glad to have the President's confirmation that he was on the right track in using a copper pipe with a good many bends in it. With respect to the belt-drive for the pumps, and the fact that different pressures were obtained when running forward and back, he supposed that must be due to the sag of the belt. The tight part of the belt was on the lower side when running in one direction, but on the upper side in the other direction, so that there was then more belt slip.

He wished to raise the question as to whether it was right to attempt to put the oil in at the top of the brass. Most engineers had been educated, by the classical experiments that Beauchamp Tower made years ago, into the idea that they must not put it in at the point of maximum pressure. If the system were used where the bearing was not in vibration and had not any end play, would there be a successful result? He asked, with respect, why not make two

(Mr. William Sisson.)
oil ways, one on each side of the crown? There were two oil-pump connections. That oil way which was on the leading side of the bearing could be fed by the pump which was in gear, so that the oil should be fed upwards on to the crown of the bearing, whichever way the vehicle was running.

He would never forget a diagram which the late Mr. Beauchamp Tower showed. He tried to oil his experimental brass at the centre, and he could not oil it; it seized. He gave that up and put a wood plug in, which was blown out. He then put on a pressure-gauge, and it showed about 700 lbs. to the square inch; the nominal pressure on the bearing was about 500 lbs. per square inch, so that the maximum pressure was thus about 200 lbs. above the mean. Most of them had got fixed in their heads the idea that they must not put oil into the crown of the bearing, and he submitted whether these two oil ways would not be an improvement. There were two pumps and two oil connections; why not give the crown of the bearing, where the maximum pressure was, the best chance?

He was exceedingly interested in the Paper, because it opened up a new development of the forced or assisted lubrication system, with which the names of Messrs. Allen and Messrs. Belliss and Morcom were associated. Splash lubrication had been a good servant. The Willans engine was a great success, and was bound to be a splash lubrication engine because it was a single-acting engine. With care good results could be obtained, but there was no doubt that forced or assisted lubrication gave facility in running at speeds and pressures that could not be attained so safely otherwise. Another advantage was the continuous filtering of the oil.

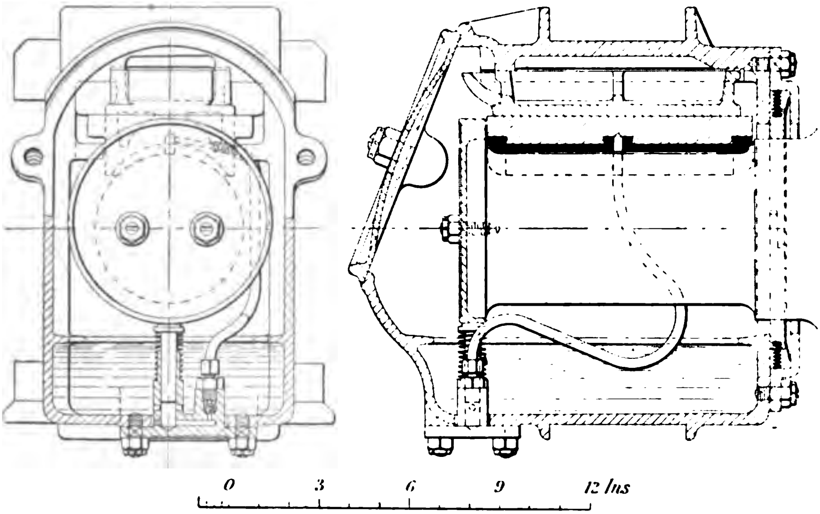
Mr. Ewart C. Amos said that he read with very close attention the valuable Paper for which the President and Mr. Bertie Reynolds were responsible. The subject was to him of more than ordinary interest, as he had been studying for some time past the question of forced lubrication as applied to rolling stock. He, for one, was therefore able to assure the President that the hope expressed by the authors in the concluding paragraph of the Paper, namely, that it would be useful to those investigating the subject, was amply justified. Judging from the discussion, there could be no doubt that a great many engineers were now considering the matter very closely. In view of the wide and long experience which the President possessed in respect to railway matters, it was not his intention to offer any criticisms on the Paper; indeed he wished to thank the authors for the valuable information they had given. Mr. Tannett-Walker had remarked that there was nothing new under the sun, and that this was particularly true in respect to engineering, but he thought he was right in saying that the question of forced lubrication as applied to railway axles was of modern conception. His own investigations had led him to one conclusion on which he believed he was on sure ground, namely, that sufficient attention had not yet been paid to the question of lubricating railway carriage and locomotive bearings, and further that the solution of the question was only to be found in some system of forced lubrication. It seemed strange that members of the Institution should tolerate such a statement at the present date, or that their President should be introducing for the first time the question of forced lubrication as applied to locomotive bearings. He therefore very heartily thanked the authors of the Paper for laying before the members a method of achieving that very desirable object.

He had no doubt that more experienced members than himself would deal in detail with the Paper, but he might perhaps be permitted to refer to a few points. In the first place, the authors said that ordinary methods of lubrication unduly wasted oil and produced hot bearings. They then went on to describe the means they adopted for avoiding these troubles, and showed the difficulties which had to be contended with and how they were overcome. In conclusion they stated that theirs was one method of dealing with the subject. In view of that statement he asked the kind attention of the members, with the President's permission, to another way of effecting the same object. It was called the "Tilston" system of forced lubrication, and had recently been taken up by Messrs. Vickers, Sons and Maxim. So far its application had been confined to ordinary bearings, and with marked success, although he believed the Great Western Railway had adopted it in connection with some

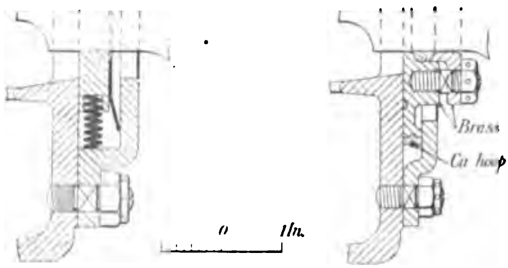
(Mr. Ewart C. Amos.)

of their rolling stock at Fishguard. At the present moment experiments were being made with railway bearings, and he exhibited some drawings illustrating the application of the Tilston system to

FIG. 6.—*Forced Lubrication System* (Tilston) *applied by Messrs. Vickers, Sons and Maxim to Cast-Steel Axle-box for 42-ton Bogie high-sided Wagon.*



Alternative Designs for Packing Ring.



standard axle-boxes, one of which was reproduced in Fig. 6. He also exhibited a working model of the system as applied to an ordinary bearing. Briefly described, the mechanism consisted mainly of an eccentric disc which was securely attached to the end of the

axle, and as that revolved it actuated a small plunger, which forced the oil through suitable passages to the point of greatest pressure. The question as to where the lubricant should be introduced was one on which he expected a good deal of discussion. In his opinion the point of greatest pressure was the only point at which lubrication should be applied. In the Tilston system no belting was employed, and each bearing had its own pump, which he thought was the best method. In these respects the system differed from that described by the President.

The advantage to be derived from a forced system of lubrication was that much less bearing surface could be used than was possible with ordinary lubrication, as there was practically no wear. Every locomotive engineer would say that that was ridiculous—and he was quite right, unless a particular object which everyone was seeking just now was achieved, namely, to get rid of the dust. The method of lubrication which he had described and illustrated claimed to be able to do this. In this country a good deal was known about dust, but in the Argentine, India, and other countries the nuisance was far greater. If dust could be kept out of a locomotive or railway-carriage bearing, forced lubrication was a simple matter. Until the dust was kept out, he questioned very much whether forced lubrication would obtain the success it was entitled to, because it was being run under unfair conditions. He believed Messrs. Vickers' difficulties had been chiefly in finding a proper method of keeping out the dust. Then again it must be remembered that in forcing the lubricant there was a greater opportunity for it to get out of the bearing than existed under the ordinary system. The Paper, however, had brought to the notice of the engineers of this country and of the Institution that the time had arrived when some method of forced lubrication should be applied to rolling stock generally, including locomotives.

Mr. Mark Robinson, Member of Council, desired to thank the authors for their careful and detailed description of a special application which was in itself a most interesting and valuable one; indeed he must echo the surprise the last speaker had expressed that

(Mr. Mark Robinson.)

it should be possible to describe this Paper as the first which had been published upon the application of forced lubrication to railway stock. His main object in rising to speak, however, was to call attention to the great general interest of the Paper, and to remind the younger engineers that during their time they might have to carry forced lubrication into most things that required lubricating. There was an increasing tendency to run most rotating things at higher speeds, too high for the old-fashioned lubrication; and where the difficulty could not be got round by ball or roller bearings, forced lubrication was necessary. He could not go back quite so far as Mr. Allen did in the history of the subject, but it was interesting to point out that not long after the time he mentioned, 1881, the double-acting engine found itself practically barred from high-speed work, which was then becoming of supreme importance, by the impossibility of lubricating the bearings satisfactorily by ordinary methods; the single-acting, or rather the "constant thrust" engine, with splash lubrication, had things all its own way. But in a few years forced lubrication, applied to the bearings of the double-acting engine, restored the balance, and the two types were again on a footing of equality, so far as good running was concerned. Thus nothing less than a revolution in an important branch of steam-engine construction was worked by forced lubrication, and it might be destined to do as much for other branches of engineering.

Mr. Sisson had referred (page 606) to the use of forced lubrication in bearings where there was not a variation in the direction of stress, and asked if it was suitable in such cases. The answer was that the steam-turbine (with the possible exception of very slow-running marine turbines) could not be used without forced lubrication; they absolutely relied upon it. Yet in turbines the weight of the rotor and shaft was constantly on the lower brass, never relieved by alternation of stress in even the smallest degree; not even by such vibration as, probably, helped the lubrication of the axles of rolling stock. As both Mr. Sisson and Mr. Amos indicated, in the satisfactory working of forced lubrication, a great deal depended upon the position of the oil channels in the brasses, and upon the particular place at which the oil was taken in. The laws governing these points were not always as obvious as they seemed to be.

Mr. DANIEL ADAMSON thought it would have been better for those members who were not railway engineers, if the authors had reminded them that the point of maximum pressure referred to by Mr. Sisson was not actually at the top of the bearing but a little to one side. These being driving axles the point of maximum pressure would fall alternately on the forward side of the top centre and on the rear side (depending upon the direction of motion of the piston) giving the alternate action referred to by Mr. Sisson. He reasoned it out that, under those conditions, the position of maximum pressure would be a certain amount to the front of the centre of the top during the time the piston was moving in the same direction as the locomotive, and on the return stroke a smaller distance behind the centre. If this reasoning were correct, then reference to the diagram given by Beauchamp Tower * would show that the actual pressure at the point chosen by the authors for the application of the lubricant would be less than the maximum pressure, and would also vary according to the direction of motion of the piston of the engine. The effect of this variation would be to allow easier access for the oil during the alternate strokes of the engine, and might explain the variation in the slip of the belt referred to by the authors. Perhaps the authors would in reply express an opinion as to whether this suggestion or the one by Mr. Sisson was the more likely to be correct.

He wished to express his agreement with Mr. Sisson in his criticism of the position chosen by the authors for the application of the oil, and he did so with more confidence because a Paper upon Assisted Lubrication of Axle-boxes (it had already been said by previous speakers that the method described in the Paper was "assisted" lubrication rather than "forced" lubrication) was written by an eminent railway engineer, Mr. W. Bridges Adams, more than fifty years ago† describing a system in which the oil was applied on the *lower* side of the bearing, in that case by rollers, as against pumps in the present instance. This seemed to confirm his own

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* Proceedings 1885, page 61.

† Proceedings 1853, page 57.

(Mr. Daniel Adamson.)

opinion that it would be better to apply the oil (at the low pressure chosen by the authors) at some other point than at the upper portion of the bearing.

Mr. JOHN A. F. ASPINALL, Vice-President, inquired whether part of the idea, and perhaps the leading idea, in dealing with the question of forced lubrication had not been to have a rather better mechanical distribution of the lubricant than forcing it between two surfaces. With rolling stock there was not the same difficulty in getting a lubricant to flow easily that was experienced with engines of a stationary character, because the intense vibration to which the rolling stock was subjected served in some way or other to open out the surfaces, and to induce the lubricant to flow in a way it could not be made to do in other kinds of machinery. He assumed that possibly there might have been another idea, namely, a certain amount of oil economy. The present systems of lubrication for rolling stock, though perhaps looked upon as crude, were certainly very efficient when one considered that a locomotive starting, say, from Paddington and going for a long run to the West of England, or from Euston right away to Liverpool without a stop, had nothing whatever done to it during the journey. The driver had to look after his signals; the fireman had to look after his coal; the engine must look after itself. The only time that could be given to the engine was before it started and after it arrived; and the mechanism of lubrication must be of such a perfect character that it required no inspection whatever during the journey. If mechanical lubrication was to be introduced instead of the simpler methods of the past, it must be of such a character that it would require no looking after whatever.

One of the difficulties of lubrication upon a railway was that of the dust which in the summer was of such a serious character; and not only on account of the dust but of those very fine ashes which came out of the smoke-box, and which were familiarly known by locomotive men as "chimney end." There was no aperture so small that they could not enter; there was no cavity so great that they would not fill in time. The form of axle-box that was used in a locomotive, which had naturally to be open at both sides because it had a crank-web on the one side and the wheel-boss on the other, was perhaps a little more difficult to look after than the forms of axle-box shown in the diagram exhibited, Fig. 6 (page 610), which were the forms generally used for wagons or carriages, but which had the advantage of being closed at one end. That form meant that a dust-guard could be used, and so long as it was a good fit, it prevented a great deal of the dirt from entering between the surfaces.

He noticed in one case on the diagram that apparently the lubricant was being transmitted from the central reservoir to the bottom of the journal. Although the President's diagram, Plate 17, showed the lubrication to be forced between the surfaces at the top of the journal, he would have thought it would be better to adhere to that form of lubrication which had been found so good in all axle-boxes of that class—lubricating from the bottom rather than attempting to force the lubricant in from the top. In the method which was apparently shown in the diagram he assumed that the oil was forced in a kind of jet which spread itself over the surfaces as the axle rotated. Whether the authors had tried that in any larger vehicle than the rail motor-cars he did not know, but if so, he would be glad to have information.

Mr. ALFRED SAXON congratulated the President and his colleague on introducing the subject of the Paper, because their system of lubrication applied in many directions other than the one dealt with in the Paper. He had been particularly struck by the fact that the President's system, practically on his own admission in the Paper, was not strictly reliable. A mechanical chain-drive would, he thought, suit the system the authors had described and be more reliable.

With regard to the question of lubricating where the thrust or pressure was, he thought Mr. Sisson had touched the spot in the remarks he had made. Where for a time a bearing was under tension or thrust, so far as the pump pressures described were concerned, he did not think they were sufficiently high to give

(Mr. Alfred Saxon.)
much relief, but the flushing of the bearing was probably the best thing which could happen as an alternative to relieving the bearing of pressure.

A Paper was contributed some time ago to the Manchester Association of Engineers by Dr. J. T. Nicolson on Friction and Lubrication,* and the author there described the Tilston bearing to which Mr. Amos had referred (page 610). That, undoubtedly, was a good bearing; he had not a word to say against it in that respect. A claim was made, however, by Dr. Nicolson that if engineers and millwrights were to adopt that style of bearing they could reduce their standard length of bearings one-half or one-third. There were some drives in mill rope-races where a pull somewhat equivalent to the thrust in railway axles took place. He stated at the time that he was willing to have two of those bearings put to a practical test, of the dimensions that Dr. Nicolson thought would serve the purpose, but he (the speaker) had not heard anything about it since.

It ought to be remembered that standard practice had been adopted based upon actual working experience, and it was very unsafe for people to make the claims they did with regard to reduction of sizes and costs without going fully into the question. A fixed plate for lubrication had been described by one of the speakers. In general practice loose oiling rings were extensively used, and that was a very effective system of lubricating the rope-race bearings he had referred to, being much simpler and more reliable than pump lubrication. He believed the Tilston pump was about as simple a pump as could possibly be arranged, and if it proved to be really durable then they would have a good system of flushing the bearing, and probably relieving the friction to a slight extent.

Mr. F. G. Wright thought that there were cases where forced lubrication was of great advantage, and he had no doubt there were others where they were able to lubricate satisfactorily without using it. On the Great Western Railway they had the longest run in the

* Transactions, 23 November 1907, page 65.

world, running from Paddington to Plymouth in both directions, sometimes two or three times a day without a stop, and during last summer they never had a single hot axle. He considered that was an excellent performance, taking into account the millions of miles that the rolling stock ran, and the same remark applied to the wagon stock fitted with oil axle-boxes.

The Great Western Railway Co. made use of a system which could be explained by calling it "lubrication by centrifugal force." An axle-box was used in which a pad was inserted, and no holes were allowed through the bearings at all. When the axle was in motion there was a film of oil between it and the bearing. Even after it had run thousands of miles the scraper marks could be seen on the bearing, and where case-hardened axles were being used the grinding marks could be seen on them. He did not think there was any opening for forced lubrication on rolling stock. To his mind the great necessity for mechanical engineers was to work out problems in the simplest possible manner, and to avoid complications which were unnecessary. The rolling stock on the Great Western Railway was 70 feet long, with four-wheeled bogies, and if forced lubrication were introduced many complications would have to be dealt with. He would like to know what would happen if the pump failed, or if the pipe broke.

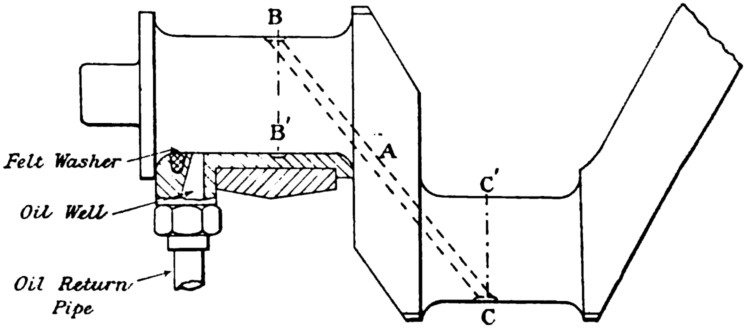
As the driver of a motor-car, there were many things he would like to do away with. If the tyre were punctured, or if the fan-belt came off, one was bound to stop. Personally he had no pump for his circulating water—it was done by thermo-syphon; and he had no forced lubrication, which was totally unnecessary in his opinion, except in very large motor-cars, because it was possible to lubricate quite well by gravitation. In that way he reduced the working parts to a minimum, which to his mind was the essence of successful rolling stock—to have an axle-box of the simplest possible construction.

Mr. L. A. Legros said he did not quite agree with Mr. Wright's remarks about motor-cars, as he thought it was advisable to fit forced lubrication to the engine. That was done in a manner very

2 x 2

(Mr. L. A. Legros.)
similar to that which Mr. Allen and Mr. Mark Robinson had already described. In the axle-box the authors had designed he noticed they had avoided one great risk there was in adopting forced lubrication for the axles of rolling stock, namely, drilled holes in the axle. The authors applied their lubrication through the brass. Personally he thought it was much more difficult to ensure proper lubrication by that means than by applying it along the shaft. If holes were drilled in the axle, fracture was liable to originate at the centre of the drilled holes. He had noticed that had frequently happened on tramways. Some tramway axles which he fitted himself had a set-screw for retaining a chain-pulley, and the axles started to crack

FIG. 7.—*Motor Crank-shaft with forced lubrication.*



through those pointed drilled holes, in the way which all engineers were familiar with in fatigue experiments. That cracking could be avoided by putting a very big radius at the outside of the drilled hole, a point to which great attention ought to be paid in making motor-car shafts with forced lubrication for the connecting-rods and gudgeon-pins. It was necessary that the holes which carried the lubricant should be very well rounded out, if one wished to have no fracture.

The hole was drilled through the bearing as shown at A, Fig. 7. It was necessary that the holes should be very well rounded out at B and C, so as to avoid the fracture starting at B or C and cracking the shaft through BB′ or CC′. In fitting these bearings it had been found that an oil-pressure of only 2 lbs. per square inch was sufficient for a motor-engine running from 1,400 up to 2,000 revolutions a minute for a journal 2 inches diameter and a crank-pin $1\frac{3}{4}$ inches diameter. It had also been found that it was possible to sacrifice as much length of bearing on the journal as was necessary for the felt guard for keeping the dust out.

Mr. Ewart C. Amos desired to make two remarks in reply to the discussion which had since occurred. It seemed to him that the channel described by Mr. Legros was more likely to produce fracture than the small set-screw adopted for attaching the disc in the Tilston system. It was not a *sine quâ non* that it should be attached in that way. In the second place, the Tilston system permitted of the ordinary system being retained, if desired.

Mr. Noel Chandler said he had recently had some experience with axle-boxes, which were lubricated from the bottom by some soft wool waste which was pushed in, and they had given complete satisfaction. The capillary attraction had the effect of taking the oil up to the bearings from the oil basin, and the axle-boxes had run completely free from wear for three months on some colliery wagons. He had also had experience with some high-speed engine-bearings, and he found that if oil were forced into an annular space cut in the centre it was quite sufficient to lubricate the bearing the whole way along. That did not weaken the bearing at the point where the greatest pressure occurred, namely, at the top and at the bottom in a double-acting vertical engine. The oil seemed to spread from the central groove, and no other provision was necessary.

Mr. Henry Davey, Member of Council, thought that if the old Watt engine had been adhered to forced lubrication would not have been required. The whole question seemed to him to turn on the conditions of working. Mr. Allen would no doubt agree with him that the modern high-speed double-acting reciprocating engine would not have been possible, had it not been for forced lubrication. He thought forced lubrication was not a question of general, but of

(Mr. Henry Davey.)
special, application. There were bearings which could be properly lubricated without it.

The President, before calling upon Mr. Reynolds to reply, said that Mr. Allen wanted to know what the system of lubrication described in the Paper cost so far as the oil was concerned. As Mr. Reynolds would state in his reply a great many experiments had been carried out, and an improvement in the working had steadily been made. The cars were now run 180 miles with only two pints of oil, a result a great deal better than had previously been accomplished. Experiments were still being carried on, and, if possible, he would supply up-to-date details of them. Mr. Wright and Mr. Aspinall had very naturally asked why the system of lubrication which had been described should be used at all. He agreed with them that where it could be dispensed with, he would not think of using it; he would not put such a complicated arrangement in where he could get engines to run perfectly freely and well, as they could with plenty of surface and proper conveniences for being able to sustain lubrication during the running of the train. But where there were heavy weights and exceptional conditions, such as where cars had to run hammering away at thirty miles and very often forty-five miles an hour, with very small wheels, with a high speed of journal, very confined in space, and where everything had been cut down to the lowest possible dimensions, it was not possible to adopt a proper and satisfactory system of lubrication in the ordinary way, and it was for that reason that the little device described in the Paper was made.

It was a great pleasure to Mr. Reynolds and himself that the members had taken such an interest in discussing the subject. Mr. Adamson and Mr. Sisson had found fault with lubricating the crown of the brass. What Mr. Adamson said was perfectly right, namely, that the maximum centre of pressure was not immediately over the centre of the journal when running in either one direction or the other, and therefore they did accomplish, although not perhaps in the very best way, what was desired, that is, to feed the supply of lubricant immediately in front of that pressure. In that way the consumption of oil had been enormously decreased, and he believed it was capable of very material further improvement.

With regard to lubricating from the haunches of the bearing, that was all right if the bearing did not wear; but those who had experience of bearings where the pressure was above knew that it did not take long for the hips of the bearing to be jammed much faster than the crown. The crown wore quicker; the hips got tighter; and, unless the entire journal was lubricated, it would be found that the hips would very soon generate sufficient heat to give trouble. That was why the lubrication had been tried. He had a large number of journals running with lubrication in the hips, but not under those exceptional circumstances. He had tried that method and found it a failure. He therefore devised another way, and was successful by the use of the method described.

Mr. Bertie Reynolds, in reply, said that many of the speakers seemed to think that a rather complicated system had been adopted for a very simple problem. He did not think that was the case. Although there were many forced-lubrication systems in existence, he did not think there was one which applied to such a problem as that connected with the steam-cars on the Taff Vale Railway Company. Some of the systems were suitable for other bearings which could be easily got at, and which could be boxed in and the dust kept out. There were also systems that would deal with wagon bearings so far as forced lubrication was concerned, but nothing that the authors knew of which would deal with the bearings of an engine or a steam-car. They had to deal with their own problem, to start with their own data, and devise a system to prevent the cars from running hot and using an excessive amount of oil, which they used to do. That was why a rather more complicated system had been built up; but one of the objects of the Paper was to discover what other people knew on the subject, to get from them that information, and see whether it could be adapted for their own purpose on the Taff Vale Railway.

(Mr. Bertie Reynolds.)

A question had been raised with regard to the point of maximum pressure on the bearings. Some members had said that oil should be put in at the sides, and others said it should be put in at the top. Personally he believed the oil should be put in at the top of the bearing. Engines were running on the Taff Vale with both systems, and the bearings with oil at the top ran very much better than those which took it in at the sides. Mr. Adamson pointed out that there was a fluctuation in the point of maximum pressure due to the engine running forwards or backwards, and that must be taken into account.

One of the speakers had raised the question that a chain-drive might easily have been adopted instead of the belt-drive, which was likely to give way at any time and give trouble. The chain-drive, however, did not allow for the relative motion of the driving axle and the pump, which motion had to be taken into account, otherwise trouble would ensue. A belt had therefore been put in which served its purpose; it slipped a little, but that was allowed for. The revolutions of the pump were 400 to 500, allowing ample margin for any slip.

The question had been raised as to whether there was enough oil-pressure to really relieve the pressure on the axle-box. They did not want to do that exactly; all they wanted to do was to get the cars to run with cool bearings, and to save oil. It was found in practice that a pressure of 20 lbs. of oil per square inch was quite enough. A journal was rigged up in the shops, and the pressure was run up to 80 lbs. per square inch, but it did not have the weight on it that obtained when under the steam-car. The experiments were still being continued, and any further results would be sent up for publication in the Proceedings.

Mention had been made of the difficulty of keeping out the dust. The authors found not so much difficulty in keeping out the dust, as in keeping out the water. As soon as the water got in, in any considerable quantity, it was found that the system was affected. That difficulty had now been overcome, and no water got in. The system had not been tried on locomotives. The present experiments were being carried out on steam-cars, and as soon as those experiments were finished he had no doubt the President would be progressive enough to try them on an engine, and obtain further information.

Communications.

Mr. J. G. H. WARREN wrote that it appeared that forced lubrication had been introduced as a corrective in a motor-carriage, which had to meet exceptionally high speeds with small journals, the reasons for adopting which were not given in the Paper. He wished to point out the undesirability of spending money generally on assisted lubrication, on the ground only that the system had been found useful in overcoming the heating of an overloaded axle. The difficulty would not have arisen with a suitably proportioned journal.

The AUTHORS wrote, in continuation of their remarks at the Meeting, that the system of forced lubrication—or assisted lubrication, as many preferred to call it—had answered satisfactorily since the writing of the Paper. Further cars were being fitted as they came into the shops, little alteration being made in the details shown in the published drawings. It was found, however, that as the bearings wore, and the play between the axle and axle-box increased, the oil, being under pressure, escaped at the sides of the boxes and was splashed around the wheel-boss, giving a much greater consumption of oil than that stated in the Paper. To prevent this, a narrow groove had been cut round the sides of the bearing of each box for a depth of $\frac{3}{8}$ inch at the crown, and tapering down to nothing at the hips. The neighbouring oil then lost most of its pressure at this groove, and flowed back to the keep to be collected, instead of being forced out round the boss of the wheel. The leading idea in

(The Authors.)

the adoption of the arrangement, in the first instance, being economy in oil, it would be observed that any device for preventing the escape of oil was important. Other small alterations had been carried out, but, in the main, the arrangement stood as described.

The opinion expressed in Mr. Warren's communication, that a single successful application of assisted lubrication was not sufficient reason for spending money on it, was not likely to appeal to an engineer who appreciated the advantages gained. As to the proportions of the railway motor-car, these were not dealt with in the Paper, but, since Mr. Warren had brought up this subject in reference to the axle, he wished to point out that in a railway motor-car of this kind it was not possible to use an axle of larger journal bearing surface; and therefore only one alternative to assisted lubrication remained, namely, to put another pair of wheels on to the car, and thus make the whole vehicle heavier and less efficient for the money spent upon it.

THE DIRECT PRODUCTION OF COPPER TUBES, SHEETS, AND WIRE.

By Mr. SHERARD O. COWPER-COLES, *Member*, of London.

Synopsis.

Introduction. Description of different methods of increasing the rate of deposit—Wilde's process; Elmore's process; Dumoulin's process; other processes; the Centrifugal process. Effect of centrifugal action. Method of making copper tubes and sheets. Mechanical tests. The formation of copper trees and nodules. Crystalline structure of electro-deposited copper. Method of forming weak line of cleavage so as to enable the deposit to be unwound from a cylindrical mandrel in the form of strip. Description of filter and atomiser. Conclusion. Appendix. Comparative costs. Analysis of copper produced. Rate at which copper can be deposited. General arrangement of a unit Centrifugal plant for producing copper sheets, tubes, and wire. Cost of plant. Cost of working Centrifugal process.

Introduction.—The numerous processes involved in the production of suitable copper and its subsequent conversion into copper sheets, tubes, and wire by a series of operations, such as rolling, drawing, and annealing, would occupy too much time to be referred to even briefly; therefore the author has limited the Paper to the direct production of copper tubes, sheets, and wire by electrolysis from impure copper.

The methods described are all based on the work of Davy and the law of electrolysis established by Faraday in 1833, namely, that when a current of electricity is passed through a solution containing metallic salts and two or more electrodes, one of which is soluble in the solution, a known quantity of metal is transferred from one electrode to the other for a given quantity of electric current; that is to say, if the soluble electrode (the anode) is connected to the positive pole, and assuming the metal and the electrolyte employed to be pure, a weight of metal will be deposited upon the cathode connected to the negative pole, corresponding to the amount of current employed. If the anode is of impure metal many difficulties are introduced, and if the current is increased to a sufficient density to enable the metal to be deposited at such a rate as will give commercial results, other serious difficulties arise. Electro-metallurgists have been working for thirty years or more devising methods to overcome the difficulties experienced in applying Faraday's law to the commercial production of copper tubes, sheet, and wire from comparatively impure copper having the physical properties of wrought copper, when deposited at a sufficiently rapid rate.

The refining of copper by electrolysis has now assumed vast proportions, and the annual output of electrolytic copper in the year 1907 has been estimated at 400,000 tons, equal to 56 per cent. of the world's production, and the capital sunk in the industry at about £15,000,000. The whole of the copper thus produced is in the form of rough slabs or cathode plates which have to be smelted and worked to the desired forms.

Electro-metallurgists have been striving for many years to devise a process which does away with the smelting of copper after it has been electrolytically refined, and to electro-deposit copper after the refining operation in such a form that it can be placed direct on the market as finished sheets, tubes, and wire.

Wilde's process.—It was observed shortly after Elkington practically applied Faraday's law to the refining of copper in the year 1865, that the electric current density, or the rate at which the copper is deposited, could be considerably increased by circulating the electrolyte or moving the electrodes. It was soon found that circulating the electrolyte alone was unsatisfactory, and that the best results could be obtained with a vertical mandrel revolved in the electrolyte. Wilde was one of the first to use a cylindrical cathode, his object being to deposit copper on iron rollers suitable for textile printing purposes, for which he took out a patent in the year 1875. The anodes consisted of copper cylindrical tubes, and the iron cylinder to be coated with copper (the cathode) was placed in the centre of the cylindrical vat and caused to rotate on its axis. Such an arrangement, in conjunction with a circulating propeller placed in the electrolyte, ensured an even distribution of copper over the whole of the surface uniformly along the length of the roller by means of the motion imparted to the solution, and the equal density thus maintained. The current density was low, considerably under 20 ampères per square foot.

Elmore's process.—The next development of importance was the Elmore process, which consists of using horizontal mandrels on which copper sheets or tubes are deposited, while agate burnishers travel continuously over the copper, so as to consolidate it, and at the same time prevent the growth of copper trees or nodules. Even with the use of a burnisher the current density could not be increased beyond 30 ampères per square foot, and the mechanical difficulties introduced by the burnisher are considerable. Large works were erected to operate this process near Leeds and on the Continent, and are principally engaged in the production of large tubes and cylinders for special purposes.

Dumoulin's process.—Dumoulin introduced, at a later date, a process for burnishing copper during deposition with sheep-skin as a substitute for agate, and claimed that the process had also the advantage of insulating any projections that might be formed on the deposited metal, the sheep-skin impregnator coating all projecting parts with a thin film of animal fat, thus preventing further deposition until the surrounding depressions are raised to the common level.

It was also claimed for this process that a current density of from 30 to 40 ampères per square foot of cathode surface could be employed at a voltage of about 1·6 per vat. This process was tried on a large scale in England, but was soon abandoned.

Other processes.—Attempts have been made at various times to increase further the rate of deposit by Swan, Elmore, Thofehrn, Graham, Poore and others, by impinging jets of the electrolyte against the cathode surface. The quality of the copper is liable to vary in density if impinging jets alone are employed; it is therefore necessary to move the cathode, otherwise the copper is deposited in the form of annular rings of varying density and smoothness as shown in Fig. 1, Plate 18, which is a photo-micrograph of a lead plate coated with copper by an impingement process at a current density of 160 ampères per square foot (9·29 dm^2), temperature 50° C.; the electrolyte being forced at a pressure of a few pounds through a lead box perforated with ⅛-inch (0·32 cm.) holes at a distance of 1 inch (2·5 cm.) apart from centre to centre.

Centrifugal process.—The author, when carrying out some experiments on the production of copper tubes and sheets by electro-deposition on rotating cathodes, observed that when the speed was greatly increased entirely new results were obtained, and that a current density of 200 ampères or more per square foot could be employed, the copper remaining smooth and having a tensile strength equal to the best rolled or drawn copper, and in some cases a tensile strength some 50 per cent. higher than that obtained by the ordinary process of casting and rolling, the tensile strength increasing with the rate of rotation of the mandrel. The result of revolving a mandrel at a comparatively high speed is that every molecule, as it is deposited, is burnished or rubbed down so as to produce a tough fibrous copper, the usual order of things being reversed, the present practice being to put the mechanical work into a mass of copper by rolling or drawing instead of treating each molecule separately.

This observation led to further experiments, which resulted in evolving the process now known as the centrifugal copper process for the manufacture of sheets, tubes, and wire, which will now be described in detail, together with the results obtained.

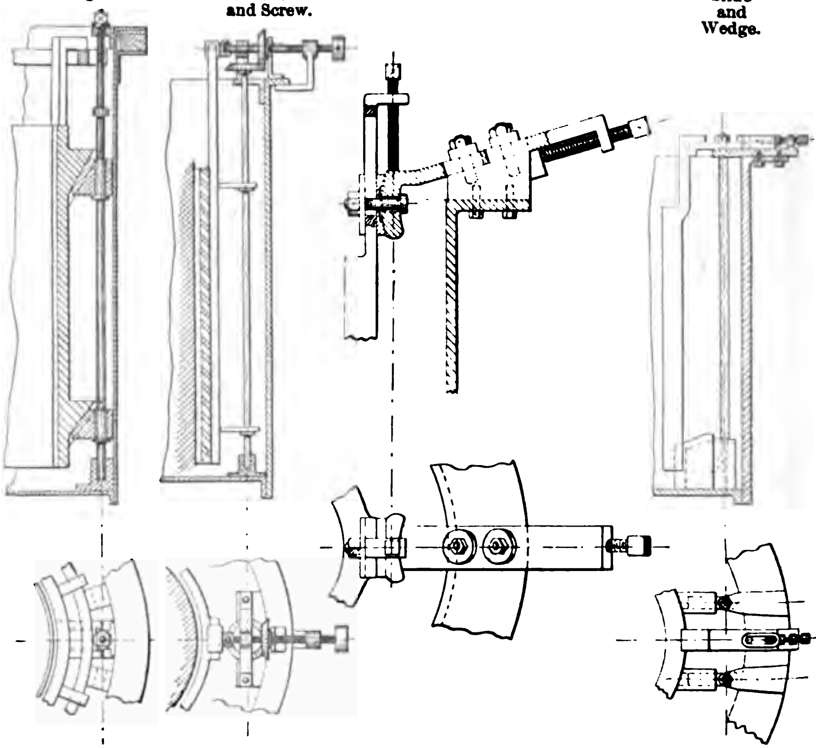
After a long series of experiments had been made to determine the best composition for the electrolyte and the most economical current density to employ, the critical speed was accurately determined by means of revolving cathodes in the form of cones, Fig. 2, Plate 18. By observing the point at which the copper remains smooth, and by measuring the circumference of the cone at that point and multiplying it by the number of rotations per minute, the critical speed is readily determined; 200 ampères per square foot is found to be the most economical current density, although a current density up to 500 ampères per square foot can be employed by increasing the rate of rotation, but the increased cost due to increased voltage renders such a current impracticable for ordinary commercial work.

One of the chief difficulties inherent in any electrolytic or wet process for the production of copper tubes and sheets is having any working parts, such as bearings, in an acid copper sulphate solution, and this was one of the first troubles encountered when working the centrifugal process on a commercial scale. This difficulty was eventually overcome by constructing vats in the form of an annular ring, as shown in Fig. 3, Plate 18. It will be observed by such an arrangement all working parts are outside the vat and do not come into contact with the electrolyte, so that the bearings can be lubricated in the ordinary way; only the actual face of the mandrel on which the copper is to be deposited is immersed in the electrolyte. The cathode consists of a steel or cast-iron cylinder closed at one end, to which is attached on the inside a steel rod projecting below the edge of the mandrel to guide it into position; the cylinder can be 5 or 6 feet in diameter or even larger so as to produce a copper sheet of say 20 feet long by 4 or 5 feet broad. Anodes composed of crude copper are placed around the mandrel with intervening spaces, and are fed forward by suitable mechanical means, Figs. 4 to 7 (page 630), as the copper dissolves away so as to keep the voltage constant.

One great advantage of the centrifugal process is that a very low voltage is required, even when employing a very high current density; for instance, only 0·8 of a volt is required at the terminals of the vat when working at a current density of 200 ampères per square foot of cathode surface. The effect of revolving the cathode is five-fold: firstly, it keeps the electrolyte agitated, so that there is always a fresh supply of copper ions in proximity to the cathode;

Anode Adjustments.

FIG. 4. Wedge. FIG. 5. Eccentric and Screw. FIG. 6. Universal. FIG. 7. Slide and Wedge.



secondly, each molecule of copper as it is deposited on the cathode is burnished or rubbed down by means of the skin friction between the revolving cathode and the electrolyte; thirdly, the rotation prevents any foreign matter that may be in suspension in the electrolyte settling on the cathode and becoming entangled by further copper being deposited around or over it; fourthly, it brushes away any air-bubbles on the cathode, which are the cause of nodules forming; and fifthly, the rotation of the cathode ensures the thickness of copper being uniform, even when a mandrel of say 8 feet in length is employed.

The method of making tubes by the centrifugal process is as follows:—A mandrel somewhat smaller than the finished internal diameter of the tube is prepared by coating it with an adhesive coating of copper, by first depositing copper upon the surface from an alkaline solution and then thickening it up in an acid solution, the surface being highly burnished and treated chemically to ensure the easy removal of the deposited tube. The mandrel thus prepared is then placed in a vat as shown in Fig. 3 or Fig. 8, Plate 18, according to the diameter of the tube and its length. When the desired thickness has been obtained the mandrel is removed and placed in a horizontal or vertical lathe, and a round-faced roller run over the surface so as slightly to expand the deposited copper, which can then be readily drawn off.

Copper sheets are prepared in a similar manner, the only difference being that the mandrels are of much larger diameter, and a narrow insulating strip is fitted down one side so that the sheet can be easily removed by inserting a tool under one of the edges of the deposited copper. It is no more costly by the centrifugal process to make thin sheets than thick ones; copper foil can be made in five minutes direct from crude copper. A modification of the process has been successfully applied to the recovery of the copper from scrap brass in the form of finished copper and zinc sheets.

Copper tubes produced by this process without any drawing have given a maximum stress of 17 tons, and tubes after drawing have withstood a pressure of 3,000 lbs. per square inch without showing any signs of distress, as shown by the following test made by Mr. W. G. Kirkaldy:—

Diameter outside.	Thickness of Metal (mean).	Length.	Weight per Foot.	Subjected to a Pressure.
Inches.	Inch.	Inches.	Lb.	Lbs. per sq. in.
1·123	0·063	4·94	0·814	3,000

Sheets made without any rolling have given a maximum stress of 28 to 30 tons and more per square inch according to the peripheral speed at which the mandrels were revolved. The following are some tests made by Mr. W. Harry Stanger :—

TABLE 1.

Dimensions.	Area.	Reduction of Area at Fracture.	Extension on 8 ins.	Elastic Limit. (Yield Point.) On Original Area.	Maximum Stress. On Original Area.	Remarks.
Inches.	Sq. in.	Per cent.	Per cent.	Tons* per sq. in.	Tons* per sq. in.	
1·109 × 0·006	0·0066	31·8	21·1	20·4	25·5	Fair break in centre.
1·135 × 0·007	0·0079	17·7	20·4	28·4	28·4	Fair break in centre.
1·114 × 0·005	0·0055	—	6·3	22·4	34·6	Specimen broke outside datum points on slightly larger area.
1·124 × 0·008	0·0089	—	14·4	22·6	27·7	Specimen broke outside datum points on slightly larger area.
1·114 × 0·01	0·0111	18·9	12·0	—	27·3	Fair break.
1·121 × 0·011	0·0123	24·4	20·0	18·2	27·3	Do. Do.

Bending test. Strip bent three times upon itself. No cracks.

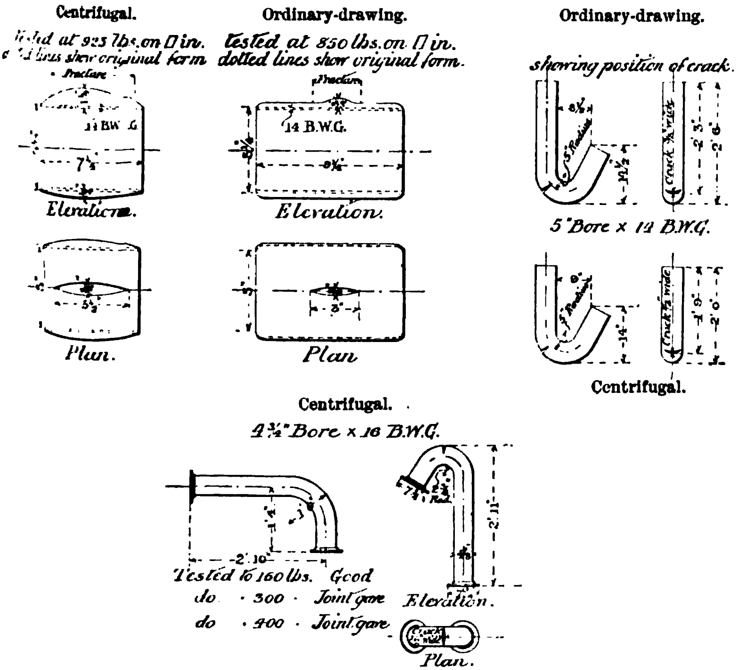
Fig. 9 shows the result of some comparative mechanical tests on copper pipes made by the centrifugal process and subjected to hydraulic pressure, giving results far above those required by the Board of Trade.

The formation of copper trees and nodules was another difficulty that had to be overcome, but which has been reduced to a minimum in the centrifugal process, for the reason that impurities held in suspension in the electrolyte have no opportunity of settling on the cathode, and all gas bubbles are swept from the surface on which the copper is being deposited.

* Tons of 2,000 lbs.

Fig. 10, Plate 19, is a section of two nodules which illustrate the way in which they crystallize radially from a microscopic nucleus, differing in their structure from the copper sheet which crystallizes at right angles to the surface of the cathode, as is clearly shown in Figs. 10 and 11, thus forming a weak line of cleavage enabling the nodules to be easily separated from the copper sheet;

FIG. 9.—*Mechanical Tests on Copper Pipes made by the Centrifugal and Ordinary-Drawing Processes.*



for which reason it is impossible to produce a good sheet by any after-process of rolling. The form of the nodules or trees is largely dependent on the amount of free acid in the electrolyte; if the percentage is high, the form is rounded; if the percentage is low, then the growth is more fern- or tree-like, Fig. 12. The percentage of free acid employed in the centrifugal process is high, amounting to 12 or 13 per cent. The electrolyte, the usual composition of which is 12·5 per cent. of copper-sulphate and

2 Y 2

13 per cent. of sulphuric acid at a temperature of 40° C. (104° F.), is kept in the cupric state, and the impurities in suspension are separated by means of a centrifugal filter provided with arc lights and an atomizer for breaking the solution up into a fine spray, as shown in Figs. 13 and 14, Plate 20. It has been found that subjecting the solution to a strong light the impurities are more easily precipitated, and the solution is kept in the cupric state.

The production of copper wire by electrolytic means is a more difficult problem than the production of copper tubes and sheets. Various processes have been suggested and tried from time to time, such as the electro-deposition of copper on thin wire, until it has obtained a considerable thickness, and then drawing the thickened wire down to a comparatively fine wire. Swan and Sanders have both experimented with such processes, but so far they have not been worked commercially.

Elmore's process consists of producing copper tubes by his burnishing process, cutting them into long spirals and then drawing them into wire.

Other experimenters have tried placing an insulated spiral strip on a cylindrical mandrel so as to produce long copper spirals, but such an arrangement only allows of a very low current density being employed, on account of the nodules which form on the edges of the strip, even at very low current densities, rendering the strip unsuitable for drawing down into wire.

Copper wire is made by the centrifugal process in the following manner :—A mandrel similar to that used for making copper sheets is employed, around which a spiral scratch is made, the pitch being determined by the size of wire required.

The effect of the spiral scratch (which need only be very light but must be angular), is to cause the crystalline structure of the copper to form a cleavage plane, as shown in Fig. 15 (page 635). It will be observed that the copper divides exactly at the apex of the scratch, that is, the copper deposited in the scratch is equally divided and forms a small V-shaped fin on two sides of the copper strip, Fig. 20, Plate 20. If the scratch is not angular, but rounded at the base, the copper will not divide, as the crystals are radial, as shown in Fig. 16. After the desired thickness has been obtained, approximating the pitch of the spiral scratch, the mandrel is removed from the depositing cell and placed in a vertical position on a lathe, Fig. 18, Plate 20, and the copper strip is unwound at an angle of about 45 degrees to the face of the mandrel, Fig. 19. During the process of unwinding, the small fin or burr is removed by passing the wire through a suitable die and then through a wire-drawing machine provided with three or more draw-plates to reduce the strip to the desired diameter. By employing a mandrel of 6 or 7 feet in diameter, lengths of wire 4 or 5 miles can be made in one operation. Very fine wires are produced by making a fine scratch on a hard wax disc or cylinder.

FIG. 15.—*Diagram showing method of forming weak line of cleavage due to crystalline structure.*

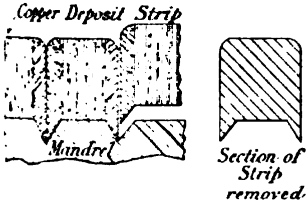
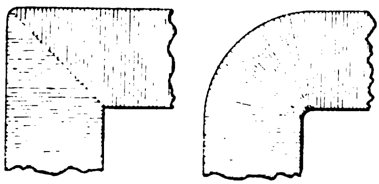


FIG. 16.—*Diagram showing the effect of sharp and rounded corners on the crystalline structure of metal castings.*



Conclusion.—The advantages of an electrolytic process as compared with a smelting process are many, and the day is not far distant when copper will no doubt be leached direct from the ore and electrolyzed with insoluble anodes, to produce finished copper sheets and tubes in one operation direct from the ore without the intermediate process of smelting and refining.

The centrifugal process is a step in this direction, as it is capable of depositing copper from its solutions by using insoluble anodes in the form of finished tubes or sheets in one operation. The centrifugal process is at least ten times faster than any existing electrolytic process, and a high current density can be employed without deteriorating the quality of the copper. There is no risk of lamination, as no burnishers are employed. The plant is simple and free from mechanical complications, and the amount of copper locked up for a given output is small compared with other processes. The process is of interest to mechanical engineers, as it conclusively proves that to obtain a high tensile strength in metals combined with ductility, it is not essential to put a large amount of work into the metals as hitherto has been considered necessary, by the processes of swaging, rolling or drawing, but that a very small amount of energy will suffice when applied in the manner described in the Paper. The centrifugal process ensures the copper being deposited in a close coherent form with a crystalline structure like wrought-copper.

In conclusion, the author hopes the special apparatus designed to overcome the mechanical difficulties that were encountered may prove of interest to the members of the Institution.

The Paper is illustrated by Plates 18 to 20 and 7 Figs. in the letterpress, and is accompanied by an Appendix with 2 Figs.

APPENDIX.

Fig. 21 gives the comparative cost of producing copper sheets by the process of smelting, refining, casting, and rolling, as compared with the centrifugal process.

Comparative Cost of producing Copper by the present method and the Centrifugal Process. (Exclusive of trade allowances.)

FIG. 21.

SHEETS.

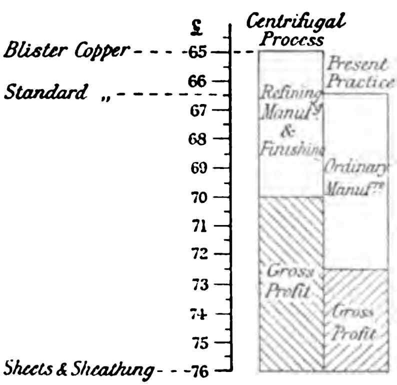
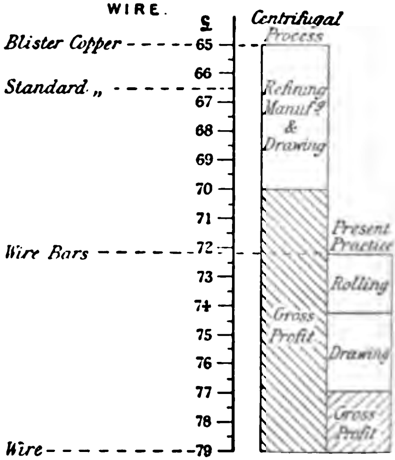


FIG. 22.

WIRE.



NOTE.—The cost of power in the above comparison was taken at a higher rate than that of the estimate in Table 3 (page 639). On the basis of that Table the dividing line between "Refining, &c.," and "Gross Profit" in Figs. 21 and 22 should be raised as far as the figures £67¾.

Fig. 22 gives the comparative cost of producing wire by the ordinary process of smelting, refining, rolling, and drawing, and the centrifugal process.

The following is a typical analysis of the copper produced by the centrifugal process:—

Iron	0·0189
Arsenic	0·0015
Lead	0·0013
Antimony	0·0010
Bismuth	0·0008
Silver	absent.
Nickel	absent.
Sulphur	absent.
Copper (by difference)	99·9765
	100·000

Under favourable conditions almost the theoretical weight of copper is obtained, and Table 2 (page 638) gives the weights and thicknesses of copper deposited in an hour at the current densities usually employed.

The capital expenditure of a plant, Fig. 17, Plate 20, for the centrifugal process both for the manufacture of sheets, tubes, and wire, compares very favourably with an up-to-date rolling mill and wire-drawing plant. The cost of such a plant, with buildings, is about £80,000 for an output of 100 tons per week or 5,000 tons per year. The following is an estimate of the cost of a plant for the centrifugal process capable of dealing with 10,000 tons of tubes, sheets, and wire per annum:—

Estimated Cost of Plant for producing 10,000 tons of Tubes, Sheets, and Wire per annum by the Centrifugal Process.

	£
Cost of 95 vats and accessories	64,000
Machinery for finishing tubes, sheets and wire	5,000
Cranes and lifting gear	1,500
Building	15,000
Plant for mandrel-making	2,000
Machinery for fitting shop	1,500
Pumps, atomizers, filter tanks	5,000
Driving machinery for vats	5,000
Conductors and electrolyte	5,000
	104,000
Floating capital for copper	30,000
	134,000

TABLE 2.

Table giving the Weight and Thickness of Copper deposited per hour at various Densities, with metrical equivalents.

Current density in ampères per square foot.	Current density in ampères per dm².	Weight of Copper deposited per hour per square foot.	Weight of Copper deposited per hour per square foot.	Weight of Copper deposited per hour per dm².	Weight of Copper deposited per hour per dm².	Thickness of Copper per hour.	Thickness of Copper per hour.
		Lb.	Grammes.	Lb.	Grammes.	Inch.	Mm.
150	16·140	0·3893	176·55	0·0419	19·0036	0·00872	0·22155
160	17·216	0·4153	188·32	0·0448	20·2704	0·00930	0·23632
170	18·292	0·4413	200·09	0·0475	21·5373	0·00988	0·25109
180	19·368	0·4672	211·76	0·0501	22·8042	0·01046	0·26586
190	20·444	0·4932	223·63	0·0530	24·0711	0·01105	0·28063
200	21·520	0·5191	235·40	0·0558	25·3381	0·01163	0·29540
210	22·596	0·5451	247·17	0·0586	26·6149	0·01221	0·31017
220	23·672	0·5710	258·94	0·0614	27·8718	0·01279	0·32494
230	24·748	0·5970	270·71	0·0642	29·1387	0·01337	0·33971
210	25·824	0·6230	282·48	0·0670	30·4156	0·01395	0·35448
250	26·900	0·6489	294·25	0·0698	31·6725	0·01453	0·36925

TABLE 3.

Estimate of Cost per ton of Producing Copper Tubes, Sheets, and Wire by the Centrifugal Process direct from Crude Copper.

	£	s.	d.
Power per ton (2,240 lbs.) 1,015 kw.-hours at 0·275*d.* per kw. . .	1	2	2
Wages at 8*d.* per hour, 18½ hours		12	4
Management		5	0
Interest on copper lock-up		1	0
Depreciation on plant and building		10	0
Heating electrolyte		1	0
Finishing and gauging		5	0
Cost per ton . .	2	16	6

These figures represent the actual working cost on which there would be a further reduction of the precious metals recovered, and if £1 10*s.* be deducted from the above cost, which may be taken as an average difference between Chile-bar and electrolytic copper, the cost per ton is reduced to £1 6*s.* 6*d.*

Discussion.

On the motion of the PRESIDENT, a cordial vote of thanks was passed to the author for his interesting Paper.

MR. F. G. WRIGHT, in opening the discussion, said that it appeared to him that the subject appealed more to manufacturers of copper tubes and wire than to engineers who used them. There could be no doubt, however, that it was a very valuable Paper on the subject, and he would much prefer to hear the opinions of those gentlemen who had to do with the manufacture of copper than of those who used it.

MR. EDWARD P. MARTIN, Past-President, said he had had the opportunity of seeing the experiments, which had been referred to in the Paper, carried out, and he had been struck with the fact that the

(Mr. Edward P. Martin.)
production of the thinnest sheets, which usually was far more expensive to make than thick sheets, was cheaper than the production of the thick sheets. By this process complicated tubes and other finished articles seemed to be produced easily and cheaply. The process, he thought, might considerably affect the cost of manufacture of iron, steel, and copper into thin tubes and sheets.

Mr. H. H. Cox hoped manufacturers would not be carried away by the idea that the new process the author had described would be everything that was perfect. Before putting it into commercial use he trusted they would give it practical trials, not only in the way of tensile tests but also tests of durability on actual work, especially in connection with copper tubes. Manufacturers knew the disastrous results of some of the work done by another process, which had been tried for marine work and steam-piping, and unless the latter was of dependable material and was well made there was a great risk to life and limb.

Mr. G. T. Child said that a good deal of trouble was sometimes experienced by the deposited copper sticking to the mandrel, and he would therefore like to know whether any insulating material was used on the mandrel before the copper was deposited on it.

Mr. William Langdon said that the author had given the typical analysis of the copper produced, but he would like to ask him what analysis he had obtained by his process, from the slimes, compared with other electrolytic processes, because gold and silver were often precipitated to a certain extent from the copper anodes. He had had something to do with the Dumoulin process at Widnes some years ago, and although it was not quite a success, they managed to obtain some precious metal out of these slimes, which was about the only profit they did get. [*See* page 643.]

Mr. W. H. Dugard thought the process was a considerable improvement on the usual one. According to the Tables it appeared as though it would be considerably cheaper, but he thought there was not sufficient evidence yet of its thorough reliability as to homogeneity and tensile strength. If more evidence of that nature from actual use under ordinary working conditions was forthcoming it would be useful, and would be more likely to lead to its adoption.

With regard to the production of wire, it appeared to him that unless the small ridge or fin was properly removed, it would be liable to produce two laminated spills in drawing down the wire. He noticed that some of the sheets were very thin, and therefore would like to know whether they had been rolled at all since the deposition, or polished in any way. They appeared to him to be of very uniform thickness, and he would like to know whether a uniform thickness over a large surface for large sheets could be relied upon in the process of deposition.

Mr. EDWARD B. ELLINGTON, Vice-President, asked the author to inform the members what practical use had been made of the sheets and pipes described, or whether the process was at present in a purely experimental stage.

Dr. W. CAWTHORNE UNWIN thought that a remarkably high yield-point was given in Table 1 (page 632). A yield-point up to 28 tons per square inch was very remarkable indeed for copper. Engineers understood very well what the yield-point meant when they were talking of mild steel, but he was not quite sure they understood so well what it meant when referring to copper. He therefore thought it would add very much to the value of the Paper if the author would give an autograph diagram of one of the tensile tests showing exactly where he placed the yield-point.

Mr. LOUGHNAN PENDRED asked whether in all cases cylinders had to be deposited in the way described, or whether it was possible to make bends and various shapes without working the tube up afterwards.

Mr. DANIEL ADAMSON suggested that the author's estimate for power of 0·275*d*. per kw. given in Table 3 (page 639) was very low. In his opinion three times that amount would be more nearly correct.

(Mr. Daniel Adamson.)
He asked the author in his reply to state on what assumption that figure was based.

Mr. W. C. GOODCHILD enquired whether wire made by the author's process would withstand the ordinary torsion and bending tests such as were required by the Post Office, because he noticed the only tests mentioned in the Paper were what might be called "static" tests, that is, hydraulic and ordinary extension tests.

Mr. COWPER-COLES, in reply to Mr. Martin's remarks, said the process showed a greater saving for thin sheets than for thick, as the electrolytic process was a building-up and not a breaking-down process. The centrifugal process as described in the Paper was limited to the production of copper in the form of sheets, tube, wire, and cylindrical vessels. Mr. Cox had referred to the production of tubes for steam-engine purposes, and had mentioned the burnishing process. The great difference between the process he (the author) had described, and other electrolytic processes was that there was no mechanical burnishing during the process of deposition, a feature which had always led to failure in the past. Wherever the burnisher passed over the metal, after a time it was found to laminate. In the process described in the Paper the copper was not treated mechanically, so that there was no fear of lamination.

Mr. Child had asked whether any insulating compound was put on the mandrel to enable the copper to be readily stripped. The mandrels were treated chemically, so as to produce a film of copper-sulphide on the surface, which enabled the copper to be readily stripped off. In reply to Mr. Langdon's enquiry, the slimes obtained by the process were the same as those obtained from any other electrolytic process, with the exception that the percentage of copper was less; all the gold and silver were recovered from the anode copper.

In answer to Mr. Dugard's enquiry, samples of sheets exhibited had not been rolled or treated in any way; they were just as they were removed from the mandrel. In some cases, when produced in the form of cylinders and then cut down the side after removal, a roller was passed over to loosen the cylinder on the mandrel to enable the cylinder to be drawn off, but usually an insulating strip was put down one side of the mandrel, to enable the sheet to be taken off without any rolling. With regard to the production of wire, the small fins shown had to be removed to produce a good wire, and this was done in the first drawing operation. The first die was constructed in such a way that it drew off the fins; if they were not drawn off, a skin was formed on the wire which was objectionable for electrical purposes.

In regard to Mr. Ellington's question as to whether the process had been applied commercially, for over four years large cylinders had been made for the textile industry, which were put to very severe tests under actual working conditions. The cylinders used for stencilling work were put under a heavy tensile strain as a continuous copper band, the inking rollers being inside. A number of tubes and wires had also been put to the usual tests, which they had withstood as well and in many cases better than similar cast and drawn copper specimens.

The power figures to which Mr. Adamson referred were taken from actual contracts which had been offered by power stations, provided the plant was put down close to the generating station. The load was reduced at certain periods; power could be obtained under such conditions at the present time in several districts at the price mentioned. In answer to Mr. Goodchild's enquiry, wire produced by the electrolytic process would stand the ordinary Post Office torsional tests, and was equal in every respect to drawn wire.

In reply to Mr. Pendred's question, as to whether it was not possible to make bends by the process, straight cylinders had to be made and bent afterwards, although flanges could be made direct on pipes by the centrifugal process.

Communications.

Mr. WILLIAM LANGDON wrote, in continuation of his remarks at the Meeting, that he would like to ask the author whether any trouble or difficulty arose with his mechanical feeding arrangement, Figs. 4 to 7 (page 630), by dissolving away, with the anodes themselves, as the whole seemed somewhat complicated for an immersion in the electrolyte. Seeing that the anodes were thinned away, often very

(Mr. William Langdon.)
irregularly during the process, the wedges might therefore be liable to work loose or unevenly and alter the vertical alignment, and also voltage. If the feeding apparatus were insulated and protected, possibly this difficulty might not be great.

The vertical cathode with all working parts outside the vat was a great advance over the horizontal position, and overcame one of the chief difficulties encountered hitherto in the electrolytic process, but it would be of interest to know, whether large perfectly smooth sheets, say up to 1 inch in thickness, by 12 feet by 4 feet, such as were produced at Widnes by the Dumoulin process, could be made, and which after annealing required no finishing in the rolling mill to bring them to a uniform thickness and smooth surface. In the thick sheets or plates referred to, laminations were very seldom met with, and the surface by the continual passage of the chemically prepared skin lightly touching it (no burnishing as with agates) produced a very smooth face; a great advance however has been attained if this operation could be suppressed altogether.

There was a considerable difference in the composition, treatment, and temperature of the electrolyte described in the Paper from that used at Widnes; this was certainly an important factor, together with the enormous increase in the current density to 200 ampères per square foot of cathode area.

The author was to be congratulated on having overcome great difficulties met with in successfully producing copper strips (pages 634 and 635) suitable for wire-making, the writer being one of the first to experiment with the spiral scratch on the mandrel as described in Fig. 15; but owing to the brittle nature of the metal produced and other difficulties, was not successful. Therefore Figs. 18, 19 and 20, Plate 20, were of unusual interest.

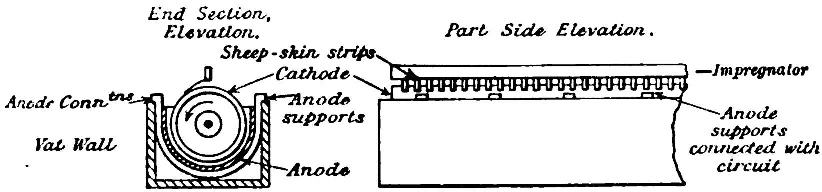
In considering the progress and improvements introduced by the author over other centrifugal processes for the production of copper sheets, tubes, and wire by electrolysis, the writer, who was for nearly two years manager of the works in Widnes operating Dumoulin's process, had therefore experienced most of the difficulties described in the Paper (page 629). He regretted the author did not state what the annual output of the works was, and where his plant was working.

The following is a short description of the "Dumoulin" process:—

Plant.—The dynamos are direct current machines, yielding 1,300 ampères at 75 volts, equal to 97·5 kw. There are thirty vats for depositing sheets, each being a shallow wooden trough, lined with lead provided with supply and exit pipes, for the circulation of the electrolyte. This contains about 7 per cent. of sulphuric acid, 40 per cent. of cupric sulphate, density 22–23 Beaumé, temperature 24° C.

Cathodes or Mandrels are hollow cylinders of copper, 12 feet long by 16 inches in diameter, capped at each end and mounted on insulated bearings, and they are immersed horizontally. The electrolyte covers about two-thirds of their surface, and is kept in constant

FIG. 23.—*Depositing Vat* (Dumoulin), *Centrifugal Process.*



agitation during the passage of the electric current by the centrifugal movement of the cathode; the sheep-skin impregnators (from which all the fat has been extracted by chemical treatment), which give coherence and density to the deposit, are fixed in a light metal frame, extending from end to end above the cathode, and are kept in motion sliding to and fro, the travel being varied by an eccentric operating a pall and rack so as to alter the position of contact with the cathode. The lateral speed or travel of the impregnator for a 16-inch diameter cathode making 45 revolutions per minute was found to give best results when making about 60 strokes. The surface of the cathode is covered with a thin film of tallow or plumbago, to prevent the deposit adhering, and to facilitate the removal of the sheets, at the end of the operation.

(Mr. William Langdon.)

Anodes.—These are cast in halves in a semi-circular form, 2 inches thick, 4 feet long, with oval holes to aid circulation of the electrolyte; they rest on eight copper supports, provided with flanges resting on the tops of the vats. Fig. 23 (page 645) shows the Dumoulin arrangement of anodes and cathodes. Aluminum supports were first tried, but without success.

After the deposit has "struck" all over the surface of the mandrel, the bar holding the strips of sheep-skin is brought into the vertical position, and the deposition of copper proceeds without further attention. The mandrel is revolved at a high speed, and the electrolyte is kept in rapid circulation during the whole period of deposition.

Under normal working conditions it requires about 10 hours to deposit 44 lbs. copper in one vat, and the tube thus obtained is about 25 gauge in thickness and weighs about 14 ounces to the square foot. The current density used is between 35 and 40 ampères per square foot of cathode area, whereas 20 ampères is the maximum now attained in electrolytic refineries with stationary cathodes; and formerly the current density used in these rarely exceeded 4 ampères. The gain in the time to deposit large amounts of copper at the cathode is very marked, and the output of a plant could therefore be greatly increased by use of rotating cathodes. The voltage required is about 1·6 per vat, but this rises as the anodes are eaten away. When the deposit has attained the desired thickness, the mandrel, with its casing of pure copper, is bodily removed from the vat by a travelling electric crane, and is carried to a specially designed lathe, where a longitudinal cut is made from one end of the cylinder to the other, and the resulting sheet of electrolytic copper stripped off with ease. The whole operation does not occupy more than five minutes, and after applying a special composition to the surface of the mandrel, it is again ready for immersion in the electrolyte. The sheets of copper formed in this manner weigh about 44 lbs., and have a superficial area of 48 square feet. In the case of boiler-tubes, the removal of the mandrel from the interior of the deposited copper tube is effected by means of a hydraulic press. The depositing building at Widnes contains 30 vats similar to the above, and therefore, when worked to its full capacity, can produce 60 sheets per working day. The sheets of copper are carried from the depositing house to an adjoining building where they are annealed in a muffle furnace at a dull red heat, and then pickled in dilute sulphuric acid to remove the scale of oxide formed during the annealing process. Opening out of the depositing house is a large building in which the electrolyte of copper sulphate is filtered, cooled, and pumped to the storage tanks, from which it flows by gravity through the depositing vats back to the well in the same building. The filtration and cooling of the electrolyte after each passage through the depositing vats is found to be essential to the successful conduct of this process.

A large machine shop, a laboratory, and a store house for the finished copper complete the works. Tests of the sheet copper produced by this process have shown a tensile strength of 18½ to 24 tons and an elongation of 28 to 30 per cent.

Mr. R. D. SANDERS wrote that the author, in alluding to what had been done in this direction by Mr. Swan and the writer, said that the process of depositing upon a thin wire had "not been worked commercially" (page 634). That was a statement which required correction. As a matter of fact very many tons had been deposited upon a thin wire by the writer's process, and used in nearly all foreign countries and by principal users in this country. Orders and repeat orders had been received far in excess of what their works were able to produce, and they were only waiting for the erection of larger works to take in hand the very extensive contracts which had been offered.

It would seem that the author's experiments led to the conclusion that a very rapid revolution of the cathode was necessary to produce a smooth homogeneous deposit, and that high current densities were only applicable with such high speeds. The writer's experience during the manufacture of over 100 tons of wire rather pointed in the opposite direction, and his opinion was that the best deposit was obtained when the natural formation of the crystals at the cathode was not interfered with. With this communication he sent a piece

(Mr. R. D. Sanders).
of deposited wire cut from one of his 100 yard coils, just as it came from the vat. This was deposited in practically *a still electrolyte.* Its conductivity was 102 per cent. of Matthiessen's standard, thus proving it to be pure copper. Its surface and density showed that rapid rotation was not essential to a good deposit, and power so employed was so much waste energy and expense.

The author seemed to insist upon the rapid rotation of the cathode being essential to the employment of high currents and rapid deposition. The writer had deposited good copper with a current density of over 250 ampères per square foot, and he was informed that Mr. Swan had succeeded with a current density of 1,000 ampères per square foot. He did not mean to say that rotation of the cathode was unnecessary for the employment of high current densities, but his practical experience from a commercial point of view had convinced him that excess in either brought about many difficulties and waste of energy. This had been proved in the daily working of 84 vats capable of turning out about 10 tons of $\frac{3}{8}$ inch copper-wire rods per week. After working six months with a moderate rotative speed of the cathodes, he reduced the speed one half with very beneficial results, both in the quality of the deposit and rate of production.

He agreed with the author's remarks as to the difficulties inherent in an electrolytic process for the production of copper tubes, etc., by which he meant the destruction of the working parts in an acid copper-sulphate solution. Many years ago he manufactured wire on metal cylinders grooved in a similar way to the author's, but owing to their rapid destruction they were abandoned in favour of porcelain, which in like manner had to be discarded.

It would be useful if the author would explain of what metal or substance his vats were constructed, and how he prevented destruction of the stuffing-boxes, glands, and the internal supports exposed to the action of the liquid. The cost of working so far as the power was concerned was easily ascertained, because it was well known what weight of copper a given current would deposit, but the cost and upkeep of an electrolytic plant was a matter of great moment affecting the cost of production. Unless the author had found perfectly indestructible material for the whole of his apparatus, the cost of maintenance and renewal would be very heavy indeed.

A most important matter, which the author had not touched upon, was the circulation of the electrolyte. Perhaps he would explain how he kept the electrolyte of uniform composition in a series of vats, without which the deposit would not be uniform.

Mr. Cowper-Coles wrote in reply to Mr. William Langdon that, so far, no difficulties have been experienced with the special anode adjustments; the wedges were at the back of the anodes and insulated so that little or no corrosion took place. It would be interesting to have further particulars of the experiments made by Mr. Langdon with spiral scratches on the cathode; the chief cause of the failure of his experiments was probably due to the scratches being rounded instead of V-shaped, which was essential to success. There was no difficulty in making thick sheets, of even larger dimensions than those given by Mr. Langdon, by the centrifugal process without rolling. Mr. Langdon wrongly described other processes as centrifugal; they were not dependent on centrifugal action, but relied on some mechanical rubbing process.

As regards Mr. Sanders' remarks, he had no intention of doing him an injustice by saying that his wire process had not been worked commercially. Those who had studied the question of the rapid electro-deposition of copper were aware that rapid circulation or rapid rotation of the cathode were essential conditions to obtain a smooth coppor of high tensile strength which did not require smelting. Mr. Sanders omitted to state that the deposits obtained under the conditions he mentioned were rough and covered with nodules, and therefore useless for commercial purposes.

Mr. Sanders' statements with reference to the manufacture of wire on metal cylinders grooved in a similar manner to that employed for the scratch method were liable to mislead those who had not made a special study of the subject. His methods consisted of depositing in grooves with an insulating strip between, so as to produce a triangular or flat-shaped strip which afterwards had to be drawn down. Such a process was impracticable for reasons mentioned

(Mr. Cowper-Coles.)
in the Paper. Mr. Sanders would no doubt observe, on reading the Paper, that there were no stuffing-boxes, glands or internal supports exposed to the action of the liquid; the difficulty had been overcome by using an annular vat as described and as shown in Fig. 3, Plate 18, and Fig. 17, Plate 20. He would also have observed that the solution was circulated by allowing it to enter at the bottom of the vat and flow out near the top, and in addition to this the solution was circulated in series from vat to vat as shown in Figs. 3 and 17, thus ensuring the perfect mixture of the electrolyte.

As regards Mr. Sanders' method of making wire by depositing it on a fine wire matrix, it would have been interesting if he had stated how he had overcome the following difficulties which were inherent in any such process:—(1) The high voltage required; (2) the low current density which must be employed to obtain a coherent deposit; (3) the large amount of plant required for a small output; (4) the rough surface of the wire-rod produced which created flaws in the wire, and (5) the difficulty due to lamination between the internal wire core and the deposited copper.

THE EVOLUTION AND METHODS OF MANUFACTURE OF SPUR-GEARING.

By Mr. THOMAS HUMPAGE, *Member*, of Bristol.

Origin of Spur-Gearing.

The best authorities on the subject are unable to say when spur-gearing was first introduced, but it has certainly been used for an exceedingly long period. The following is a suggestion put forward by the author as to its origin. Fig. 1, Plate 21, shows two trunks of trees lying on the ground at right angles to each other, the stumps of the branches of one being interlocked with those of the other. When the branch is pressed down it causes the trunk to roll slightly on the ground, and the interlocked branches transmit the motion to the other trunk. Fig. 2 is a sketch which suggests the first piece of work made in the evolution of spur-gearing.

The first practical applications of spur-gearing to machinery were undoubtedly in connection with wind-mills and water-wheels for moving stones to grind corn. Fig. 3 is taken from an ancient drawing of a wind-mill in which the wheels and axles were made entirely of hard wood. The arms were fixed, high above the ground, to a horizontal shaft which transmits the motion through a pair of wheels to a vertical shaft. This vertical shaft drives the upper stone, and the weight of the stone combined with the circular motion crushes and grinds the corn.

From the earliest times waterfalls must have impressed the mind of man with the idea of utilising their force, and the outcome of this was the water-wheel. Fig. 4, Plate 21, is from an old drawing of a water-wheel. Spur-wheels were the only means of conveying the motion to the stones, belts and chains being unknown at that period.

For a great number of years all gearing of this kind was made of wood. Fig. 5 is taken from an old built-up wheel entirely made of hard wood. It is about 44 inches in diameter, having 55 teeth of 2½ inches pitch. The spurs are fitted into square holes in its periphery and pegged, the projecting parts being square.

The pinion is made up of two discs of oak. Through each disc nine holes were bored at equal distances round the correct pitch circle for nine teeth. Nine wooden bars of round section were fixed in the holes, and kept the two discs apart. These bars acted as teeth and geared with the large wheel. Similar pinions were very common in the old mills, and as they suggested the shape of a lantern, they were called "lantern" pinions.

In the old days nearly all millers built their own mills and kept them in repair. Later on some of these men found it to their advantage to give up milling and to devote their whole time to putting up mills and doing the necessary repairs, and these specialists were called millwrights.

The wooden spurs from continual use wore very badly and the millwright put in spurs with larger wearing faces, which gradually shaped each other, becoming hollow in the flank and rounded towards the points. When broken spurs were replaced, the curved shape was given to them so that they would work smoothly with the others, and when new wheels were put in they were fitted throughout with shaped spurs. This was the origin of the epicycloidal form of tooth. An old cider-mill in Herefordshire, which must be considerably more than a century old, has wheels of oak in which the spurs have been roughly shaped to an involute form. Iron spurs were once tried in place of the wooden spurs, but after a little work they became loose. The noise that they made was very objectionable, and eventually a return was made to wooden spurs.

For heavy work the millwright introduced an iron wheel with spurs on the rim, cast in one piece. A wooden pattern of the whole wheel was made with the teeth shaped and spaced round the circumference as accurately as possible. Then, after the casting was made, the millwright had to pitch and trim every tooth with hammer and chisel, finishing them with a file or piece of grinding-stone. To work with this wheel the millwright devised an iron wheel which, instead of having teeth cast on its periphery, had holes or mortices cored in the rim at equal distances apart. Into these mortices hard wooden teeth or cogs were fixed and the projecting parts were divided and shaped to gear smoothly with the cast-iron teeth. Many of these mortice wheels are working at the present day and are considered most suitable for their purpose. As time went on the wooden cogs gave trouble, for owing to shrinkage and the great pressures they became loose. Eventually another iron wheel with cast teeth took the place of the mortice wheel.

It was the common practice to have what was known as a hunting tooth in the large wheel, that is one tooth more or less than an exact ratio between the wheel and pinion. The object was to obtain a complete interchange of all the teeth so that they wore evenly and smoothly.

Clocks.—In the early part of the 13th century a machine had been invented which the maker called a "time machine." It was a mass of spur-wheels, pinions and spindles, and was to supersede the sand-glass, water-clock, and sun-dial. This, which at first appeared to be an unimportant mechanical device, now beats time for the whole of the civilised world. In a book * called "Former Clock and Watch Makers," by F. G. Britten, we read of a clock which is said to have been made about the year 1335 by Peter Lightfoot, an ingenious monk of Glastonbury Abbey, for and at the expense of his superior, Adam-de-Sodbury, who was promoted to the Abbacy of Glastonbury in 1332. The old interior works of this clock were of iron, not differing materially in principle from the mechanism of much later date clocks, except that the appliances for the variety of the

* Published by E. and F. N. Spon, 125, Strand, London.

movements of the dial plate were necessarily complicated. After going for nearly five centuries, the works were found to be so completely worn out that about the year 1835 they were replaced by a new train; the old movement, now controlled by a pendulum, may be seen in action at the South Kensington Museum. Reference is also made in the same book to a water-clock with a rack and pinion, Fig. 6, Plate 21, which was used in Egypt about 300 B.C., so that it can safely be said that spur-wheels have been in use for an exceedingly long period. The author has in his possession an ancient clock-wheel which is probably some centuries old. The diameter is about 10 inches, there being seventy-eight teeth of about $\frac{3}{8}$ inch pitch and $\frac{3}{8}$ inch thick. The whole wheel is made of wrought-iron. The rim was bent and welded together and shows clearly the scarfed joint. The four arms and the boss appear to have been forged out of one piece, and the extremities of the arms are let into the rim for about $\frac{1}{4}$ inch and riveted over. A circle has been scribed on both sides for the whole depth of the teeth, and from this circle to the outside diameter division lines are scribed radially for each tooth. These division lines are much more accurately spaced than the teeth themselves, which vary considerably. There is absolutely no trace of any machine work having been done on the wheel. It is generally believed that all clock-wheels made up to the end of the 15th century were of iron and made entirely by hand. Some time during the 16th century clock-wheels were made of brass, and a great change was made in the method of cutting the teeth.

Wheel-Cutting Machinery.

Fig. 7, Plate 22, is taken from a photograph of an old wheel-cutting machine which has almost certainly been in use for 150 years. The present owner, Mr. George Lewton, of Winterbourne, near Bristol, is 85 years of age and he still cuts wheels on it. It was used by his father and grandfather before him, and neither of these claimed to have made the machine. The machine is made of wrought-iron, with the exception of a few small parts which are of brass. The handle for working it is seen on the right-hand side of the machine. This handle turns a spindle provided with a brass wheel which gears into a small wheel on the arbor or cutter mandrel. On this arbor is fixed a circular saw of the exact thickness of the space required. The whole is carried on a hinged frame and kept up from the bed by a flat spring. The cutter is fed down through the blank by pressing down the handle seen on the left-hand side of the hinged frame. The bed proper of the machine is oblong in plan, having apparently been welded at each corner. Short legs are fixed to the under side of the bed, of sufficient length to protect the dividing plate, which is carried underneath a slotted bar extending the whole length of the frame. The dividing plate is fixed to an arbor or work mandrel, which is free to revolve in a bearing carried by the slotted bar, and it can be moved by a long screw to suit the diameter of the wheel to be cut. The dividing plate has a number of holes drilled in concentric circles, each circle containing a different number of holes according to the number of teeth to be cut. The plate is fixed by a conical point carried on the end of a long flat spring and dropping into the holes. From 100 to 200 teeth per hour can be cut in clock-wheels by this machine when worked by hand. No attempt was made to shape the teeth on the machine, the points being rounded off afterwards with a file. These teeth are exactly similar to those which were cut during the 16th century.

Fig. 8 shows a wheel-cutting machine which may still be seen in use in Messrs. Dell and Co.'s Shop, Broad Street, Bristol. This marks a considerable advance over the machine just described, as the cutter is carried on a vertical slide. A foot treadle supplies the motive power, and the feed is put on by hand. This machine is about a century old.

Clock Pinions.—In all the old clocks the pinions were either made of wrought-iron or steel from the solid, or they were iron lantern pinions built up in the way already described in connection with old mills.

Cut Wheels for Patterns.—The speeds at which machines were driven had been increased from time to time, and better wheels were called for. Eventually the teeth of the patterns for small wheels were divided and cut in a machine similar to the clock-maker's engine. The teeth were epicycloidal and shaped entirely in the machine itself by formed cutters. From these metal patterns very good wheels were cast, and little labour was required to get them to run smoothly and quietly. For the better class of work, such as cotton spinning machinery, the wheels were cut from the solid, and these proved far superior in practice to cast wheels.

Wheel-Cutting Machine.—One of the first known makers of wheel-cutting machines was J. G. Bodmer, a Swiss engineer, whose works were in Manchester. Fig. 9, Plate 22, is from a photo of wheels cut by his machine about 1820 to 1830. The spur-wheel and pinion are patterns for the founder to mould from. They are of ½ inch pitch and have 145 and 15 teeth respectively. The length of the teeth is the same as the pitch, and at first sight it appears impossible for them to gear, but when tried together they work very smoothly. These teeth were cut with a formed disc cutter. Fig. 12 shows one of its six segments which were apparently held together by a collar on each side, and fixed rigidly by a nut on the mandrel. The teeth of this segment were cut by a milling-cutter guided by a former, and the top portions were filed after milling. Cutters like this composed of segments were novelties, but the style of the teeth, copied from the rose-bit, was common. If these cutters were sharpened, the thickness of the teeth would be slightly increased, and the parallel portion which cuts the part below the pitch line would cut too narrow a space. Hence the cutters were not sharpened, and their life was very short.

Fig. 10 is taken from a photo of a wheel-cutting machine made between the years 1824 and 1834. A vertical frame carries at the back a dividing wheel and worm, and a set of change wheels is provided to give the divisions for any number of teeth required. The blank is carried on the front of the frame on a horizontal spindle, and the cutter is fed in horizontally by hand. An arrangement is also shown whereby the cutter-head can be tilted for cutting bevel-wheels. The method of driving the cutter was evidently by a gut-band passing over two jockey-pulleys, and as no gearing was used to help the band, only small pitches could be cut.

In the middle of the cutter mandrel is seen a hole for a single pointed cutting tool or fly-cutter. The machine has all the essential points of an up-to-date Gould and Eberhardt machine, with the exception of the automatic feed and the end support for the mandrel. This machine together with others of the same type, but of larger capacities, are still working at an engineering works in Salford. The design is generally credited to Richard Roberts, a partner in the firm of Messrs. Sharp, Roberts and Co., of Manchester, but it is thought by others to be the work of J. G. Bodmer. After Bodmer had given up his works in Manchester he settled at Bolton, where he made another wheel-cutting machine. This machine has a work-table 6 feet in diameter connected to a worm-wheel, 5 feet 4 inches in diameter, having 360 teeth of $\frac{9}{16}$ inch pitch. The accuracy of this worm-wheel at the present time leaves nothing to be desired. The cutter-head, carried on a pillar, is moved on the horizontal bed according to the size of the wheel to be cut, and there was also an arrangement, not now available, whereby the cutter-head could be swivelled to any angle, for cutting bevel-wheels.

Involute teeth generated.—In 1835, Joseph Whitworth (afterwards Sir Joseph) was granted a patent for a wheel-cutting machine. From his specification it will be seen that the wheel blank being cut was a worm-wheel geared to the cutter by a train of wheels in an exact ratio and in such a manner that no slip could take place. In all probability, this was the first machine to generate involute teeth. Fig. 11 represents a machine made by Joseph Whitworth between the years 1834 and 1844, capable of cutting spur and bevel wheels. The main drive was by a gut-band and a pair of spur-wheels. The dividing was done by a large plate with holes drilled in circles and the cutter was fed by hand. Fig. 13, Plate 23, represents a much larger machine built by Whitworth for cutting spur-wheels only. In this the first drive is by a flat belt and then through a worm and wheel.

Machine for milling formed Cutters.—Fig. 14 shows a machine for milling the teeth in formed cutters. The former is nearly five times the dimensions of the cutter to be milled, so that any error in the shape of the former is reduced to one-fifth in the actual cutter. This machine was a great help to the tool-maker. It was no longer necessary to turn the blank to the exact shape, as the former would finish every tooth with the greatest accuracy. Bodmer probably used a machine of similar construction to this to produce his formed milling-cutters.

About the year 1851, Messrs. Shepherd, Hill and Spink made their first machine for cutting wheels. Fig. 15, Plate 23, is taken from a photograph of one of their earliest machines. The bed is long and narrow. The cutter bracket can be swivelled at its base for cutting bevel-wheels, and it is set to zero for cutting spur-wheels. The drive is by an endless rope and pair of spur-wheels to the cutter mandrel, and there is a self-acting feed. When one tooth is finished, the blank must be turned round by hand to the next, and the correct division is obtained by means of change-wheels. The dividing head and work mandrel are moved along the bed by a horizontal screw to suit the diameter of the wheel being cut.

Amongst J. G. Bodmer's many inventions was the "railway car solid tyre rolling mill" which gave the name to the Salford Rolling Mills. The owner of these mills, Mr. P. R. Jackson, took out a patent for a machine to mould the teeth of spur-wheels. Fig. 16, Plate 23, is from a photo of the earliest working machine made. A pattern is made forming a space between two teeth of the required wheel. This pattern is fixed to a vertical slide carried on the main bracket which can be moved along the bed by means of a rack and pinion to suit the diameter of the wheel to be moulded. The slide is lowered vertically until the pattern touches the surface of a sand bed contained in a circular moulding-box. This box is carried on a table which can be revolved by a worm and wheel, driven by suitable change-gears for the number of teeth required. The moulder rams sand into the space, thus forming the sides of two teeth, and the pattern is then lifted vertically out of the sand. The dividing handle is given one or more turns and this moves the table round through one space. The process is repeated until all the teeth are completed. At first the pattern teeth were made by hand, but soon afterwards these teeth as well as the teeth of mortice wheels were cut by machines specially built for the purpose. The first machine-moulded wheels ever made were shown by P. R. Jackson at the Great Exhibition of 1851 in London.

In 1856, Christian Schiele, of Oldham, took out a patent for a thread milling machine which was also capable of cutting the teeth of wheels. From his specification it is seen that the blank to be cut is geared up with the worm cutter, and when this cutter is efficiently guided the teeth will be perpendicular as in an ordinary spur-wheel. This marks a step in advance of Sir Joseph Whitworth's device already referred to, for Sir Joseph Whitworth's machine was only for cutting such wheels as have their teeth oblique to the axis. In Schiele's patent is undoubtedly the germ of the modern gear-hobbing machine, but the author has been unable to find any trace of such a machine having been made from this specification.

Fig. 17 (page 660) is a reproduction from an old drawing of the first gear-shaping machine designed by Mr. Potts, a member of the celebrated clock-making firm. It is described on the original drawing as "Potts' Patent Wheel cutting and dividing engine for cutting the teeth of bevel and spur gearing mathematically correct. Manufactured by Shepherd, Hill and Co., Leeds." This machine appears to be the first attempt at planning or shaping bevel and spur gear-wheels from a large former plate. A gold medal was awarded for this machine at the Paris Exhibition of 1867.

Fig. 18 (page 661) and Fig. 19, Plate 24, are taken from a book which illustrates all the important wheel-cutting machines exhibited at the Paris Exhibition of 1867, and their main features can easily be understood from the figures. There are no makers' names on these machines.

Machine Relieved Cutters.—It has already been seen that the early formed milling cutters were a very expensive item, owing to the fact that it was impossible to sharpen them without spoiling them. This gradually brought about the introduction of a new kind of cutter, now known as the relieved or backed-off cutter, which could be easily sharpened without altering its form. These relieved cutters have about one-fifth the number of teeth of one of the old formed cutters of the same size. The teeth are cut through from side to side, like a saw, for the whole depth of the formed part, and the

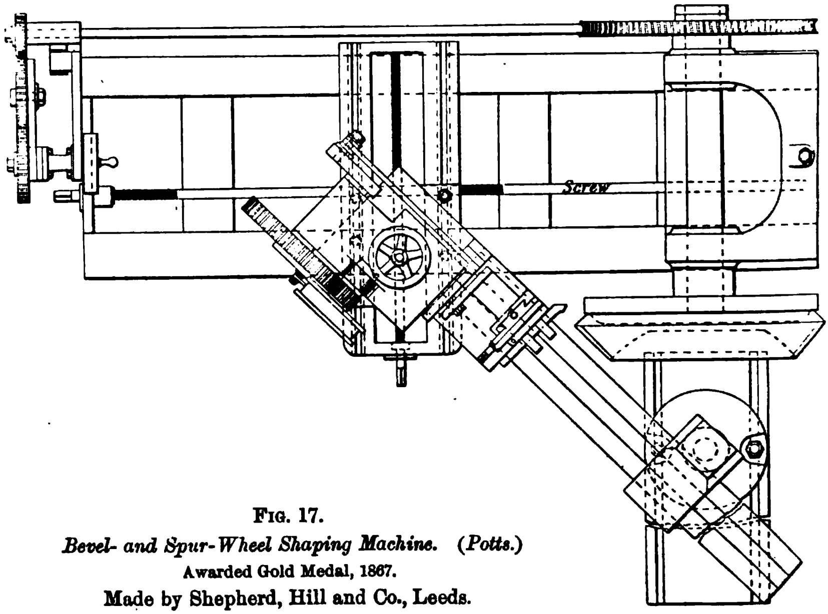
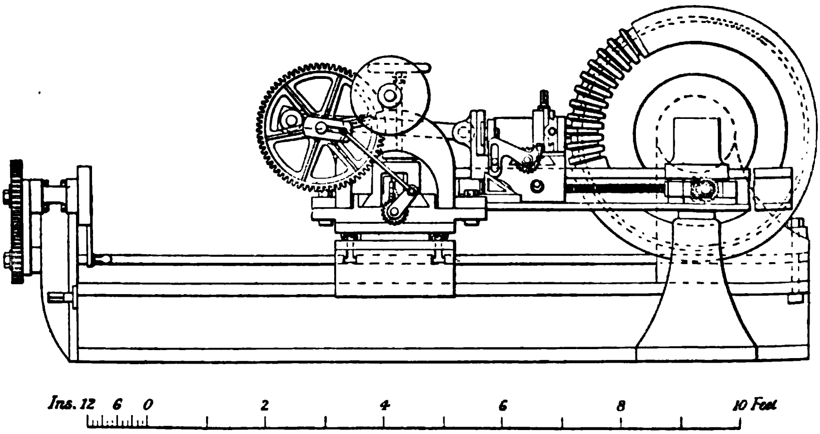


Fig. 17.

Bevel- and Spur-Wheel Shaping Machine. (Potts.)

Awarded Gold Medal, 1867.

Made by Shepherd, Hill and Co., Leeds.



cutting face is radial. The backing-off to the teeth was done on a slotting or shaping machine with a formed tool. Fig. 20, Plate 24, shows a cutter made in this way. At this time the great majority of spur-wheel teeth for engineers were of the epicycloidal form. These teeth were difficult to cut even with a relieved milling cutter, owing to the flanks of the teeth being nearly parallel. After a little use the cutters jammed in the work and so caused endless trouble. Yet with all this the milling cutter had proved very useful, and it was

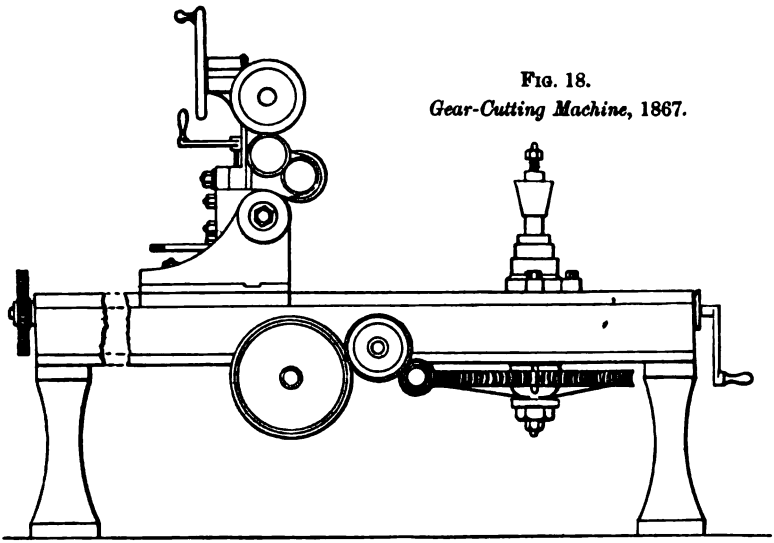


FIG. 18.
Gear-Cutting Machine, 1867.

not long before an alteration in the shape of spur-teeth was made for small wheels.

Involute Cutters.—About the year 1874 Messrs. Brown and Sharpe, U.S.A., brought out complete sets of machine relieved involute gear-cutters. The shape of the cutters was based upon a system first introduced by Professor Willis, of Cambridge, in 1836. In his book on forming the teeth of gear-wheels he recommended that the obliquity of the line of pressure should be made 14½ degrees. The suggestion was afterwards put into practice by Messrs. Brown and Sharpe, and cutters made on this system have been used in their own works since 1851. It was necessary that the roots of the teeth should be strong, and at the same time there must not be too great an outward thrust on the bearings. An angle of about 14 degrees to 16 degrees was considered to be the most suitable for meeting both these requirements. It was essential to adopt some uniform method, and a very simple construction was found by which an angle of 14½ degrees could easily be set out. The way in which Messrs. Brown and Sharpe arrived at the shape of the cutters was somewhat as follows. A rack with teeth having straight sides inclined to each other at an angle of 29 degrees formed the basis of the whole system. It was decided that twelve teeth in a pinion was the smallest practical number that could be used. The teeth were drawn of the correct involute form, but to allow the pinion to roll into the rack it was found that the flanks had to be very considerably undercut. This would have made the teeth weak, and it would have been difficult to mill out the spaces. On this account, it was determined to make the flanks radial, so giving the necessary clearance and enabling a disc milling-cutter to be used. In American practice involute teeth are invariably employed, but in this country whilst all teeth of small pitch are involute, epicycloidal teeth are often used for the larger pitches. The great advantage of involute teeth is that the distance apart of the centres can be varied without impairing the efficiency of the gearing, and the angular velocity ratio remains constant. With epicycloidal teeth, on the other hand, the wheels must be kept exactly in gear on their correct centres or the teeth will wear very badly. With epicycloidal teeth the outward thrust is less than with involute teeth.

In 1877 or 1878 Messrs. Gould and Eberhardt, U.S.A., brought out an automatic gear-cutting machine. One of these machines was bought by Messrs. John Lang and Sons, Johnstone, about the year 1881 for cutting the wheels of their lathes, and this firm also made arrangements with the makers to act as their agents in Europe.

Double Helical Spur-gearing.—About the year 1880 Messrs. P. R. Jackson and Co. brought out the double-helical spur-gearing, the object being to bring the teeth into gear more gradually, thereby reducing the noise. The true action of the teeth can be best understood from the following explanation. Take two short screws, one right and the other left hand, both of the same diameter and pitch. If one thread is rolled into the other the screws are single helical wheels. If the driven wheel is retarded the screws tend to move endwise in the direction of their axes and in opposite directions. To balance this end-pressure, add another pair of screws similar to the first pair, fixing a right-hand and left-hand screw together on each spindle. The result is a double helical wheel. It will be readily seen that the resistance has a tendency to separate the pair of screws on one spindle, while it tends to press the pair on the other spindle closer together. In heavy gearing the bursting and compressing forces due to the wedge action would become very great, but they are actually reduced by using multiple threads. This alters the angle of the threads, so that the threads are more nearly parallel to the axis of the wheel, and the ends of the threads have more the appearance of ordinary spur teeth.

Another very practical way of explaining this system is to make forty-one metal discs about $\frac{1}{16}$ inch thick. Bore and turn them and then, stringing them on a mandrel, clamp them together and cut teeth on them just as if they were one solid blank. Then slack the nut of the mandrel and, beginning from the outside, turn each disc so that the teeth are slightly in advance of those on the one before it. When the twenty-first or middle disc has been reached the other discs must be turned in the reverse direction, so that the teeth are now slightly behind those on the preceding discs. Great care must be taken to turn each disc through exactly the same amount. It will now be seen that one half of the teeth form a stepped right-hand helix and the other half a stepped left-hand helix, and the forty-one discs clamped together in this position form a stepped double helical wheel. If the edges of the teeth in a stepped wheel were bevelled off they would form correct double helical teeth, and the action would be more gradual. Stepped wheels and racks were made in many cases where smooth working was required, and many examples are still to be found in old planing machines. Correct double helical gearing when made by experienced firms is very silent in action, and for heavy duty nothing has yet replaced it either in regard to strength, silence or cost. The largest gears in the world have been made on this system by Messrs. P. R. Jackson's moulding machine, capable of moulding wheels up to 30 feet in diameter by 36 inches width of face and 9 inches pitch. The form of tooth is epicycloidal. The wooden pattern teeth were cut on a special device attached to the machine.

Machinery was now advancing with very rapid strides. Gear-cutting machines and sets of standard involute cutters were being imported from the United States in large quantities, and in spite of the prediction of engineers that this state of things could not last long, it has, however, lasted up to the present day. The machines sent over were lightly built and of soft material, but the workmanship was very good. One of the pioneer machines from America was the Brainard, a full automatic gear-cutting machine for either spur or bevel wheels. The main frame of the machine is of the same type as a milling machine. The self action for advancing the blank after each space has been cut and the automatic return motion of the disc cutter are extremely ingenious.

In this country Messrs. P. R. Jackson and Co. have made gear-cutting machines for their own use, capable of cutting spur gears in iron or steel up to 30 feet in diameter by 36 inches width of face and 9 inches pitch. Messrs. Darling and Sellers, of Keighley, build an automatic machine of the vertical type for cutting heavy gearing.

Spur-Gear Planing Machine.—Messrs. Gleason, of Rochester, U.S.A., have made machines for planing the teeth of spur gears up to 24 feet diameter by 24 inches face and 6 inches pitch. A former plate is used as in Potts' original system. The large pitch gears usually cut on these machines are generally cast with teeth sufficiently thick to allow for machining. This reduces the weight of the castings, saves the time otherwise spent in stocking out the teeth, and the teeth are freer from sponginess owing to there being less metal in the rim. Fig. 21, Plate 24, shows one of these machines capable of planing wheels up to 15 feet in diameter at the works of Messrs. David Brown and Sons, of Huddersfield, and similar machines are used by Messrs. Arnold Pochin and Brother, of Manchester.

Spur-Gear Shaper.—A machine which works on an entirely different principle is known as the Bilgram spur-gear generating shaper, and its action is similar to that of the well-known Bilgram bevel gear planer.

Gear-shaper.—Another kind of spur-gear generating machine is the Fellows' gear-shaper. Its action is similar to that of a slotting machine, but instead of the ordinary slotting tool it carries a twelve-toothed pinion for its cutter. The teeth are of true involute form, hardened and ground up all over. The spindle carried in the reciprocating vertical slide is geared up by spur-wheels and change-wheels to the work-table. The cutter is fed into the blank to the full depth of the teeth, and then, while the cutter is continuously reciprocating, the blank and cutter slowly revolve together at the exact ratio between the number of teeth in the cutter and the blank being cut. One revolution of the blank completes the operation. Only one cutter is required for all wheels of the same pitch, and the machine is equally suitable for spur-wheels and internal wheels.

Other steps in the development of wheel-cutting machinery are exemplified in the Sellers, the Thompson and Fitton, Birch's, Gibson's (worm and bevel wheel cutter), Smith and Coventry's, and the Oerlikon machines. Each of the methods above mentioned or described forms a link in the development of wheel-cutting machinery. Sometimes the process has been by some sort of planing action, the tool being guided by a former, sometimes the process has been done by shaping tools, and at other times by milling cutters in various ways.

HOBBING MACHINES.

Principle.—In all machines that have been described so far, one tooth must be finished before the next one is begun, but in the gear-hobbing machine the teeth are generated in circles, and they are all begun and finished practically simultaneously. The cutter or hob consists of a cylinder having wound round it a single right-hand thread. The thread has straight sides inclined to each other at an angle of 30 degrees. This thread is divided into teeth by spiral slots cut through it at right angles to the thread, and the tops, sides and bottoms of the teeth are backed off. The cutter is fed down through the blank, and the blank and cutter are geared together by change-wheels, so that they revolve at the correct ratio between the number of teeth to be cut and the thread of the hob. That is to say, for one revolution of the blank the hob must make as many revolutions as there are teeth to be cut. The action is the same as that of an endless rack which is moved along in gear with the wheel that is being cut. It is clear that the pitch line of the rack must move at exactly the same rate as the pitch line of the wheel. All the metal which interferes with the rack teeth is removed. Thus the teeth of the wheel are generated to the true involute form, and only one hob is required for all wheels of the same pitch.

In order to cut a correct spur-tooth, the axis of the hob must be tilted to the angle of spiral of the thread. Otherwise, as the cutter is fed downward, the spaces would be cut too wide. It is also necessary that one tooth should be set exactly on the centre line of the machine. This is the tooth which finishes the bottoms of all the teeth in the wheel. If no tooth in the hob is set exactly on the centre line, the wheel teeth will be cut slightly out of upright. The hobbing principle was first foreshadowed by Sir Joseph Whitworth's invention of 1835, and a hobbing machine was actually invented more than fifty years ago by Christian Schiele, who has already been referred to.

Gear-Hobbing Machines.—It is probable, however, that one of the first gear-hobbers actually made is a machine that has been working continuously since 1893 in the works of Messrs. George Juenpt and Sons, Croton Falls, New York. This machine is shown in Fig. 22, Plate 25. Fig. 25, Plate 26, represents a gear-hobbing machine which was brought out about 1894 by Messrs. Reinecker, of Chemnitz, Germany. This machine was made to cut spur-wheels, worm wheels, and spiral wheels. In both these machines the gear blank is carried on a horizontal mandrel and the hobbing cutter is fed horizontally. A later example of the same type is the Biernatzki. By far the greater number of gear-hobbers are now, however, of the vertical type, that is to say the wheel blank is held on a vertical mandrel, and the cutter is fed vertically downwards.

The best known is the Pfauter. These machines are made in many sizes; the largest, capable of hobbing wheels up to 10 feet in diameter and one diametral pitch, is shown in Fig. 23, Plate 25. The main drive is from a countershaft and stepped cone pulley in the bed near the ground. From the first driving shaft the motion is taken off to change wheels at the back of the machine and to a vertical shaft, and from this vertical shaft the motion is conveyed to the hobbing cutter by bevel wheels and spurs. The hob bracket can be swivelled completely over, so that the hob can work at any angle. The arrangement for cutting spiral wheels is very ingenious. A differential gear is placed between the change wheels and the worm-shaft which revolves the work-table. This differential gear can be set by means of suitable change wheels to advance or retard the worm-shaft by the exact amount required. Another set of change wheels is used for the feed.

The first British firm to enter the field with a gear-hobbing machine was Messrs. John Holroyd and Co., of Milnrow. Fig. 24, Plate 26, shows a machine by this firm capable of hobbing a wheel 10 feet in diameter by 14 inches face and one diametral pitch. It is very heavily built, weighing about 30 tons. The machine will cut spur, worm or spiral gears, and it is so arranged that taper hobs or single pointed cutters can be used for cutting worm wheels.

Messrs. Armstrong, Whitworth and Co. make a machine to hob wheels up to 6 feet in diameter. The special feature of this machine is that instead of the work-table sliding on the bed to suit the diameter of the wheel being cut, the vertical column which carries the hob bracket is adjustable on the bed. In Messrs. Wallwork's machine the cutter spindle is driven by a worm and wheel to give smooth running. The feed is through a gear-box giving three changes. The top of the work mandrel is supported by a bracket fixed to two vertical columns carried by the base slide of the work-table.

Fig. 26, Plate 26, represents a machine built by the author's firm for cutting spur and worm wheels. In this machine no countershaft is required, and as the driving pulley is fixed on the top of the column, the machine can be put down anywhere in the works and the belt received at any angle. It is also so arranged that a motor can be mounted on the top of the column. When belt-driven there is a light, loose pulley and a heavy fly-wheel, which is found to be an advantage owing to the intermittent cutting of the hob. The fly-wheel runs at a constant speed, and a gear-box, Fig. 27, Plate 27, and Fig. 28 (page 669), giving four changes of speed, is provided, so that a constant torque is always maintained from the belt to the hobbing cutter. The rate of feed can be altered while the machine is running. The feed-gear, Fig. 29, Plate 27, consists of two taper cones and a belt which can be shifted by means of a fork, moved by a screw. To obtain a wide range of feeds the difference given by the cones is multiplied by means of an epicyclic gear, and practically all the strain is taken off the belt. Thus any feed can be given from 5 to 130 thousandths inch per revolution of the blank being cut. The work mandrel is tied to the top of the vertical column by two cross-stay bars to prevent deflection and stiffen the blank whilst being cut. A section through the worm driving the work-table is shown in Fig. 30. The machine is very stiffly built, and is intended to cut steel wheels of large pitch.

Manufacture of Hobs.—The chief trouble of this system of generating gears lies in the manufacture of the hobs. The hob is made out of one solid piece of steel, which is bored and turned and the keyway cut. Then the thread is roughly milled out and also the spiral slots between the teeth. Next the teeth are relieved or backed off in a special lathe, and the lathe tool is carried in a rest which has a multiple motion. For every tooth, the tool is moved in and out by means of a cam, and at the same time it is fed forwards to follow the thread of the hob. During this process an allowance can be made for expansion or contraction anticipated in the hardening of the hob. After the teeth have been relieved, the hob goes into the tempering department. This is the most dreaded part of the process, for the work which has been done so carefully may

32-INCH GEAR-HOBBING MACHINE (FIG. 26, PLATE 26).

FIG. 28.—*Change-Speed Gear.*

Scale ⅛th.

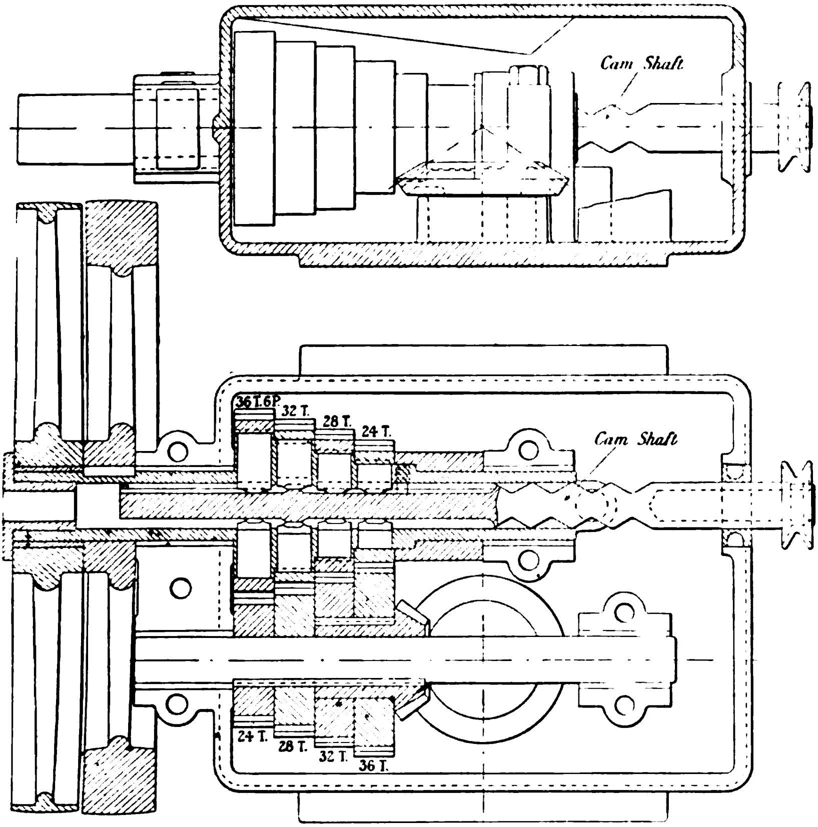
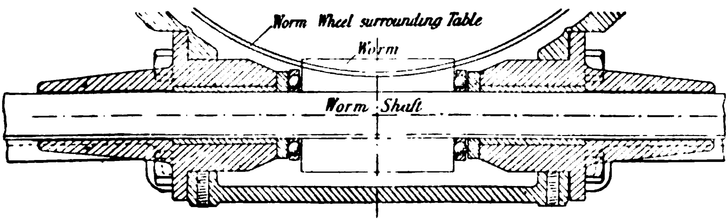


FIG. 30.—*Worm driving the Work-Table.*

Scale ⅛th.



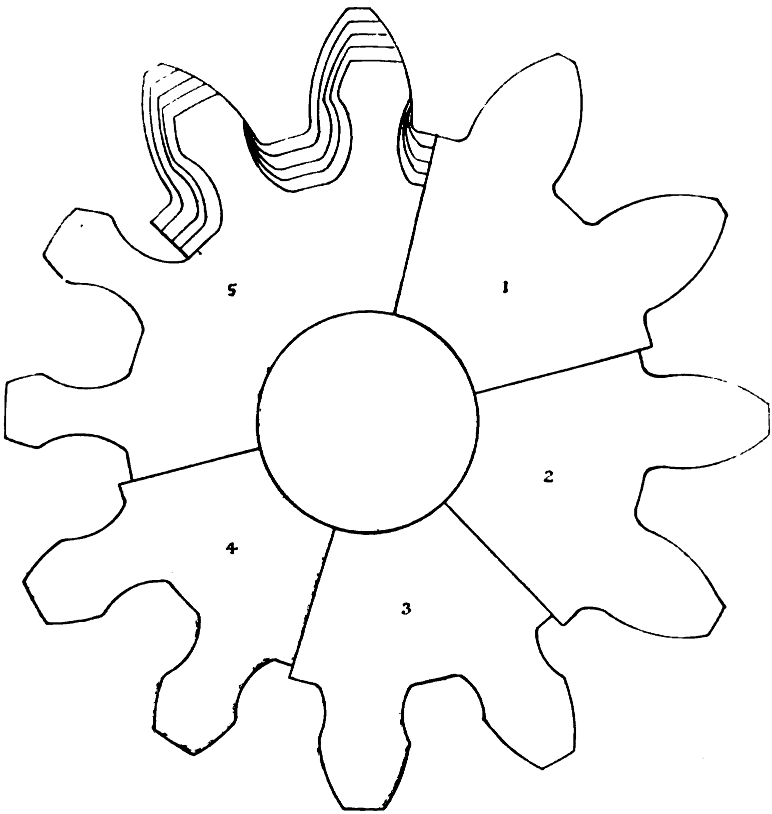
be spoilt in the fire or in cooling, even with the most experienced men. To complete the hob it is necessary to grind out the bore and over the tops of the teeth to true them up. Finally the cutting faces of the teeth are ground back just sufficiently to remove the grinding marks on the tops of the teeth.

Grinding Hobs.—Even after this lengthy process it is sometimes found that a hob has gone slightly out of pitch in the hardening. Attempts have been made to correct this by grinding the sides of the hob teeth after hardening. For this purpose a small emery wheel was used in the backing-off machine, but, owing to the small diameter of the emery wheel which had to be employed to pass between the threads and the great speed required, this has not proved very successful.

The author has brought out a hobbing cutter with inserted blades or racks which are fitted into grooves cut in the body of the hob. These grooves are not cut radially, for in a cross section of the hob the centre lines of the grooves are tangential to a small circle concentric with the periphery of the body. The thread is roughly cut and then the blades are taken out and tempered, and the parts that fit in the body are ground. They are then replaced in the body and the thread is ground up all over, so that any error due to tempering is corrected. The blades are again taken out of the body and turned end for end in the grooves, being replaced so as to keep the continuity of the thread. Owing to the grooves being tangential, this will tilt the blades and so give the necessary clearance or backing off to the teeth. The blades are rigidly held in the grooves of the body by long keys. Several sets of blades of different pitches either diametral or circular can be used in the same body, and if a tooth gets broken, it only means that one blade is spoilt, and this can easily be replaced. It is thought that this method of construction will lend itself particularly to hobs of large pitch, as at present the large solid hobs are very expensive. At the time of writing only two of these hobs have been made, and it is still too early to say how far they have an advantage over solid hobs. The results obtained are, however, sufficiently good to encourage further trials.

FIG. 31.

Portions of five 12-tooth Pinions cut on blanks sized for 11 teeth up to 13 teeth.



Undercutting of Pinions.—One point sometimes urged against the hobbing principle is that, as all the wheels are generated by rolling into a rack, the flanks of pinions must necessarily be undercut. The teeth of pinions could be made stronger by increasing the angle of the sides of the rack teeth, but this has the disadvantage of increasing the angle of obliquity and so throwing a greater outward thrust on the bearings. Nevertheless the evil effects of this increased angle of obliquity are thought by many to be exaggerated, and Wilfred Lewis recommends the use of involute teeth having an angle of obliquity of 22½ degrees.

The author is, however, in favour of retaining the present form of hob having sides inclined to each other at an angle of 30 degrees. In the case of wheels of less than thirty teeth, he recommends that the blank should be turned to a rather larger diameter than the correct diameter for the number of teeth required. The cutter is set to the full depth of the tooth just as if the blank were the correct size. The base circle, from which the involutes are unwound, is not altered by altering the size of the blank, but if the blank is over size we shall get teeth very strong in the roots with short flanks and long addenda. The centres of the wheel and pinion are, however, slightly further apart and the angle of obliquity is increased. Thus with the same hob, almost any desired strength can be given to the teeth of a pinion, and all the pinions will gear perfectly with the wheel cut on a correctly-sized blank.

It must be understood that there are limits to the amount of error which can be given to the diameter of the blank, for if the error is too great the teeth will be cut off altogether. As an illustration, take a 24-tooth wheel gearing into a 12-tooth pinion of 2 diametral pitch. The correct centres for these are 9 inches apart and the angle of obliquity is 15 degrees. Now cut twelve teeth on a blank intended for thirteen teeth. The centres will now be 9¼ inches apart and the angle of obliquity is 21 degrees. This is rather an extreme case, but a very strong form of tooth can be obtained with a blank sized for 12½ teeth. The longer involute of the pinion teeth causes these wheels to run very smoothly together. Fig. 31 (page 671) illustrates a series of 12-tooth pinions cut on blanks sized for 11 teeth up to

13 teeth. The third in the series is cut from a blank of the correct diameter.

Disadvantages of Disc Milling Cutters.—The introduction of automatic gear-cutting machines cheapened cut wheels to such an extent that they soon came into favour for all high-class work. As has been explained, unless the number of teeth to be cut in the blank correspond to the lowest number stamped on the cutter, the teeth will not be correctly shaped. Moreover, as the cutter gets blunt, the centres of the cutter and work mandrel are forced apart, and the bottoms of the teeth describe a slight scroll. Also as one tooth is finished at a time, the strains of the metal being released locally and the heat generated cause the wheel to be distorted from a true circle.

Disadvantages overcome by Hobbing Machines.—The extraordinary demands of modern high speed machinery rendered it necessary to find something still better. In all gear generating machines the teeth, no matter what number there are in the wheel, are developed to the true involute form so long as the tool keeps sharp, and in the gear-hobbing machine, which generates the teeth simultaneously, nearly all the disadvantages of the disc milling cutter are overcome. Moreover, while the milling cutter has about twelve cutting teeth, in the case of a hob the cutting is done by about thirty teeth. In practice it is found that with a good stiff hobbing machine, from two to three times as much metal can be removed per hour as with a machine using a disc milling-cutter of the same pitch. With the improvements in hobs suggested by the author the troubles caused by the hob going out of pitch in hardening may be eliminated, and wheels cut with such a hob as this probably come as near to perfection as can be obtained on any wheel-cutting machines.

Disadvantages of Hobbing principle.—Nevertheless, there are certain disadvantages of the hobbing principle. In the first place, owing to the spiral twist of the blades a section of the blade normal to the axis of the blank is not a perfectly true rack, and in consequence the points of the teeth being cut are very slightly too thick. Secondly, while the blank rotates continuously the cutting is intermittent, and after one tooth of the hob has taken a cut a small piece of metal escapes before the next tooth comes into action. If a hobbed wheel is examined it will be seen that the sides of the teeth show a series of small flats. By increasing the number of teeth in the hob, the flats are made smaller, and if there were an infinite number of teeth in the hob it would generate a smooth curve.

Grinding the Teeth of Wheels.—Of recent years there has been a great tendency towards grinding the teeth of the change gears for motor cars. At first the wheels were run in with emery and grease. This was found to take off as much metal from the parts that were correct as from those that were incorrect, and while some wheels ran much better after this treatment others were decidedly worse. However, something in the way of grinding has long been requisite, and about two years ago a machine was made by Messrs. Reinecker on the same principle as the machine used in the Fellows' gear-shaper system, for grinding the involute teeth of the cutters. The machine carries an emery wheel bevelled on each side to the shape of a rack-tooth with sides inclined at an angle of 29°. This wheel revolves at about 2,000 revolutions per minute. At the same time it moves bodily up and down through the space of tooth whilst the blank rolls under the restraint of two steel tapes, as in the Bilgram bevel gear planer. A few thousandths of an inch are left on the teeth for grinding, and the teeth are generated to the true involute form. One tooth is finished at a time, and then the blank automatically moves forward to the next space. The amount of wear on the emery wheel is said to be small, and the wheel can be trued up in its place. Gears ground by these machines show a great improvement over those which have not been ground. Nevertheless, owing to the gradual wear of the emery wheel there is a difference between the first and the last tooth finished in this way.

The author has devised a machine for grinding the involute teeth of gear wheels, which works on the principle of the hobbing machine. The teeth are generated simultaneously so that distortion due to the heating of the blank is eliminated, and, as the downward feed of the abrasive wheel is very rapid, the wear is practically negligible. For purposes of experiment an ordinary 22-inch gear hobbing machine made by the author's firm was chosen. In place of the hob was substituted a cylinder of corundum, grit 50 and grade M, 10 inches in diameter and 7 inches long, having a continuous thread of 7 pitch cut upon it. The sides of the thread are straight and inclined at an angle of 30°, which is the exact shape of the thread of the hobbing cutter. The thickness of the thread on the pitch line is however made rather less than the correct thickness for a 7 pitch tooth. This corundum worm practically amounts to a hobbing cutter having an infinite number of teeth. The thread was roughed out in a lathe with Huntingdon dressers in seven hours, and finished by grinding on a Greenfield universal tool grinder with a carborundum wheel in twenty-one hours. It is thought that it may be possible to save much time in manufacture by moulding the thread roughly into shape. In place of driving the corundum worm through the gear box and vertical shaft of the machine, a pulley is fixed directly on the spindle of the corundum worm itself. By this means the effects of the torsion of the shafts are got rid of. The corundum worm is revolved at a speed of 2,400 revolutions per minute, and it is geared up to the work table through change wheels as in a hobbing machine. A rapid downward feed is provided for, and the driving belt is led horizontally to the driving pulley to permit this.

The author has ground up several cast-iron wheels of 7 pitch on the experimental machine. The wheels are first hobbed, but the hob is not put into the full depth, so that a few thousandths of an inch are left on the sides of the teeth for grinding off. Before the wheels are ground the bottoms of the teeth are cut to the full depth with a special formed cutter. It would of course be far better to hob the teeth in one operation with a hob having teeth that are slightly too thin. The wheel is then put on the work mandrel, and the corundum worm moved down by hand until its centre is level with the top of the wheel to be ground. The corundum worm is then adjusted endwise by means of a screw turned by a worm and worm wheel by which a very fine cut can be put on, so that one side of the thread touches one side of the teeth in the wheel. Owing to the thread on the corundum worm being thin, as has been explained, the other side of the thread is not in contact with the teeth. The corundum worm is then allowed to feed down automatically, grinding up one side of all the teeth and generating them truly. The machine is then stopped, the corundum worm raised by hand, and a finishing cut taken. The other sides of the teeth are ground and finished in the same way. A stream of lubricant consisting of water, soda and oil is kept running on the wheel to prevent glazing.

In the best results obtained so far a cast-iron wheel of 70 teeth 7 pitch and $1\frac{1}{4}$ inches face was completely ground in eight minutes.

The wear on the corundum worm appears to be very slight, about $\frac{1}{1000}$ inch in the worst part, but in the finished machine it is proposed to provide a carborundum wheel for touching up the corundum worm after each cut. The author has found that when he grinds $\frac{1}{1000}$ inch off the corundum worm to true it up, the carborundum wheel which grinds it shows only $\frac{1}{4000}$ inch of wear. The author has also found that the corundum worm is only worn on three threads for about one-third of their circumference. In the finished machine an arrangement will be provided for traversing the wheel that is being ground across the face of the corundum worm, like a wheel meshing with a rack, thereby wearing the corundum worm evenly. To compensate for this traversing motion, a differential gear will have to be provided like that of the Reinecker machine when cutting worm wheels with a taper hob. The results obtained with the experimental machine have been so good that with these improvements there is every prospect of the success of a future machine.

Conclusion.—The author's idea is that not case-hardened wheels only should be ground on this machine, but every kind of metal should be ground in the soft state, no matter for what purpose the wheels are required. The wheels would be roughed out rapidly in the gear hobbing machine with no attempt at finish, and then sent to the grinding machine to be finished, just as all lathe work that is required to be both accurate and cheaply produced, is first roughed out in the lathe and then finished on the universal grinder.

The author's best thanks are due to those firms and others who, by their courtesy in supplying him with information, photographs and exhibits, have materially assisted him in the preparation of this Paper.

The Paper is illustrated by Plates 21 to 27 and 5 Figs. in the letterpress.

Discussion.

On the motion of the PRESIDENT, a hearty vote of thanks was accorded to Mr. Humpage for his interesting Paper.

Mr. CHRISTOPHER W. JAMES, in opening the discussion, thought the author had pointed out the chief trouble of the system of generating gears by means of hobs. The final method of grinding seemed to him to be eminently practicable for case-hardened gearing, but he failed to see that for ordinary gearing of cast-iron or soft materials he was likely to attain any greater accuracy by his grinding arrangement than by means of steel cutters, because the amount of wear upon the corundum wheel would be perceptibly more than the wear on the steel tools. For himself he was inclined to think that the difficulty of the inequality of expansion or contraction that might take place in hardening a hob, which was extremely difficult to get over, might be evaded by the adoption of a totally different system, namely, that of planing or shaping the teeth. If that were done with a simple tool, that is, a tool more or less of the character of a lathe or slotting tool, which could be hardened and subsequently ground to any desired degree of accuracy, the inclination of the sides could be made anything that was suitable for the gear in question. He by no means took the view that any one angle was necessarily correct for the angle of obliquity, and he thought such an angle required to be regulated according to the purpose for which the gear was intended. It was perfectly practicable to make a machine operating with a single tool of the sort described which

(Mr. Christopher W. James.)

would truly generate the shapes of the teeth. At the present time his firm was engaged in the manufacture of a machine of that character, but it was not at present in a state which would enable him to describe it in detail to the members. Its principle, however, was well known. He thought that method of shaping teeth was very nearly as quick in operation as the hobbing machine, because with the slotting action of a tool of that sort much heavier cuts could be taken than could be taken with the milling action of the ordinary hob.

Mr. ALFRED SAXON thought the author had certainly shown some resource in the early stages of the Paper, when dealing with the historical aspect of the question, in trying to explain his idea of how spur-gearing was originally introduced. He did not know whether the author had consulted Fairbairn, who wrote a very good book dealing with the early history of gearing. There could be no doubt, however, that the first gearing made on any large scale was carried out by the Manchester engineers in connection with corn and cotton mills, and other industries. In textile mills the practice of applying spur-gearing for main driving was gradually dying out, and was being substituted by other forms of driving, such as rope driving, strap driving, and electrical driving.

He thought the author had not explained the whole of the reasons connected with the adoption of the mortice wheel. The author said (page 653) "For heavy work the millwright introduced an iron wheel with spurs on the rim, cast in one piece," and did not make any reference at all to the large driving wheels which were made from a full segment pattern and built up, and that those wheels were only comparatively small driving wheels, which were made whole. He, therefore, suggested to the author that he might add to that portion of the Paper that wheels were also made of segments made from a full segment pattern, the mortice wheels being used as pinions. The author left the question rather open to doubt as to what the purpose of the mortice wheel was. It was undoubtedly adopted to give smooth and noiseless running, but in starting and stopping there was a considerable amount of backlash, and with iron pinions it was very frequently found there was a tooth out when an inspection was made of the gearing after stopping time. That was found to be the case particularly where engines were coupled. When high-pressure engines were applied to existing condensing engines and coupled on to second-motion shafts, it was found to be almost a necessity for mortice pinions to be introduced to avoid the breaking of teeth through the shocks caused. Those were amongst the reasons for using mortice wheels, and, as the author said, there were wheels of that kind running today, and running very satisfactorily.

Reference was made on page 656 to some special forms of cutters which were shown in Fig. 12, Plate 22, and mention was made of milling cutters made in segments. In his firm's works they formerly had a wheel-cutting machine of the exact type of that shown in Fig. 10, Plate 22, and more than thirty years ago he occasionally worked on that very machine. He believed it was bought at a sale by his father, and there were boxes of the various types of cutters which the author referred to, particularly the segment cutters. The machine was used for cutting replace change and other small wheels for the various lathes and machines in the works. It was afterwards broken up, and some portions of it were used for milling key-ways in the coupling ends of shafting for a time.

The author referred on page 662 to the double helical spur-gearing which Messrs. P. R. Jackson and Co. introduced. That style of gearing undoubtedly had great advantages for strength and ease of working, but it also possessed disadvantages. It was frequently found in cotton mill practice, where long second-motion shafts were in use to which were secured other wheels for driving the card-room line shafts and upright shaft, that the helical type of gear created a certain amount of end-play, thus causing the bevel wheels fixed on the shafts to work with a varying depth of gear. A certain amount of end-play had to be allowed for in helical gearing of large size, and this was accomplished by applying expansion couplings at the end of the portion of the second-motion shaft on which the pinion-wheel was fixed.

(Mr. Alfred Saxon).

The author had not referred to another style of tooth that was introduced by a member of the firm of Messrs. P. R. Jackson and Co., which was known originally as the "Gee" tooth; it was also known as the buttress or the sloping-back tooth. This form of tooth gave increased strength compared with the ordinary form of tooth.

Mr. Ewart C. Amos proposed to confine himself to one point, and that a very elementary one. He believed he was right in saying there were three methods of cutting teeth: (1) By shaping or planing, (2) by a disc-cutter, and (3) by a hobbing machine. The author had mentioned the disadvantages of the disc milling-cutter and of the hobbing machine, nor did he appear to be in favour of the planing machine principle. He also stated that he had adopted a machine which he thought was the best, and that it was of the hobbing-machine type. He (the speaker) thought it would be most interesting if it were possible to ascertain the general consensus of opinion of the meeting as to whether planing, milling, or hobbing was the best known method today of cutting spur-gears. He himself felt that the author's method of hobbing, in combination with an emery grinder, was a good method.

Mr. L. A. Legros said that in motor-car practice a very great deal of difficulty was met with in cutting the teeth so as to be exactly correct in shape after they had been case-hardened. The wheels used in motor-cars were made of special steels, and had to be case-hardened to a considerable depth in order to stand the excessive pressure to which they were subjected; and in case-hardening, in spite of the precautions which were taken, they went somewhat out of shape.

He thought the author of the Paper had touched on a most important subject when he suggested that wheels should be finished by grinding, and that his remarks applied not to heavy mill gear, which could be finished in the old way, but to those wheels which were used in high-speed machinery. The wheel went out of shape in case-hardening; sometimes it went a little eccentric, but generally it went elliptical and buckled somewhat. Bevel gears were particularly troublesome. In the method adopted by the speaker's firm, the teeth were machined and the wheel treated in the case-hardening furnace and annealed, leaving a very large amount to be turned off after the wheel had been treated in the case-hardening furnace. The rest of the wheel was then machined to a considerable extent; then the teeth were hardened and the wheel machined again true to the finished teeth; that is, the bore and faces were trued to the teeth. In spite of that, distortion was still left in the wheel, and it was that distortion which could be removed by grinding only one-thousandth or two-thousandths of an inch away from the tooth. By removing that small amount he thought the wheels would be made quite quiet, where at present there was some slight noise. With spur-gearing a machine had been brought out by one of the German firms, Messrs. Reinecker, for grinding those teeth, and it was probable that for bevel gearing a similar machine would be of use.

Mr. LOUIS W. SMITH said that not very long ago he had much difficulty in deciding the best way of cutting cast-steel gears, because cast steel was not always equal in quality, but had hard places in it. He was in doubt as to whether it would not be best to use the hob, which was acknowledged to be the most accurate way for bronze and cast-iron. The question arose, however, owing to the difficulty of the inequality in steel, as to whether it was not too expensive to go in for hobs, even although gears of only a certain number of teeth had to be dealt with, which did not necessarily mean that it was compulsory to provide the whole eight cutters of a certain pitch, but only one or two. Under those circumstances it was questionable whether it was not cheaper to put an ordinary automatic gear-cutter down than the one the author recommended. He found, on making numerous tests about a year ago on some steel castings, that the whole cost in a year, of taking the hobs, the cutters and the speeds on the one machine as against the other, came out in favour of the single-disc cutter, although he quite acknowledged that for bronze and cast-iron and such materials hobbing was by far the best and most accurate method.

(Mr. Louis W. Smith.)

Those engineers who were not quite familiar with regard to motor-car work must have been very much interested in the grinding operation which the author had so clearly explained, but he supposed that that would only be applicable up to very small pitches. He thought the leading point in the Paper for the future was the special hob with the teeth let in, which had been fully explained. In his opinion there was absolutely no doubt that the hobbing of spur-wheels was quite established, and that the cutter of the future was one with high-speed inserted teeth, which got over the difficulty of cracked cutters and heavy expense in material.

Mr. E. A. RAINER thought that, as a good deal had been said about grinding, it might interest the members to know some of the experience his firm had had with regard to motor-car work. He thought, as most people did, that if they could only get a case-hardened gear true it would run quietly. He was sorry to say their experience did not bear out that assumption, and they had come to the conclusion that grinding, from a sound point of view, was of no advantage. They had found grinding to be satisfactory in the way the author had mentioned. It was possible to rough out a blank and grind it to shape after case-hardening. That certainly was an economical process; very good wheels could be turned out much cheaper, but he did not think they were any quieter. Perhaps with No. 4 or No. 5 Brown and Sharpe pitches, grinding was an advantage; the experience of his firm was that in smaller pitches, such as No. 6 or No. 7 Brown and Sharpe, grinding would not make the wheels any quieter, and he knew in several cases that other firms had thrown out gear grinders.

Mr. P. J. WORSLEY, Jun., said that in the course of his experience he had had a good deal to do with high-speed machinery, in which very small gears were used, running at a great rate, and it had been found necessary to make them as accurately as possible. He had had the advantage of seeing the hob which the author had described, and he would like to add his testimony to the extreme ingenuity which had been brought to bear in its construction. At the same time, he thought it was quite likely to carry a great deal of trouble with it. All engineers knew what a hob was if it was made out of the solid. It was not a very easy thing to make, as it had to be machine relieved or backed-off all over, both on the top and the sides of the teeth. In the author's hob those teeth were inserted blades, and, as had been described, the blades could be taken out, ground all over and put back again. That seemed an advantage, but it meant that each of the blades was practically a piece of a spiral, that is, it looked very much like one of the blades on a mowing machine. If that were taken out and ground all over so that it fitted into a spiral groove, it would be found it was an exceedingly difficult operation to perform. He thought the difficulty in correctly grinding that spiral tooth, more especially the part of the spiral tooth which fitted into the core of the hob, was more difficult than getting the solid hob tooth to the correct form. The author assumed that the difficulty of hardening a hob and obtaining the correct form after it had been hardened could not be overcome, but with the more recent methods of hardening, in which pyrometers could be used and in which certain temperatures could be much more accurately maintained, many of the difficulties of distorted hobs could be overcome. He thought there was still a great probability that the solid hob would be more useful for the hobbing machine than the hob with inserted teeth.

Mr. Daniel Adamson desired to bring to the notice of the author one difficulty in connection with spur-gearing, in the hope that some guidance would be given to the members on the subject. He referred to the fixing of a standard of inaccuracy for spur-gearing, or what was understood as a limit of error and some means by which it could be measured. Great attention had been given to the subject of limits of error for diameters and lengths by the Engineering Standards Committee, but he had not yet met with any generally accepted means for deciding whether a spur-wheel was accurately cut or not. For instance, it was very essential that the pitch of change-wheels should be accurate, not only from one tooth to another, but between any two teeth on the wheel up to half the circumference.

(Mr. Daniel Adamson.)
He suggested, for the author to criticise as a basis for a reasonable limit, one ten-thousandth of an inch per inch in diameter under or over the correct pitch; that is, if the wheel were 10 inches in diameter he suggested that no two teeth, either two adjacent teeth or any two teeth up to half the circumference of the wheel, should be away from the correct pitch by more than one thousandth of an inch under or over, the limit of error being $\frac{1}{500}$ inch. That limit he found was commercially obtainable. It might be the case that it was too large a limit, but it was evidently not too fine, because it had been obtained upon cut wheels without grinding.

Mr. WALTER DEAKIN thought the subject the author had introduced was of great interest to all the members, because the demand for correct gearing was increasing every day. Many of the points that had been mentioned in the Paper had been brought to light as the result of the demand for silent gearing in motor-cars. People were satisfied with very indifferent gearing years ago, and until the motor business had been considerably developed, ordinary cut-gearing satisfied the requirements of most people; but the quality of the gearing requisite in motor-cars had directed attention to the question of accuracy to a greater extent than had hitherto been the case.

There was one point in the Paper he would like to criticise with reference to the relative advantages of gearing cut by ordinary automatic gear-cutters and the hobbing process, which the author had particularly brought under their notice. It was stated (page 673), in enumerating the disadvantages of disc milling-cutters, that "as the cutter gets blunt, the centres of the cutter and work mandrel are forced apart, and the bottoms of the teeth describe a slight scroll." That was quite true with reference to the particular form of machine to which the author referred, but it was equally true with reference to the hobbing machine. It had been the experience of some motor-car builders that, after having milled out the teeth on the hobbing machine, it was necessary for them to put the wheels into an ordinary automatic gear-cutting machine and correct them. A great deal of that trouble arose from the expansion due to the bluntness of the cutters. In both cases he would suppose for the moment a commencement was made with a cold wheel and a cold hob, and after cutting was begun a large amount of heat was generated. That heat expanded the cutter into the wheel, and expanded the wheel blank on to the cutter. Both these processes took place in either of the machines. The author had said in reference to the hobbing machine, that with a good stiff machine, from two to three times the amount of metal could be removed per hour as with a machine using a disc milling-cutter of the same pitch. The metal could be removed, but when it was removed at such a rapid pace the element of inaccuracy was introduced, which all engineers desired to eliminate. If inaccuracy was to be eliminated, it was necessary that the work should be done slower. He thought the author appreciated that point, inasmuch as he had introduced a grinding-machine for correcting the inaccuracy resulting from that expansion. In dealing with that question he thought it would be a good thing to devise something effectually to take away the heat, and in that way one element of inaccuracy would be removed. That might be accomplished by a blast of cold air where lubrication was impracticable; but that did not do away with the difficulty of the bluntness of the teeth caused by the cutting action. In a hobbing-machine, although the hob gradually cut the whole circumference of the wheel as it rotated, when it got to the bottom of the teeth, the cutter, although it was a hob cutter, must necessarily be subject to the same disadvantages as the single cutter; that is, it became blunt by reason of the work it had done. So that, with regard to the superiority of one machine over the other, he did not think there was any difference between them; they would each produce inaccurate work if unduly forced.

With reference to the question of building up the hob for the generating machine, he thought that was open to a great many objections from a practical point of view. First of all there was the difficulty of getting the parts absolutely right, and from a practical point of view he did not feel at all sanguine as to the future of the made-up hob. The better plan would be to eliminate as far as possible the inaccuracies in the hardening. It was much better to

(Mr. Walter Deakin.)

throw one or two hobs away and get a right one, rather than to fix their hope upon a hob which was built up in pieces like the one which had been exhibited.

The description of the grinding-machine was very interesting, but personally he would like to see some practical results. In doing the work, it was necessary to get an abrasive material like corundum or something of that character, and form it more accurately than the cutter was formed, and constantly maintain it, if more accurate results were to be obtained; and he had not seen an abrasive wheel yet that did not wear. It was an interesting problem, and if the author had solved it he was sure every member would be grateful to him for his efforts. Personally he felt rather pessimistic about the solution of the problem in the way the author had suggested. Many attempts were made before wheels were cut by machines to correct them by grinding, and most of those attempts were failures. It must be said in favour of the proposal, however, that at the time he referred to, many of the abrasive materials were not of the excellent quality which were obtainable at the present time.

Mr. J. J. PODESTA, having ascertained that the author used a positive gear mechanism between the cutter and the blank, gave an item of personal experience showing the necessity for this. A worm-wheel was to be cut in the lathe. The blank was turned so as to give 100 V teeth at $\frac{5}{16}$ inch pitch on the pitch-line. The hob was made with a V thread of the same pitch and run between the lathe centres. The wheel-blank was mounted on the slide-rest, and rotated simply by the obliquity of the hob teeth. The hob of course began cutting at the point where the top of the teeth would be when the wheel was finished, and so the $\frac{5}{16}$ inch was marked off, not on the pitch-line, but at the tops of the teeth. Then too there must have occurred some slip, as the final result was 108 teeth. The special job in hand did not necessitate the rejection of the wheel, otherwise there might have been an interesting inquiry to ascertain exactly where those extra 8 teeth came from.

Mr. THOMAS CLARKSON thought it seemed rather extraordinary that, at the present time, engineers should be discussing gearing and the best way to cut teeth. But it was obvious that gearing was a subject which interested all classes of mechanical engineers, because it applied in such a variety of ways, from light, delicate watch mechanism to machine tools and heavy gearing used in mills. The hobbing appeared to be a natural development in the construction of a worm-wheel applied to a spur-wheel. He remembered many years ago, when he worked the Whitworth wheel-cutter, he got worm-wheels with a straight tooth cut with a single milling-cutter. Then at a further stage engineers began to cut their worm-wheels with a hob which gave larger bearing surfaces, while the next development was the application of putting the hob on the skew and getting a spur-wheel. He believed a great deal of the difficulty in getting an accurate spur-wheel with a hob lay in the hob itself. First of all, it was a difficult thing to make, as the members had already heard, and part of that difficulty lay in the hardening operation, especially if the hobs were large. Of course, with electrical furnaces and better means of hardening and tempering, the distortion problem would be reduced, but it would be recognised at once by practical men that the mere fact of having a hob rolling theoretically against a disc did not necessarily produce a true form of tooth.

Hardening the gears might be necessary and desirable in some cases, but he preferred to work with non-hardened gears, as he thought the result was not only quieter but was steadier in every way. Personally he did not use hardened gears. All engineers recognised the difficulties of grinding in ordinary cylindrical work, and in some cases it might be justifiable for gears. The principal difficulty makers had was with reference to bevels, which were expensive to make. They became distorted in the hardening operation; they had to be softened again in order to straighten them, and that did away to a large extent with the benefit of the hardening operation. He himself was using a non-hardened pinion, that is, a high grade non-hardened steel against a phosphor-bronze wheel.

Some years ago, when he thought of using a turbine for driving a steam-car, the question of reduction of speed at once came to the fore. He looked into the matter to some extent, and found that De Laval, who was using a turbine for driving machinery, used two

(Mr. Thomas Clarkson.)

screws forming really an extended double helical tooth, and he had seen the pinions running at several thousand revolutions a minute with practically no noise at all. The metal was not hardened, but it was very well lubricated. He thought, if the non-hardened gears were encased, the dust kept out, and clean oil kept in, they would last a very long time and give no trouble. Distortion or cracking was always liable to occur with hardened gears.

Mr. William H. Allen, Member of Council, thought the Paper had raised a deeply interesting discussion, which had led up to the great existing difficulty engineers experienced in running small wheels to the pitch of perfection which was now required. The author suggested that Fig. 2, Plate 21, depicted the earliest form of gearing. He did not know whether Mr. Humpage had travelled in the East; if he had he would have found in India, Persia, Mesopotamia and Egypt that that kind of wheel was in vogue at the present time, not as a relic of the old days but as a present-day process of manufacture. In going from Alexandria to Khartoum one noticed many thousands of those wheels at work on the Nile in the form of Sakiehs. He was surprised at seeing in the streets of Cairo quite a large industry being carried on with that particular form of gearing. His attention was called to the subject by seeing a log being attacked with a saw and an axe by a man in the street. He asked the Arab carpenter what he was going to do with it, and was told that in the course of three days it would be made into a true-shaped wheel. On visiting the man three days afterwards he was astonished at the remarkably quick way in which the man had converted the tree into a wheel as shown in Fig. 2. The following day he visited Heliopolis and saw the wheel at work. He doubted whether Manchester could do better than that at the present day. The words appeared above the author's drawing "Suggested earliest form of gearing." No doubt that was the earliest form of gearing, but it was an industry to-day.

Mr. William Sisson said it seemed to him from his standpoint that the grinding of small gears was a sort of counsel of despair.

The problem had been set by motor-car engineers, and very great credit was due to the author for the way in which he had dealt with it. He did not think, however, that engineers should be asked to tackle such a problem. Motor-car people treated their gears in a rough way which ordinary engineers with a conscience would never think of—he meant a mechanical conscience. He thought it would have been far better, if all the effervescence of ingenuity on the motor-car business had been directed to getting an engine that would work without a change-gear box something like the locomotive; engineers could not improve upon that.

With regard to the history of the subject, he remembered years ago being at the Hayle Foundry where large engines for pumping out Haarlem Lake were built, and there saw something which interested him greatly, namely a mortice worm-wheel on a boring machine. It had a cast-iron worm, but the worm-wheel was cogged with wood. Arising out of that, he could not help thinking that Mr. Saxon was not quite right in saying that the iron tooth wheel was always the largest. As far as he knew, the cogged or mortice wheel of a pair was usually the larger, on the ground of both strength and durability; the former because the root thickness of the tooth of the larger wheel was greater than that of the pinion or smaller wheel. and the latter because the greater number of teeth in the wheel distributed the wear of the wood teeth.

With regard to hobbing, he wished to ask what angle the worm on the hob shaft was set to. There were an infinite number of spirals on the tooth: to which spiral angle did he set the axis of the hob, and what size was the worm hob made in proportion to the pitch? It ought to be an infinite diameter in theory, but if it were made very small it was quite certain that it would be impossible to cut deeper properly because it would foul. There must be a sort of compromise in the size of the worm-cutter, the generating cylinder so to speak, in proportion to the pitch.

Mr. Charles Pendlebury, in dealing with the historical part of the Paper, said he noticed that Messrs. Gould and Eberhardt were credited (page 662) with bringing out presumably the first automatic

(Mr. Charles Pendlebury.)
gear-cutting machine. He happened to know personally that Messrs. Craven Brothers, of Manchester, so long ago as 1877 made an absolutely automatic gear-cutting machine which was used in connection with change wheels for cotton spinning. It was on very much the same lines as the present one, but he did not know the name of the inventor.

Mr. HUMPAGE, in reply, said that Mr. Christopher James had pointed out that his firm was making a machine which he presumed was not a hobbing machine, but a machine with a single cutter or cutters. If Mr. James would cut a big wheel having a large number of teeth, with a single formed cutter, he would find that by the time he got round the wheel the cutting edges would have worn considerably. He was inclined to think that the more cutting points on a cutter, if they all did their duty, meant a longer life for the cutter and more accuracy in the wheel when it was finished. In reply to Mr. Saxon's remarks, it was of course impossible for him to deal in his Paper with everything that he knew on the subject. Mr. Saxon had lived and worked in his particular line of business, and knew considerably more about it than the author. He only spoke from his own knowledge, and the information that he could get from others. Large gearing had undoubtedly been replaced by cotton ropes and belts, owing to the great demand for higher speeds with less noise. When however large wheels could be more accurately machined and the cost and noise reduced, they would gradually come into favour again, owing to their efficiency being at least 10 per cent. higher, and their cost of maintenance considerably less than that of cotton ropes.

In reply to Mr. Amos (page 680), in his opinion better gears could be cut with a hobbing cutter than with any other cutter, because of the number of teeth in the hob. He did not think the single or disc cutter had a chance with the hobbing cutter for either quantity or quality of work done, a point he would deal with later on when referring to hard metals.

In reply to Mr. Legros, up to the present time the wheels he had ground had been small, as he had only been at work on his idea for a few months. He did not mean to say that his machine would revolutionise the world so far as that kind of work was concerned. He did not know at present what its limits were, because it was in its very early stages, but up to the present time after hobbing wheels, and also cutting them with single cutters, he could always show an improvement by his method of grinding, both in soft wheels and in hard wheels. Since writing the Paper he had dealt with some case-hardened wheels for one of the leading motor-car manufacturers which were as much as $\frac{1}{32}$ inch oval after hardening, and in his opinion had made a very good job of them. Running them as high as he could with a fairly good load he could not hear the teeth at all; they were absolutely as silent as a belt. He did not say, however, that they were absolutely perfect; but a good deal more time was spent on the wheels than the ones referred to in his Paper, namely, eight minutes. This however was a natural result, as they were the first case-hardened wheels he had ever dealt with. He believed the wear on the corundum worm was very little indeed. He ground a pair of wheels, and after examination he could not detect more than $\frac{1}{1000}$th of an inch of wear, although he shifted the corundum worm after each wheel had been ground. But as the members would understand, it made a mark on the corundum worm starting from the right-hand side down the thread, from the top to the bottom and up again, so that about one-third or one-fourth of the circumference of the corundum worm showed a line just as if a black lead pencil had been drawn down it. That could be improved if the wheel was traversed across the face of the corrundum worm at the same rate, like a wheel meshing with a rack.

With regard to Mr. L. W. Smith's remarks (page 681), there could be no doubt that hard wheels were more difficult to cut, and punished the cutters more than those in softer metals. If the cutting edge of a tooth in the hob were dull or broken, a piece of metal was left on each involute tooth; but if the man who was working the hobbing machine would turn the cutter round one-tenth or one-twelfth of its revolution for every wheel cut, he brought other teeth of the hob into use that were not doing so much work, and in that way the cutter could be made to last about ten to twenty times as long. He

(Mr. Humpage.)
believed that was not generally understood by people who worked hobbing machines; they thought there were plenty of teeth and it did not matter, but when the hobs were examined after half a dozen wheels had been cut it would be found that there were one or two teeth only with their corners worn. He advised those who worked the machine to move the hob round. It did not take a minute to perform that operation, and the life of the cutter was thereby greatly lengthened, while better working was obtained. As it was an expensive tool, very special care was required, otherwise the up-keep of the cutters would run into a big item.

He had very little experience of cutting hard steels, and those were for motor-car manufacturers, who used a metal of very high tensile strain, which punished the cutters greatly. It was mentioned in the Paper that if inserted blades were fixed in the body of a hob, and each blade was dealt with separately, they could be treated better than a solid hob, especially if they were ground all over after hardening. All engineers knew that in working a machine, even after grinding a tool, if an oil stone were rubbed on the sides as well as the top, the roughness would be taken off and a better finish obtained. So it was with a hob. If it were taken straight out of the fire and sand-blasted, only the front of it was ground off; a burr was left on the rest of it, and naturally a very fine finish could not be obtained. He had found in grinding a hob that if a great pressure were brought to bear upon it when it was being sharpened, it threw a considerable burr into the space, and in cutting gun-metal wheels he found that these burrs did not wear off until the hob got half an inch down the face of the wheel. That required to be looked after, as in the ordinary cutter, by the man who had charge of the machine.

With regard to Mr. Rainer's remarks (page 682), the method adopted by Mr. Rainer's firm was evidently that of grinding one tooth at a time, and, if this were so, the author quite agreed that it would be impossible to make silent running gears, but he still maintained that his own system of generating all teeth simultaneously, as described in the Paper, after being roughed out by the hobbing machine, was the best method of getting silent running gears. In his own case he put the feed on about six times the rate of the ordinary gear cutter for roughing, which was a considerable saving in time, as one did not trouble so much about the finish, because that was left to the grinder. All engineers knew that after a wheel had been cut with teeth it was often found out of truth. Therefore to try and finish that wheel at one cut, in any machine, even in a hobbing machine, which was the best known method, was wrong. Two cuts or more as they knew were taken off every spindle to make a good job, and it should be so with the teeth of gear wheels.

In reply to Mr. Worsley, when he saw the hob in its original state, the blades were inserted in spiral grooves naturally following the same system as the solid hob, so that, when the hob was tilted up, the slot between the teeth was horizontal. In the second type of cutter as exhibited the blades were not made in that fashion at all; the grooves and the blades were absolutely straight, and there was no spiral at all, which cheapened the manufacture. In this particular case the hob was not inclined at all, but it was simply put horizontally in the hobbing machine and allowed to go through; so that the blades were perfect racks in every shape and form. The pitch of the hob in the whole of its length was certainly not a quarter of a thousandth out.

With regard to the question of solid hobs, he had found them made by very good makers, who used the pyrometer, etc., to be four to six thousandths out in pitch, and he had even found them out a good deal more than that. He was sure the members would agree with him that it was impossible to cut a correct wheel with an incorrect pitch cutter; any rack that was out of pitch could not possibly work smoothly with a wheel that was of correct pitch. Therefore it seemed to him that to cut a good wheel it was necessary that the tool must be carefully made as regards pitch and angle. Although the point had not been raised, he would like to say that some people had been hollowing out the sides of the cutter, making a curve so that they could take a little more off the points of the teeth. But directly they got off a straight line trouble was experienced, especially in curve making. He was afraid it was more guess work than anything else; a good job might or might not be obtained. He therefore thought the best thing was to keep to a straight, angular side and not to depart from it.

(Mr. Humpage.)

In reply to Mr. Adamson (page 683), he would say that with a good hobbing machine greater accuracy than he had suggested could always be obtained, and by grinding, both the pitch and the involute curves of the teeth were much improved. He would prefer to leave the question of fixing a limit of error to a Committee, if it were considered of sufficient importance.

With regard to Mr. Deakin's remarks (page 684), he did not agree that the hob had the same disadvantage as the disc cutter, because the hob when blunt would cut a slight taper and not a scroll. There was no first and last tooth cut by the hobbing machine, and when cutting steel gears the heat generated was entirely carried away by the lubricant used; therefore the blank and cutter did not expand into each other. When cutting cast-iron gears the heat was evenly generated and distributed and thrown off all round the rim, whereas a disc milling-cutter generated heat in one spot only. Also the hob, having more cutting points, each of which had much less to do, was enabled to distribute the heat, throw it off much more quickly than the disc cutter, and retain its edge much longer. He did not agree that the element of inaccuracy was introduced in removing two or three times the amount of metal, provided that the hob was revolved and fed at a speed which ensured undue heat. This rate of removing metal was always two or three times as fast as the disc milling-cutter of the same pitch.

With respect to the rapid wear of grinding wheels, he would be quite satisfied in getting as good results when grinding the involute teeth of gears, as Mr. Deakin and others had got in finishing spindles and such-like accurate work on their grinding machines. He quite agreed that it was impossible to find any substance that would not wear, but in spite of this wear the most accurate work obtainable was being done by grinding machines. He maintained that a solid hob could not be made so accurate for pitch and with smooth sides and correct angles which finished the involute as the built-up hob described in the Paper.

In regard to Mr. Podesta's questions, as described in the Paper, the blank and hob were suitably geared together.

Mr. Clarkson suggested (page 687) the use of non-hardened gears, and he quite agreed with him, but where case-hardened wheels were used he thought grinding the involute teeth after hardening was absolutely necessary.

With regard to Mr. Allen's remarks, he had never seen gears of the crude form shown in Figs. 1 and 2, Plate 21; these were entirely his own suggestions, and he was glad to know that something of this kind had actually been made.

In reply to Mr. Sisson, he thought that so long as petrol motors were used for motor-cars, and until something better than change-speed gears to give the speeds required was found, the gear wheels must be made of small size and of light construction to reduce weight, and it was necessary, owing to the heavy duty they had to perform, to case-harden the teeth; therefore grinding with an abrasive wheel could be the only satisfactory way of finishing the teeth. With regard to hobbing, the tangent of the angle to which the axis of the hob shaft was set was found by dividing the circular pitch of the hob by its pitch circumference. The larger the hob, the more cutting points and the greater the accuracy of the work done, the smaller the hob the greater the cutting speed. There was no rule, but the majority of makers adopted the smallest convenient size.

He was interested to learn that Messrs. Craven Brothers, of Manchester, had made an automatic gear cutting machine about the same year as Messrs. Gould and Eberhardt (page 662).

A METHOD OF DETECTING THE BENDING OF COLUMNS:

INCLUDING A DESCRIPTION OF THE SPHINGOMETER.

BY MR. C. A. M. SMITH, B.SC., *Associate Member*, ASSISTANT PROFESSOR OF THE EAST LONDON COLLEGE (UNIVERSITY OF LONDON)

In the course of certain investigations upon materials now being conducted at the East London College (University of London), it became necessary to determine accurately the load at which a strut of any desired ratio of length to diameter commenced to buckle. The importance of determining this critical load is considerable. In the case of a column the whole of Euler's theory is built up upon the assumption that under some critical load P the strut is in equilibrium. He says that if the end-load has a certain value, say P, then the deflection will persist; if it has a smaller value P_1 the strut will straighten itself. If it has a greater value P_2, the deflection will increase. The general equation to the Euler formula is :—

$$P = \frac{\pi^2 EI}{L^2}$$

where

P = the critical load as above,

E = Young's Modulus of Elasticity,

I = Moment of Inertia of cross section of column,

L = Length of column.

There are two main points in connection with this formula which the author wishes to emphasize:—

(1) That the value of P is dependent upon Young's Modulus of Elasticity.

(2) That Euler's theory assumes that the strut is long in proportion to its diameter and the load perfectly axial.

Therefore, in order to check the theory by experimental results, it is necessary to be able to find for each specimen:—

(*a*) A value for E. This is also needed for various comparisons.

(*b*) To ensure that the load is (as nearly as possible) truly axial.

(*c*) To note the exact load at which bending of the strut commences.*

(*d*) A value of E and the exact load at which bending commences for struts of varying ratios of length to diameter.

(*e*) Some means of measuring (*a*) and (*c*) which would enable the specimen to be a minimum length.

Various efforts were made to do (*a*), (*c*), and (*d*), with the existing forms of measuring apparatus. Clearly (*a*) offered no difficulties; (*d*) required that considerable modifications would need to be effected in any of the instruments in common use for doing (*a*). It quickly became evident that any method involving microscopes was too expensive. It was not difficult to measure strains with some of the mirror type of instruments, but there was a great deal of work involved in the calibration of such apparatus. As far as the author could discover there was nothing available to accomplish (*c*). It was therefore determined to construct a new type of instrument which, it is believed, enables (*a*) (*c*) (*d*) and (*e*) to be accomplished with but little trouble to the observer. The instrument, which has hitherto been called a "sphingometer," can be quite easily used for

* For it is clear that, when once curvature is induced in a specimen of ordinary dimensions, the load does not act along the axis of the specimen. And the curvature induced might continue to increase until the specimen buckled under the action of the load. It is by no means certain that such buckling would take place rapidly. It was therefore believed that a true measure of the actual critical load would be obtained, if it could be definitely determined under what load the first flexure of the specimen took place.

the purposes to which an ordinary extensometer is put. Plate 28 and the following description of the instrument will enable these points to be discussed.

The instrument is fastened, Fig. 1, to a specimen A by six set-screws B as shown. These are at exactly 120°. They pass through gun-metal (probably cast-iron would do as well for this purpose) carriers C, which are thus fastened to the ends of the specimen. On these carriers C are carried three separate, but exactly similar and quite simple, twisted strips, encased, and each carrying a mirror D. A separate section of the strip, mirror, case and calibrating apparatus is shown in Fig. 2. A metal ribbon is twisted for about one-half of its length in a right-hand direction, and for the other half in a left-hand direction. The axis of the strip is kept parallel to the axis of the specimen by means of the attachment in the carriers C, Fig. 1. A mirror is attached to the centre of the twisted strip, whereby its rotation may be measured.

This is the general principle of the means of measuring an extension or shortening of the specimen. The strip might be attached directly to the carriers C, and any motion of those points of the carriers to which the strip is attached would be recorded by the angular twist of the mirror. A measure of this is easily obtained by using the weightless lever—a beam of light. But when the above arrangement is carried out (as indeed it was at first) then there is difficulty in calibration. What extension of the specimen does one division on the scale used for the beam of light mean? Therefore one end of the strip is not attached directly to the carrier C but to a fitting adapted to slide without rotation in a hole in the carrier. This fitting receives a known longitudinal motion from a screw * with a divided micrometer head.

To calibrate the instrument the ray of light is caused to move through a scale length. The longitudinal motion necessary to produce this rotation is read off on the micrometer head. The

* The pitch of this screw may be, of course, different for different degrees of sensitiveness required. There seemed no difficulty in obtaining a screw cut accurately enough for the purpose.

extension or shortening of the space between the two points of the carrier which corresponds to one scale division motion of the ray of light is thus determined. In the instrument shown, Plate 28,

FIG. 3.—*Tensile Test.*
Stress-Strain Curves in three Planes.

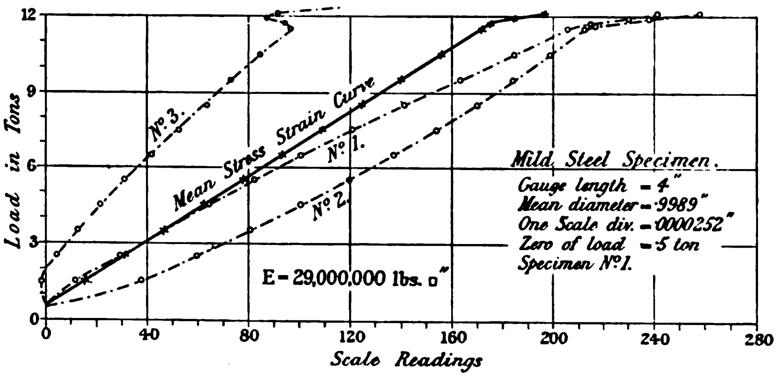
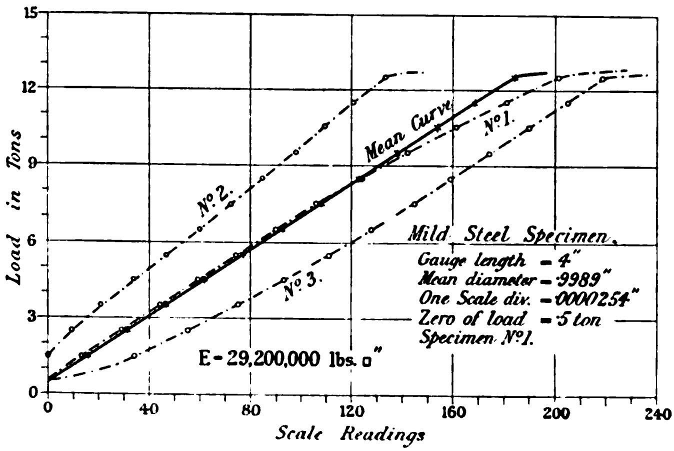


FIG. 4.—*Tensile Test.*
Stress-Strain Curves in three Planes.



three such twisted strips, parallel to each other and the axes of the specimen, are shown. Any bending of the specimen will then be at once detected by the unequal movement of the strips.

FIG. 5.—*Compression Test.*

Stress-Strain Curves in three Planes.

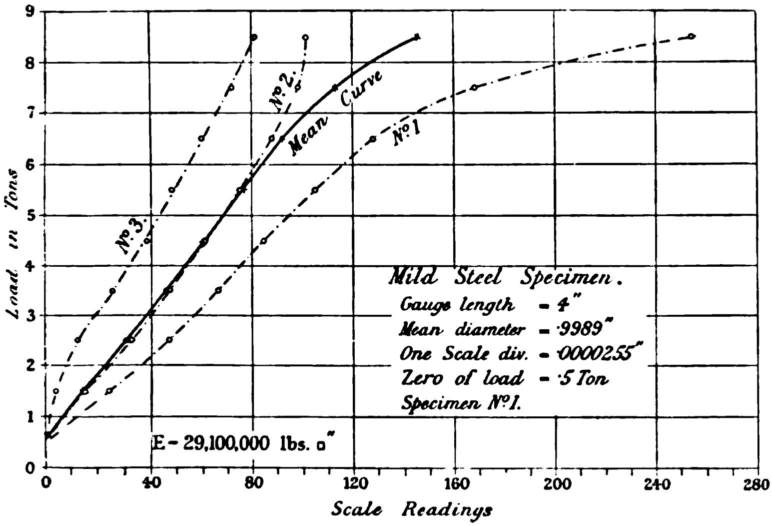
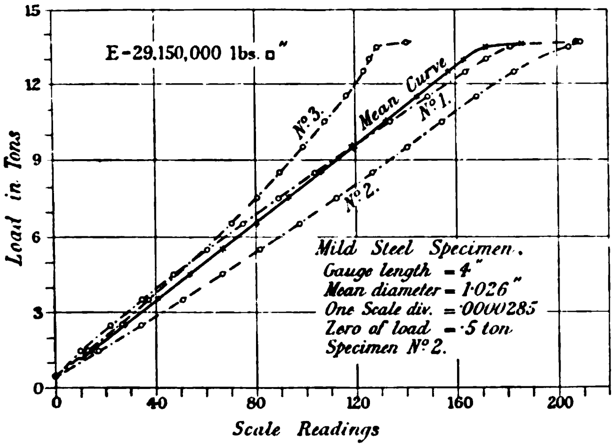


FIG. 6.—*Compression Test.*

Stress-Strain Curves in three Planes.



Bending in Tension.—In order to test the instrument, it has been repeatedly tried with specimens placed in tension. The specimens are screwed, and the load is made as nearly axial as is possible by means of a socket joint. The curves, Figs. 3 and 4 (page 700) are shown, and the results of the tests throughout gave similar results. It will be seen that the specimen is either yielding or bending unequally in the three planes. A great deal of this may be due to the fact that no great care was taken to have a good fit at the screwed ends of the specimen.

The mean curve gives a noticeable result. Within the elastic limit it is a perfect straight line. Various values, however, of E are obtained unless the mean curve be taken. Thus in curve 1, calculating for E at the yield point, $E_1 = 26{,}900{,}000$ lbs. per square inch; similarly for curve 2, $E_2 = 40{,}600{,}000$ lbs. per square inch; and for curve 3, $E_3 = 24{,}600{,}000$ lbs. per square inch; and for the mean curve, E mean $= 29{,}200{,}000$ lbs. per square inch. The stress-strain diagrams for curves 1, 2, 3 are probably not to be read directly. The three strips of the instrument measure extensions so long as the column does not bend. If the column bends, the strips measure an extension from which can be calculated the extensions of the specimen—knowing the radius of action of the strip and the diameter of the specimen—but they do not read this directly.*

A result of a test in compression, Fig. 5 (page 701), is also given. It will be seen that at some definite load, well below its yield-point in tension, the material commenced as a whole to bend. This specimen did not fit well on the end cap (described later), and probably there was non-axial loading. With this curve contrast Fig. 6, where more nearly true axial loading was obtained. In the tests, each scale division meant an extension of about 0·0000254 inch of the specimen. It is a very simple matter to vary the degree of sensitiveness of the instrument. Moving the scale nearer or farther away is an obvious method, and the winding of the strip can also be so varied that a division may read quite a small strain. It was usual, at first, to read

* The above values are calculated under the assumption that there is no bending of the specimen.

to a scale of 0·00000926 inch equal one division (say $\frac{1}{100,000}$th of an inch).

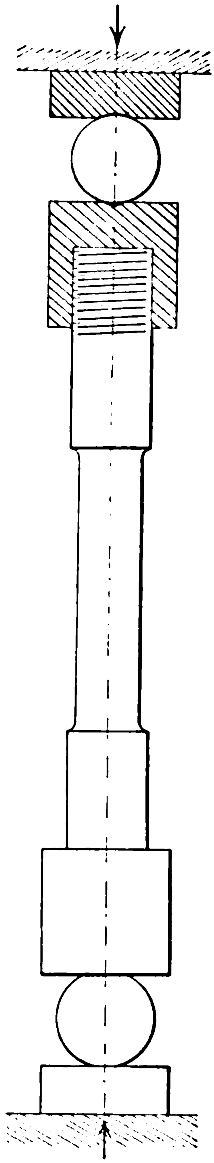
It was found to be quite possible to so wind the strips that the three beams of light rested on one scale, and that a division of the scale meant the same extension for each strip to within 1 per cent. If this were not sufficiently accurate, the difference of the scale divisions could be made to mean the same strain by using a reduction factor. A small Nernst lamp was used to illuminate the strips, and there was no trouble in requiring any special focussing apparatus.

To Secure Axial Loading.

It was suggested above that axial loading is desirable in the experiments now being made. To secure this the following arrangement is adopted. Screwed caps of hard steel are placed on the ends of the specimen, Fig. 7. Truly axial with the screw is a small nick on the head. On this is placed a ball. A cap, with a similar nick, is on the ball as shown. Provided that the screw thread of the specimen is truly cut to fit the cap, this device answers well, Fig. 6 (page 701). But it requires that the specimen be a tight fit in the cap, or poor results are obtained, Fig. 5. The author would, however, prefer some method in which the screw thread is not used.

In conclusion, the author wishes to thank Professor D. A. Low, *Member*, and Professor J. T. Morris, for their encouragement during the many experiments. To Messrs. E. Tindall Cook, Instrument Makers, of Leyton, are due great thanks for the very accurate and reliable

Fig. 7.
Arrangement to secure Axial Loading.



workmanship of the instrument. Mr. W. J. Webb, B.Sc., has recorded many of the tests and, with the help of Mr. E. J. Surman, has prepared all the diagrams. The authorities of the East London College have kindly afforded the necessary facilities for conducting the work.

The Paper is illustrated by Plate 28 and 5 Figs. in the letterpress, and is accompanied by 2 Appendices with 1 Fig.

APPENDIX I.

(A Note on the Numerical Value of E and the Time Effect on Strains.)

In the early experiments the author was surprised at the wide range in the value of E obtained for steel. This caused him to search through records, and he came across the following results: "A Report of Tests on Metals" for 1881, made on the Government testing-machine at Watertown, Mass., U.S.A., shows that the value of E for W.I. calculated on a bar 80 inches long varies from 25,000,000 to 37,209,300 lbs.—a variation of 50 per cent. of the lowest amount. Professor Burr, of Columbia, U.S.A., points out that "this fact has a most important bearing on those theories of continuous girders which assume E to be constant."

A more astonishing series of results are those given by Professor Woodward in "The Saint Louis Bridge." He gives the results of 67 specimens (W.I.), which varied from 6 to 18 inches in length and from 0·045 to 1·13 inches in diameter, and from 17 different producers. He found that the value of E varied from 9,500,000 lbs. per square inch to 65,500,000, and some of the widest variations were in specimens of the same brand.

From an examination of many results it would appear that the value of E (for tension) for good wrought-iron may be taken, under ordinary circumstances, to lie between 25,000,000 and 30,000,000 lbs.

per square inch, with extreme values arising from a variation of modes of manufacture, chemical constitution, size of bar, etc., lying some distance either side of these limits.

With regard to steel, Professor Ricketts (1886) in the Rensselaer Polytechnic Institute made some tests, which are fully reported by the Am.Soc.C.E. (1887). He finds that with two specimens with a high percentage of carbon (Bessemer steel) the tensile elastic limits are higher than those for compression. In Mr. Kirkaldy's experiments on steel in compression the specimens were supported in a trough. They were 100 inches long and 2·25 inches wide. The values of E obtained for compression are larger than those obtained for tension. In the compression specimens the behaviour is very irregular, and there seems to be no true elastic limit. Our tests go to show that this may be due to non-axial loading.

"The Steel Committee of Civil Engineers" (British) in 1868 had tested specimens 1·382 inches diameter and 50 inches long (36 diameters). On crucible steel the value for E in compression varied from 31,500,000 to 28,000,000. Mean value obtained was 29,474,000.

It will be shown below that, in the accepted strut formulæ, a great deal depends on the value of E. It has been shown above, however, that this is a very variable quantity. In attempting to obtain empirical constants, it is therefore possible that differences in the value of P, obtained from various experiments under apparently similar conditions, may be due to variations in the value of E for the specimens used.

The Strut Formulæ.—The attention of engineers was drawn to the problem of the design of struts by the Quebec Bridge disaster. Professor W. E. Lilly, D.Sc. (of Trinity College, Dublin), has published* the results and deductions made from a number of tests which he conducted. Of the various reasons for the collapse suggested at the time of the failure the author will mention only one, viz. "that

* "Engineering," 10th January 1908, page 37.

Euler's formula only takes into consideration E, and does not involve the strength of the material." It is probably the yield-point of the material that should be taken into account rather than the ultimate strength.

Professor Lilly shows that in the usually adopted Rankine-Gordon formula for struts

$$p = \frac{f}{1 + c\left(\frac{l}{k}\right)^2}$$

$$\text{and } c = \frac{mF}{\pi^2 E}$$

where F = ultimate strength in compression of material in pounds per square inch, and m = a constant.

The ultimate strength of the material in compression is very hard to define. It is therefore an advantage to use the yield-point rather than ultimate strength for comparative purposes. And, in experiments to compare the above formula with actual results, it would seem to be an advantage to determine both E and the yield-point for the materials used.

The Time Effect on Strains.—Experiments will show that if a piece of wrought iron or steel be under tensile stress, nearly equal to its ultimate resistance and held in that condition, then extension will increase as time elapses.

Professor Thurston conducted experiments on flexure. A bar (it was an alloy of tin and copper) sustained 1,485 lbs. at the centre for thirteen minutes, and then failed. A second bar (a different alloy of tin and copper) was loaded at the centre. The deflection at first was 1·294 inches. After three days it increased to 3·00 inches; then the bar failed under the original load. Professor Thurston also found that 60 per cent. of the ordinary "breaking load" of seasoned pine caused failure at the end of eight, twelve, and fifteen months.

The effect of continued flexure upon columns made of steel has apparently not been closely observed.

It seems certain that the molecules under the greatest stress "flow" over each other to some extent. It is probable that the fatigue of metals is associated intimately with the phenomenon of "flow" of solids.

APPENDIX II.

Properties of Ductile Materials.

There are innumerable records of tests carried out on the simple tension, compression and shearing of materials.

In the matter of compound stresses, such as exist in many instances (e.g. a boiler, crank-shaft, etc.), the author has attempted to show, from results obtained by Guest, the effect of a second stress simultaneously applied at right angles to the first stress, on the capability of the material to stand the larger stress.*

In the ordinary tension, compression and shearing tests there is a sharp contrast in the behaviour of ductile and brittle materials.

Since the tests on ductile materials show that the rupture surfaces are, to a large extent, coincident with the surfaces of maximum shearing, it would seem that the final failure takes place somewhat in the nature of a viscous flow. As further evidence in support of this theory, Tresca showed that a ductile material eventually behaves very much in the manner of a very viscous fluid.

Guest has advanced, as the result of experimental work, the somewhat startling theory of elastic strength, that the condition of yielding is the existence of a shearing stress of specific amount. Belief in the truth of this has gradually gained ground and supplanted the trust in Rankine's theories.

* "Engineering," 10th July 1908.

In wrought-iron and steel the ultimate resistance to shearing is probably about three-fourths the ultimate resistance to tension of the same material.*

The Yield-Point.—There is considerable diversity of opinion as to what really is the yield-point—as many as five different yield-points have been proposed.

Take the case of the specimen in tension in a testing machine.

As the load is gradually increased, and measurement taken of the extension, it is found that until a certain load is reached, the strain is proportional to the load. Beyond this point, this proportionality no longer exists. Popplewell calls this point the "limit of proportionality." The elastic limit, which term is often incorrectly applied to this point, occurs at a somewhat lower load.

Fremont, however, holds that it is merely want of precision and accuracy of measurement which prevents these points being coincident. By means of optical observations on the physical appearance of the material under test, he arrives at what he contends to be the only true elastic limit. The author's experiments in many cases tend also to support this theory.

The yield-point can, the author thinks, be best defined as the load at which the specimen continues to stretch without further increase in the load. This continuous strain can be very readily observed in the sphingometer. Too much importance cannot be attached to the necessity of having some well defined, generally accepted yield-point.

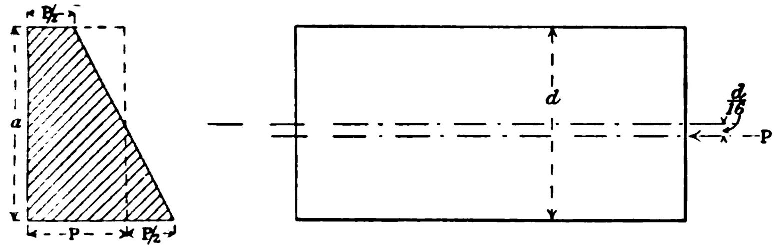
The yield-point is becoming an important factor in specifications, and for many reasons it would be preferable to take the yield-point as the criterion of strength of a ductile material rather than the ultimate strength.

It may be objected that the experiments quoted in the Paper show that there are local variations of strain, that is, that the specimen in tension does not draw out in the same manner on all sides. If there is not a truly axial load, there will also be considerable

* Cotteril's "Applied Mechanics," page 425.

variations in stress. With a rod of circular section, a deviation from the axis of $\frac{1}{16}$ the diameter of the rod increases the effect of a thrust or pull 50 per cent., Fig. 8. Therefore it is conceivable that it is the variation in stress that causes the variation in strain shown. The effect may be due to local variations in the material, which cause small volumes of the material to reach the yield-point prematurely. This would account for the gradual, instead of sharply defined yield-point which is commented upon in all text-books on materials. Against the variation of stress theory must be placed the proven

FIG. 8.
The Effect of Non-Axial Load.



fact that, if a specimen be strained beyond the elastic limit, the material does not show this gradual yield-point. This probably means that the local hardness or variation in material which gave rise to the well-known "elastic limit effect" would be strained beyond the yield-point. So that on a second testing the whole material yields together.

It is, however, more satisfactory to use the yield-point rather than the elastic limit as a criterion of strength. It would be, of course, an advantage to use annealed specimens in all tests, but some difficulty is obtained in getting them true.

Discussion.

On the motion of the PRESIDENT, a hearty vote of thanks was accorded to Professor Smith for his exceedingly interesting Paper.

Professor W. E. LILLY had much pleasure in congratulating the author on the exceedingly delicate and interesting type of instrument he had shown. The sphingometer was quite new to him, and he was surprised at the exceeding great delicacy of its measurements. He had never personally been able to obtain measurements to one-hundred thousandth part of an inch in any instrument he had used. Looked at from that point of view, the instrument itself was a distinct advance. It was, however, more in the results which had been obtained with the instrument than with the instrument itself in which he was interested. The author had deduced certain values of E, Young's Modulus of Elasticity, from his measurements, and showed that in a tension test it was possible with the instrument to get as many as three different values for E, Young's Modulus of Elasticity. He had always been accustomed to look upon Young's Modulus as a constant, and to look for that constant in very much the same way as one looked for the constant of gravity or any other physical constant. If it was not constant, Hooke's Law would disappear altogether, and engineers would have no reason for using that law at all.

He was glad to find that the average of the readings the author obtained gave a constant, and from that point of view the instrument corrected what investigators had already been able to find out by direct measurement with other forms of extensometers. If the instrument had shown that, instead of getting a straight line, a curve was obtained, under those conditions they would no longer have been able to hold Hooke's Law. He thought that in using an instrument of the kind described its over-sensitiveness was in some ways against it. He did not mean to say an instrument could be used which was too sensitive, but what he did say was that on a specimen of the kind the author had exhibited, no consideration was taken of what was happening to the bar itself, which was described as in a state of strain. The bar might be variously strained in different parts, and with the extreme accuracy of the instrument those minute changes in the strains were measured in different parts of the bar; whereas what was usually done when looking for Young's Modulus was to look for the average value of the strain for a certain length, and therefore when a measurement of a piece of wire or a small bar was made, the inaccuracies which the instrument showed up were got rid of. In ordinary practical work one had to look at the average value rather than to any particular value which one happened to get for one part of the bar.

He was a little doubtful as to the use of the instrument for the testing of columns, because certain assumptions were made which the investigator did not know would hold true. A particular bar was taken, and certain things were assumed about it as to its straightness and homogeneity before the test was made. If the bar were variously strained before it was tested, then the measurements would show that the bar had already got a curvature before the applied load was put on, and therefore really accurate deductions could not be made from the measurements taken.

The author had remarked on page 697 with regard to Euler's formula, and incidentally in connection with that he mentioned his (Professor Lilly's) name and some of the work he had done. In using Euler's formula, as the author showed, there was a critical value of load under which the strut was in equilibrium. If it were less than that the column was supposed to be straight; if it were greater it was supposed to bend and eventually break. He had tested a large number of round-ended columns, and he had never been able to find the critical load, and he confessed he did not believe it existed. He did not think Euler's analysis in that particular result was correct. The value of the critical load given by Euler's formula was the load that produced failure in a long column—that was certainly correct from the experiments made; when, however, loads were put on to the column there was always some deflection, and the deflection was some function of the load if other things were constant. Euler's formula showed that the deflection of the column was independent of

(Professor W. E. Lilly.)

the variation in the load, and once it had got to its critical value the column would break. He could not say that he believed that, and he had spent a considerable time in trying to get what was called the critical load. He desired to point out that, in mentioning the Rankine formula, the author referred to the value of F, the crushing strength of the material. This was very difficult to define, more especially for ductile materials. In the testing of columns it would be found that the constant which had to be adopted in the Rankine formula, the value of F referred to, must be found incidentally from the experiment, that is, the value of F was chosen so as to give the average curve. For steel and like metals he found a very good value to take was the tensile strength of the material for the value F. The crushing strength of the material was that stress which caused it to flow, or fracture, and it had no relation whatever to the value of F used in the Rankine formula.

With regard to the yield-point, in testing the columns the yield-point certainly had a great deal to do with the strength of the column upon a certain range of its length. For values of the length divided by the radius of gyration from 30 up to about 80, the ductility of the material had a great influence upon what the strength of the column would be, and two things then had to be considered, the strength of the yield-point and its ductility.

Dr. W. Cawthorne Unwin noticed that the author had found in some tests a great range in the value of Young's coefficient for steel, and in Appendix 1 (page 704) he referred to a Report of Tests on Metals, for 1881, made on the Government testing-machine at Watertown, on a bar 80 inches long. He did not exactly know the details of those experiments, but a quite similar result was obtained earlier in the tests of the steel made for the St. Louis Bridge. Great trouble was taken in the testing of the steel for the St. Louis Bridge, because an exceptionally hard quality of steel was used, and the matter was one of great importance. As far as his recollection went, the value of Young's coefficient in those tests varied from 25 million to 37 million lbs. That was very striking, because observers on this side of the Atlantic had not obtained such results.

He confessed his own conviction was that the difference was due to an error in the American measurements. A very delicate instrument was used in measuring the extensions, but unfortunately the extensions were observed on one side only of the test-bar. Extensions measured in that way were unreliable.

Mr. W. G. Kirkaldy said he desired to express the opinion that the instrument described by the author was a beautiful piece of mechanical work. The method of rotating the mirror by the spiral strip was exceedingly ingenious, and appealed to him as a nice piece of practical work. Another point which appealed to him was the very ready method of calibrating the value of the scale. By rotating the micrometer head through so many divisions, the travel of the spot of light was seen, and that seemed to him of great practical importance, because on any experiment the value of the readings could be obtained at once. The instrument appeared to be much more practical than the ordinary microscope form of instrument. Very fine results could be obtained with the latter form, but it required a great deal of care in handling.

Professor C. A. M. Smith, in reply, stated that Professor Lilly had said he did not quite follow what the three values given in the Paper meant. He (the author) had given the three values for the purpose of showing that the value did vary round the bar. Professor Lilly also said the instrument was so delicate that it would not record what the actual value was; but that was the whole purpose of the mean curve, which showed it most distinctly and quite accurately. In the Paper it was stated that he thought there was a variation of stress going on in the bar, which he would show quite clearly in Figs. 9 and 10 (page 714). Assuming there were two solid bars, A and B, if a force were applied not directly on the centre but somewhere as at K, the result would be that B would stretch up as in Fig. 10, and that the bar B would stretch more than the bar A. That was what he had tried to show in the Paper, but evidently Professor Lilly did not quite follow it. The result was quite accurate as given from the mean of the three curves.

(Professor C. A. M. Smith.)

Professor Lilly had also said that the instrument was too sensitive, whereas Mr. Kirkaldy said that it was accurate, because it was sensitive. Dr. Unwin had shown how misleading and inaccurate values of E had been obtained in America with instruments which were not reliable. As a matter of fact, the sensitiveness of the sphingometer could be varied at will, and its accuracy was always the same. Professor Lilly also thought the instrument would not be useful for practical work, but he could assure him that it had been running very close to an old gas-engine, which caused a great deal of vibration, and it had been quite easy to read the spot

FIG. 9.
Before the Load is applied.

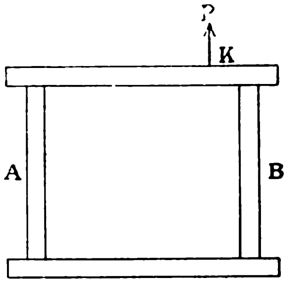
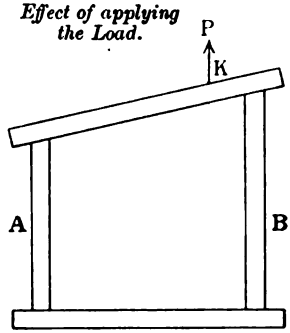


FIG. 10.
Effect of applying the Load.



of light. Again, some people might say that the temperature effect upon the strip would be very bad, but some hundreds of experiments had been made with the instrument, which had been carefully calibrated, and those temperature effects had not been obtained. At first a little effect from draught was found, and that was the reason a shield was put round, but the effect was small, and the instrument could be used without a shield if necessary. He preferred, however, to use one.

Dr. Unwin had mentioned the value of E, and had stated that the various results obtained from the American tests on the St. Louis Bridge were due to the inaccurate instrument used. This supported the author's contention that a sensitive instrument was needed for such work. Professor Lilly mentioned that the value of

E must be taken as being constant the whole way through; but, in the Appendix to which Dr. Unwin had referred, he (the author) had quoted a Report of the British Committee which showed that the value of E was not *absolutely* constant the whole way through, although it was very near. But the small variation in the value of E might account for some at present inexplicable results.

It seemed to him in making the researches, which had been going on for some time, that in the whole of their work on ductile material they had been taking too much for granted, and he had found that many of the results were not quite what engineers thought would be obtained. It was assumed too often that ductile and non-ductile materials followed the same general laws. To cover our lack of knowledge we used too readily different factors of safety, which factors were often factors of ignorance. He had not given many of the results, because experiments to be of any value necessarily must be made on some dozens of specimens, and it was quite obvious it was no good putting forward the results obtained on four or five. Great difficulty had been experienced in getting specimens and in getting the work in hand. Too much praise, however, could not be given to Messrs. Tindall Cook, who had made the sphingometer so well. Up to the present the only great result he could show was the instrument; and what he desired to get was better suggestions for the non-axial loading.

[For other Papers, *see* "Measurement of Strain," by Mr. John Morrow, Proceedings 1904, Part 2, page 469; and "Strength of Columns," by Professor W. E. Lilly, Proceedings 1905, Part 3, page 697.—Secretary, I. Mech. E.]

EXCURSIONS.*

On TUESDAY AFTERNOON, 28th July, after luncheon in the Victoria Rooms, Clifton, an Excursion was made by special train to Avonmouth, where the Members and Ladies accompanying them visited, under the guidance of Mr. W. W. Squire, Chief Engineer of the Bristol Docks, the Royal Edward Dock, which had recently been opened by His Majesty.

In the evening the Institution Dinner was held in the Victoria Rooms, Bristol. The President occupied the chair; and the following guests accepted the invitations sent to them. Those to whose name a dagger (†) is prefixed were unavoidably prevented at the last from being present:—

Bristol Reception Committee.—Chairman, Mr. J. Weston-Stevens; *Vice-Chairmen*, Mr. James H. Howell, Mr. G. K. Stothert, and Mr. G. A. Wills; *Honorary Treasurer*, Mr. Herbert S. Thynne; *Honorary Secretary*, Mr. B. de Soyres. Colonel H. G. Cary Batten, Sheriff; Sir George White, Bart.; His Honour Judge J. V. Austin; †Mr. T. H. Miller, Mayor of Bath; †Mr. Charles Adams, Master of the Society of Merchant Venturers; Mr. Sidney R. W. Humphries, President of the Bristol Chamber of Commerce; Professor C. Lloyd Morgan, LL.D., F.R.S., Principal of the University College; †Mr. Charles Thomas, Deputy Chairman of the Taff Vale Railway; Mr. William Thomson, President of the Bristol Association of Engineers. †Mr. G. Duncan Armstrong; Mr. H. E. Chattock; Mr. George J. Churchward; Mr. T. Sturge Cotterell; Mr. R. Earle; Mr. Herbert G. Edwards; Professor R. M. Ferrier, University College, Bristol; Mr. I. A. Forestier-Walker; Mr. F. B. Girdlestone, General Manager, Bristol Docks; †Mr. P. F. Hodgson; Mr. Thomas

* The notices here given of the various Works, etc., visited in connection with the Meeting were supplied for the information of the Members by the respective authorities or proprietors.

Humpage; Mr. Daniel Irving, Chief Engineer, Bristol Gas Co.; †Mr. C. Kislingbury, Divisional Superintendent, Great Western Railway; Alderman C. J. Lowe; Mr. G. Palliser Martin, Vice-Chairman, Chamber of Commerce; Mr. James McMurtrie; Mr. J. A. McPherson, Engineer, Bristol Water Works Co.; Mr. A. Wharton Metcalfe; Mr. T. J. Moss-Flower; Mr. T. R. Murray; †Mr. Walter Newton, District Superintendent, Midland Railway; Mr. H. C. Parkinson; Alderman George Pearson, Chairman, Bristol Electricity Committee; Mr. Thomas Peckett; Mr. Walter Pitt; Mr. John E. Pritchard; Mr. H. Faraday Proctor, Chief Engineer, Electricity Department; Alderman A. J. Smith; Mr. William Stagg; Mr. A. D. Swan, Resident Engineer, Avonmouth Dock; Mr. John Watts; Mr. Nicholas Watts, Honorary Secretary, Bristol Association of Engineers; Mr. Mark Whitwill; Mr. Frank W. Wills; Mr. W. Windus; Colonel T. H. Yabbicom, V.D., City Engineer.

Dr. W. Cawthorne Unwin, F.R.S., Honorary Life Member; †Mr. Cuthbert A. Brereton; Mr. Sherard O. Cowper-Coles; Mr. Bertie Reynolds; Mr. C. A. M. Smith.

The President was supported by the following Members of the Council of the Institution:—*Past-Presidents*, Mr. Edward P. Martin and Mr. William H. Maw. *Vice-Presidents*, Mr. John A. F. Aspinall and Mr. Edward B. Ellington. *Members of Council*, Mr. William H. Allen, Mr. George J. Churchward, Mr. Henry Davey, Mr. John F. Robinson, and Mr. Mark Robinson.

After the loyal toasts had been proposed, the PRESIDENT gave that of "The City and County of Bristol." He alluded to the commercial capacity of the Bristol men of fifty years ago, and said he was glad to see that those who had succeeded them had followed the good traditions of their fathers and relatives, and sustained that high position of commercial integrity for which Bristol had always been celebrated. The Members would remember with gratitude the kindness which they were receiving from their friends in Bristol, and those who knew Bristol long years ago could not help feeling that it had moved ahead. Bristol had had a high reputation for shipbuilding in the past, and he believed the traditions of those days were in the hearts of the Bristol men of to-day. Cardiff was a great exporting port, but he did not think that in Cardiff they would pretend to say that their imports were to be compared with the import trade of Bristol. He hoped the new docks which they had had the pleasure of seeing that day would develop and increase that great and prosperous trade, and, in conjunction with the ports lower down the Channel, they would work together in fostering the trade of the Bristol Channel. Bristol was well placed, had a good anchorage, and every facility for making a good naval base. He hoped the University would be established, as Bristol had done a great deal for education in the past.

The toast was acknowledged by the SHERIFF OF BRISTOL, Colonel H. G. Cary Batten, and by Sir GEORGE WHITE, Bart., who pointed out that circumstances had changed, and it was necessary to adapt ourselves to new circumstances. As long ago as 1162 Henry II. considered Bristol of sufficient importance to grant it a charter, and after a period of 746 years the King of England thought it of sufficient importance to say this: "Its natural advantages have not been allowed to fall into disuse, and its trade has developed with changing circumstances, and will, I trust, be further stimulated by the opening of the magnificent dock which is the occasion of my visit to-day." He was not prepared to admit that Bristol had in any respect gone back. It was true that circumstances had changed. Within the lifetime of the President the population was something like 100,000. To-day it was nearly 400,000, with a rateable value of £2,000,000. The imports were remarkable, and were advancing by leaps and bounds. The first steamship to cross the Atlantic went from Bristol. He hoped those who visited the city would go to the local industries to form an estimate of the character and position and the trading capacity of Bristol. He felt that the Bristol people had maintained the reputation of their forefathers, and that everything they saw around them bore evidence that they meant to continue in that direction.

The toast of "The Trade of the District" was proposed by Mr. John A. F. Aspinall, Vice-President, who, as a Liverpool man, said that they had not in Liverpool dock cills which were deep enough to let out the Lusitania or the Mauretania at any kind of tide. Therefore for once he was bound to admit that Bristol had beaten Liverpool. But there were great docks in progress at Liverpool, and he had no doubt that in time Liverpool would again beat Bristol. He contrasted the shipping at the time of the Great Western with the modern ships, and said that they, as engineers, must hope that the trade, not only of Bristol, but of all their great ports, would receive the fillip which it so badly needed.

Mr. James H. Howell, in replying, remarked that shipbuilding was a trade which seemed adapted to particular districts, and reminded the President that Bristol was not alone in this matter, for Cardiff and Chepstow had tried shipbuilding, and failed. Liverpool had behind it the great industries of Lancashire and Yorkshire, but Bristol had merely agriculture as a background. He alluded to the great progress of the tobacco and cocoa industries in Bristol, and suggested that the new Patents Act might lead to industrial development in Bristol.

The toast of "The Reception Committee" was proposed by Mr. Edward B. Ellington, Vice-President, and was acknowledged by Mr. J. Weston-Stevens, Chairman of the Executive Reception Committee, and Mr. Sidney R. W. Humphries, President of the Bristol Chamber of Commerce.

The concluding toast of "The Institution of Mechanical Engineers" was proposed by Principal C. Lloyd Morgan, and acknowledged by the President.

On WEDNESDAY AFTERNOON, 29th July, after luncheon in the Victoria Rooms, Clifton, the following Works were visited:—

Avonside Engine Co., Fishponds.

Bennett Brothers, Counterslip Works.

Bristol Corporation Docks.

Bristol Corporation Electricity Department's Works: Avonbank; Temple Backs; Underfall Yard.

Bristol Gas Co.'s Works: Avon Street; Stapleton Road; Canons' Marsh.

Bristol Tramways and Carriage Co.: Counterslip Power Station; Brislington Depôt.

Bristol Wagon and Carriage Works Co.

Champions, Davies and Co., Confectionery Works, Lewin's Mead.

Co-operative Wholesale Society, Broad Quay.

Edward Everard, Colour Printing Works, Broad Street.

J. S. Fry and Sons' Works: Prince Street (Box Making); Canons' Marsh (Saw Mills); Quay Street (Paper Bag, Fancy Box, &c. Making).

Humpage, Thompson and Hardy, Jacob Street.

John Lysaght's Constructional Engineering and Wire-Netting Works, Netham.

Peckett and Sons, Atlas Locomotive Works.

Pountney and Co., Bristol Pottery, Fishponds.

E. W. Savory, Park Row Studios.

Stephens Bros. and Martin, Hemp and Flax Mills.

Christopher Thomas and Brothers, Broad Plain Soap Works.

In the Evening, a Conversazione was held in the Museum and Art Gallery Buildings, by invitation of the Bristol Reception Committee, and was followed by a Dance in the Drill Hall adjoining.

On THURSDAY, 30th July, three whole-day Excursions were made, in which Members were accompanied by Ladies.

One was by special train to Bath, whence four alternative Visits were made, by special motor-omnibuses or electric tramcars, to the Bath Stone Mines at Corsham, where they were received by the Directors of the Company and conducted over the Mines under the guidance of Mr. T. Sturge Cotterell, General Manager. A second party visited the Works of Messrs. Spencer and Co., Melksham, over which they were conducted by Mr. T. R. Murray and Mr. W. Littlejohn Philip, Joint Managing Directors. Other parties visited the Roman Baths, Prior Park, and various other places of interest in Bath. After luncheon in the Guildhall, by invitation of the Mayor, Councillor T. H. Miller, Bath Abbey was inspected under the guidance of Prebendary S. A. Boyd, Rector and Rural Dean. The Members and Ladies then visited some of the following Works:—

Bath Cabinet Makers' Co., Twerton-on-Avon.
Bath Corporation Electricity Works.
Bath Electric Tramways Co.'s Power Station.
James Fortt, Original Bath Oliver Biscuit Factory.
Griffin Engineering Co., Kingston Iron Works.
Mallett's Showrooms of Antique Furniture and Jewellery.
Stothert and Pitt's Works: Newark Foundry; Victoria Works.

The Mayor subsequently entertained the Party to tea in the Guildhall.

A second Excursion was made by brakes to Barrow Gurney, where the reservoirs and filter beds of the Bristol Water Works Co. were inspected. The drive was continued to the Blagdon Reservoir, where the Pumping Station and Works were inspected under the guidance of Mr. J. A. McPherson, Engineer, and of Mr. Charles Hawksley, Consulting Engineer to the Company. The Party were entertained to Luncheon by Lord Winterstoke, and subsequently drove viâ Burrington Combe to Cheddar, where the two Caves were inspected. After tea at the Hall, Cheddar, by invitation of Mr. A. Wharton Metcalfe, the return journey was made by special train to Bristol.

A third Excursion was made by train to Wells, viâ Cheddar, where some of the Party alighted to view the Caves. On arriving at Wells the Cathedral and Bishop's Palace were visited, and after luncheon at the Swan Hotel, Wells, the Members and Ladies proceeded by brakes to Glastonbury, where the Abbey ruins, the Abbot's Kitchen, and the Museum were inspected under the guidance of Mr. R. Bowring. Tea was taken at the George Hotel, Glastonbury, and after returning to Wells the return journey to Bristol was made by special train.

In the Evening an illuminated Garden Party was given in the Zoological Gardens, Clifton, by invitation of the Bristol Reception Committee.

On Friday, 31st July, two whole-day Excursions were made.

One was to Chippenham and Swindon. Those Members and Ladies of the Party who alighted at Chippenham visited the Works of Messrs. Saxby and Farmer, over which they were shown by Mr. Percy F. Hodgson, General Manager. On arrival at Swindon the Carriage and Wagon Works of the Great Western Railway Co. were visited, under the guidance of Mr. George J. Churchward, Member of Council. After luncheon in the Mechanics' Institution, by invitation of the Company, the Locomotive Works were visited. The return journey was made after tea at Swindon Station.

The other Excursion was made by train to Frome, whence after luncheon at the George Hotel, the Members and Ladies proceeded by brakes to Longleat. By permission of the Most Hon. the Marquess of Bath, Longleat House was visited and tea was provided at Shear Water. The return journey from Warminster to Bristol was made by special train.

In addition to the various excursions, &c., already mentioned, a Ladies' Committee arranged drives on Wednesday morning and afternoon, to places of interest in and around Bristol for Ladies accompanying Members, and the Ladies' Club, Clifton, invited them to be Honorary Members during the Meeting.

During the Meeting the Members were invited to be Honorary Members of the Clifton, the University and Literary, the Constitutional and the Liberal Clubs.

THE AVONSIDE ENGINE CO., FISHPONDS, BRISTOL.

This Company has been in existence since 1837, when the works were situated in Little Avon Street, St. Philips, Bristol. In 1905 new works were erected at Fishponds on a site nearly 4 acres in extent, having access to the Midland Railway by a siding, and to Fillwood Road, Fishponds, from which there is the main entrance to the works.

The present shops are large and airy, and well lighted with Keith and Blackman's system of compressed gas. The shafting is driven by a Mather and Platt high-speed vertical non-condensing engine, which is supplied with steam by Ruston and Proctor's Lancashire boilers on the induced-draught principle.

The Machine Shop contains a large number of the latest tools, including vertical and horizontal boring mills, Miley lathes, milling machines, planing machines, and an Entymon air-compressor by the Consolidated Pneumatic Tool Co., which is used to supply air for drilling, caulking and chipping.

The Smithy is provided with 20 fires, which are supplied with air by a Roots blower; there is also a steam-hammer and annealing furnace, beside angle-smiths' and flangers' fires.

The Pattern Shop is placed over the paint shop and is large, roomy, and light, and has room for 10 to 12 pattern makers, besides a large space for storing patterns.

The Paint Shop will hold six locomotives, and is kept at an even temperature by means of hot-water pipes, which also supply the Pattern Shop with hot water and an equable temperature.

The Erecting Shop is placed in a suitable position adjoining the fitters' benches; and room is provided for erecting about eight locomotives at a time.

The Company provides work for between 200 and 300 men, and turns out locomotives at the rate of about 40 per annum. The Boiler Shop employs about 60 men, and is supplied with cranes, hydraulic riveters, shears and punches, rolls, etc. The main shop is supplied with two travelling-cranes, two bicycle-cranes, and several of the radial-drilling machines have cranes to assist in placing the work in position.

BRISTOL CORPORATION DOCKS.

The shipping trade of this port dates back for many centuries. Vessels were formerly discharged and loaded at landing places along the banks of the tidal River Avon, which then flowed through the heart of the city. In 1809 a new course for the river was formed, and the old waterway for a length of two and a half miles was converted into a floating harbour. This is now equipped with modern wharves, granaries, transit sheds, cranes, railways, etc., and many large manufactories and other industrial concerns are located in the immediate neighbourhood of the quays. In the course of the last forty years the river navigation has been greatly improved. The channel has been deepened, the banks and points have been marked by a series of illuminated posts and lights, and a new entrance lock has been constructed. The Avonmouth and Portishead Docks are situated at the mouth of the river, and afford accommodation for ocean-going vessels of large dimensions.

All these docks are the property of the City of Bristol. The following are the dimensions:—

——	Area.	Length of Quays.	Area of Sheds.
	Acres.	Yards.	Square yards.
City Docks	83	4,898	66,230
Avonmouth	19	1,600	103,000
Do. (Royal Edward Dock)	30	1,677	46,210
Portishead	12	943	51,491
Total . .	144	9,118	266,931

City Docks.—The depth of water on cill is 33 feet at mean spring tides and 23 feet at mean neap tides. The lock is 350 feet long and 62 feet wide. Alongside the harbour are public quays having direct connection with the Great Western Railway Co.'s lines, and by steam lighter with the Midland Railway Co.'s lines. There are extensive transit and other sheds, granaries, warehouses, elevators, etc.

A regular trade is carried on in horses, donkeys, cattle, sheep, and pigs from the southern Irish ports, Bristol being the chief supply depot for store beasts for all the grazing districts in the south, south-western, and eastern counties. There is a large import of grain from foreign parts, also cottonseed and linseed, which are crushed at the mills situated near the docks.

The exports consist chiefly of galvanized and other iron goods, machinery, tinplates, chemical products, railway wagons, manufactured oils, salt, spar, etc.

Avonmouth Dock.—The depth of water on cill is 38 feet at mean spring tides and 28 feet at mean neap tides. The dock is 2,180 feet long and 500 feet wide, the lock being 485 feet long and 70 feet wide. There are extensive covered quays provided with railway lines and hydraulic cranes, and on the east side are 2,000 feet of continuous shedding, 140 feet wide, fitted with nine hydraulic cranes, having a lifting power of 30 cwts. each. There is also a coaling crane capable of lifting loads up to 30 tons. On the west side are large transit sheds with double floors; these are equipped with five hydraulic 30-cwt. cranes and one 15-ton hydraulic crane. A fruit store and warehouse has also been provided specially for the West Indian trade at the south-west end of the dock.

The lairage and slaughter-house accommodation is sufficient to deal with consignments at one time of 1,000 cattle and 500 sheep, and the cold stores have a capacity of 220,000 cubic feet. There are nine oil tanks, each averaging over one million gallons storage capacity, and several others in course of construction. The import of petroleum in 1896 exceeded twenty million gallons. The floating pontoon dock is 365 feet long and 62 feet wide.

Royal Edward Dock, Avonmouth.—The construction of this dock was undertaken after a report by Sir John Wolfe Barry to the Bristol Corporation in 1896, in which three schemes for the enlargement of accommodation in the Avon were described, namely: Building a new dock at Avonmouth; building a new dock at Portishead; and the dockization of the whole River Avon from its mouth to Bristol. The dock was opened by His Majesty on 9th July of this year. The depth of water on outer cill is 46 feet at mean spring tides and 36 feet at mean neap tides, the depth on the inner cill being 6 feet less. The dock is 1,120 feet long and 1,000 feet wide, the lock being 875 feet long and 100 feet wide. It is connected with the existing dock by a junction cut 525 feet long and 85 feet wide. On each side of the entrance lock are piers at which steamers can land mails and passengers. Trains from alongside can reach London, over a line almost straight, in about 2 hours. A graving dock, 914 feet over all, has been constructed, which can be divided into two compartments, 500 feet and 300 feet respectively.

The first sod of the new dock was cut by H.R.H. the Prince of Wales on 5th March 1902, the contractor being Messrs. John Aird and Co. There is a large area of land adjoining this dock, having railway and road access thereto, available for the erection of industrial works of all kinds. On the eastern side of the dock there are two transit sheds, each 500 feet in length and two storeys high, equipped with electric roof and wharf cranes, and on the southern side a transit shed, 450 feet in length, consisting of a single floor only, also provided with electric cranes. Behind the sheds, on the eastern side of the dock, a large granary has been erected capable of containing 50,000 quarters of grain, the greater portion being stored in bins and the remainder on floors.

Between the dock and the sheds on the eastern sides there is an underground passage leading to the granary, and this passage contains a number of conveyor belts for conveying grain from the vessels discharging at the sheds to the granary. Elevators will be provided to lift grain from the hold of the vessel and deposit it on to the bands or into craft or trucks alongside. The dock will be completely surrounded by lines of rails connected with the railways on the old dock.

In 1884 the tonnage of vessels entering the Port of Bristol was 1,244,537 tons; in 1894 it was 1,541,713 tons; in 1904 it had increased to 2,116,339, and for last year it was 2,058,757 tons.

BRISTOL CORPORATION ELECTRICITY DEPARTMENT.

The supply of electricity for lighting and power throughout the City of Bristol is controlled by the Electricity Department of the Bristol Corporation. The supply was commenced in August 1893, and was given from the Temple Backs Generating Station situated almost in the centre of the busy part of the City. After a few years' working, however, the progress was so great that the site was deemed inadequate, and another site of about 10 acres was procured at Feeder Road on which the Avonbank Electricity Works have been constructed. Nearly the whole of the electricity is now generated at these works, whence three-phase current at a pressure of 6,000 volts, 50 periods, and single-phase current at a pressure of 2,000 volts, 93 periods, is transmitted to 82 substations and 7 transformer kiosks situated in different parts of the City. The City has an area of 17,004 acres, and current is supplied to the extremities of the area in most directions.

Avonbank Electricity Works.—The subsoil on the Avonbank site necessitated considerable preparation in the way of foundations. The works are built upon longitudinal walls of concrete which rest upon the hard red marl, about 34 feet under ground level; eight such walls 4 feet to 4½ feet in thickness run continuously throughout the length of the buildings, except in the case of the latter extensions where there are seven walls from 4½ feet to 6 feet in width.

The superstructure is built of Cattybrook brick in cement. It is an absolutely plain structure of rectangular form, and at present consists of one generator room 402 feet long (engine-room 350 feet 9 inches, workshop 51 feet), adjoining which is a boiler-house and a stoking space 350 feet in length, provision having been made for duplicating the building, when the stoking space will be common to another boiler-house similar to that now existing. The generator room contains steam generators having a total capacity of 12,890 kw., supplying three-phase electricity at 6,000 volts, single-phase electricity at 2,000 volts, and direct current at a pressure of 250 + 250 or 500 volts. These works are also used to a limited extent as a converter station, containing three-phase to direct current converters for power supply in the immediate neighbourhood.

Coaling Arrangements.—Coal is discharged from the barges in the feeder canal by a "Hones" grab, and after passing on to an automatic weighbridge is discharged by a "Hunt" gravity railway to a "Hunt" conveyor, having a capacity of 40 tons per hour, and a speed of 35 feet per minute, encircling the whole of the coal bunkers. The whole of this plant is electrically driven.

Boilers.—There are sixteen Babcock and Wilcox water-tube boilers, four having a normal evaporative capacity of 15,000 lbs. per hour each; four 17,000 lbs. per hour each; four 18,000 lbs. per hour each; four 25,000 lbs. per hour each; from feed water at 60° F. to steam at a pressure of 200 lbs. and 200° superheat. Meldrum's stokers are used throughout. The superheaters made by Messrs. Babcock and Wilcox are situated between the water-tubes and the steam-drums of boilers. The economisers are of Green's standard type, one to each pair of boilers.

Induced Draught Plant.—There are two short steel chimney stacks. No. 1 is fitted with four induced-draught fans at base of stack, three having a capacity of 97,000 cubic feet of gas at 500° F. per minute against 2½-inch water-gauge. These are driven by Bumsted and Chandler's high-speed engines, the fourth being electrically driven by a 50-B.H.P. Laurence-Scott motor. No. 2 stack is fitted with three fans, each having a capacity of 137,500 cubic feet of gas at 500° F. per minute, driven by 110 B.H.P. Bruce-Peebles motors.

Feed Pumps.—Of these there are five, each delivering 8,000 gallons per hour, and there are four general service pumps, of a capacity of 10,000 gallons per hour each, against 45 feet head.

Main Generators:—

2 Willans high-speed, central-valve engines direct-coupled to Siemens copper type single-phase, 2,000 volts alternators, speed 224 r.p.m., capacity 750 kw. each.

3 Parsons turbo-alternators, single phase, 2,000 volts, 1,860 r.p.m., capacity 750 kw. each.

1 Parsons turbine, coupled to Siemens single-phase alternator, 2,000 volts, speed 2,790 r.p.m., capacity 600 kw.

2 Willans turbines, coupled to Dick-Kerr three-phase alternators, speed 1,500 r.p.m., capacity 1,000 kw. each.

1 Westinghouse single-phase turbo-alternator, 2,000 volts, speed 1,400 r.p.m., capacity 3,000 kw.

1 Westinghouse turbo-alternator, three-phase, 6,000 volts, speed 1,500 r.p.m., capacity 3,000 kw.

1 Willans-Dick-Kerr direct-current generator of 210 kw. capacity, speed 350 r.p.m.

2 Willans-Siemens direct-current generators, of 165 kw. capacity each, speed 275 r.p.m.

2 Willans-Westinghouse exciters, 100 volts, 88 kw. capacity each, speed 465 r.p.m.

1 Peebles-La Cour three-phase to direct current converter, of 300 kw. capacity, speed 750 r.p.m.

Condensing Plant.—The condensing plant, except in the case of the Willans single-phase sets, is placed immediately under the generator room floor. Surface condensers and motor-driven air-pumps are used throughout. Circulating water is pumped from and returned to the feeder canal, passing through two 3-foot 6-inch culverts to the circulating pit where there are fixed circulating pumps by Bumsted and Chandler, W. H. Allen and Co., Alley and McLellan, and Gwynn and Co., except in the case of the largest sets where there is a circulating pump for each condenser.

Switchboards.—Practically the whole of the switchboards in these works have been constructed by Messrs. Siemens Brothers. The extra high-tension switchboard is in course of rearrangement and reconstruction at the present time.

Tanks.—A ferro-concrete tank for soft-water storage, capacity 150,000 gallons, has just been constructed to provide stand-by for boiler feed, for use at times when the water is lowered or let out from the feeder canal.

Temple Backs.—The most important of the substations is the Temple Backs Electricity Works, these being still used for generating purposes at times. They contain nine Lancashire boilers (28 feet by 8 feet), fitted with Vicars' mechanical stokers, two Babcock and Wilcox boilers, one fitted with Meldrum's stoker and one hand-fired, and other auxiliary boiler plant. In the generator room there are ten Willans central-valve engines ranging from 100 to 750 I.H.P., direct coupled to 100-volt exciters, 500-volt arc lighting and power dynamos, and two 400 kw. Siemens copper type alternators (2,000 volts). There are also three 500-kw. Peebles-La Cour three-phase to direct-current converters, converting energy at 6,000 volts from the Avonbank Works, to supply 250 + 250, or 500 volts to the power network.

Switchboards.—Practically the whole of the single-phase alternating current is distributed from the Temple Backs Works, where the distributing switchboards are situated. These switchboards are contained in specially constructed fireproof chambers, and in addition to the twelve trunk mains there are forty-four feeder and two generator panels. The whole are fitted with maximum cut-outs and Andrews time-limit device for operating the automatic switches, and the machine and trunk panels with Andrews reverse current devices. The power and arc-lighting switchboards are situated on the gallery of the Generating Room, the former being by Messrs. Ferranti and Messrs. Siemens, and the latter of Ediswan and Cowans manufacture.

Underfall Yard Substation.—This contains two 300 kw. Westinghouse rotary converters, and one 300 kw. Peebles-La Cour motor converter. It is fed by three 6,000 volts three-phase trunk mains from the Avonbank Works, and supplies energy at 250 + 250, or 500 volts direct current.

There are two Static Substations working, from which three-phase energy is being supplied at 360 volts, 50 periods for power purposes, and 210 volts for single-phase, 50 periods for lighting, and also four in course of equipment.

There are seventy underground substations and eight transformers kiosks supplied at 2,000 or 3,000 volts, and delivering to the distributing network at 105 + 105 volts, or in some districts 210 volts (2-wire). These substations range from 20 to 250 kw. capacity each.

Public Lighting.—The Public Lighting consists of 689 arc lamps. The earlier equipment of arc lighting was supplied at 600 volts direct current, but with a view to a standardisation of pressures and simplicity and economy in the generating stations, 115 flame lamps have been substituted on many of the circuits, and the supply pressure has been brought down to a standard of 500 volts, so that the whole of the arc lighting is in common with the power supply as regards voltage. Forty-seven alternating and sixty-eight direct-current Oriflame Lamps have been substituted for the older type of lamp. 25·2 miles of streets are lighted by arc lamps, including most of the centre of the city and the main arteries in different directions. The average distance between lamps is 75 yards, although in narrow streets and the central portions of the city the lamps are somewhat closer.

Supply of Avonmouth.— Mains, three in number, have been laid from the Avonbank electricity works to Avonmouth, a distance of 8¼ miles, where a rotary substation has been equipped for the purpose of supplying the Avonmouth Docks, and other demands for power and lighting in the neighbourhood of Avonmouth; three-phase energy is transmitted at a pressure of 6,000 volts, and direct current is supplied at 250 + 250 volts, or 500 volts for power as in other portions of the city.

Mr. H. Faraday Proctor is the City Electrical Engineer.

THE BRISTOL GAS CO.

Gas lighting in Bristol has a rather curious and not uninteresting history. In 1811 Mr. Breillat, of Broadmead, a dyer by trade, introduced the new illuminant to the City by lighting his own shop and part of the street where it was situate, and giving descriptive lectures on the subject. The first works were at Temple Backs, and were in the hands of a syndicate. Progress was at first very slow, as it was not until the year 1816 that the idea was first entertained of lighting the City by coal gas. At the end of that year a sum of just over £1,000 had been expended on the works and mains, the latter being laid as far as the centre of the City. Meters at this time were not in use, the charge for light being by contract, based on the size of the burner and time of use. For instance, a Cockspur No. 1 burner from sunset to 8 o'clock cost 10*s*. 6*d*.; from sunset to 10 o'clock, 17*s*. 6*d*.; and till sunrise, £2 2*s*. 0*d*. per annum (of 313 days). An extra charge of 1*s*. was made for two additional hours once a week, presumably for use on market days. By the summer of 1817 the five principal streets of the City had been lit by gas, and a general demand for further extensions was made on all sides. At the end of 1817 the number of customers was 142, the price of gas being 15*s*. per 1,000 cubic feet.

The Committee in January, 1818, proposed that the capital of the concern be increased to £20,000, and that application be made to Parliament for a charter. As a result, "The Bristol Gas Light Co." was incorporated, and the works were removed to Avon Street, St. Philip's.

In 1823 a rival company was started to supply oil gas, the style of the company being "The Bristol and Clifton Oil Gas Co." Their works were situate at Canons' Marsh (then known as Lime Kiln Lane), and the price of the gas was 40*s*. per 1,000 cubic feet. The light was, however, claimed to be four times as brilliant as that from coal-gas. The price of oil went up, and the company were unable to pay any dividends. They applied to Parliament in 1836, and were granted power to use coal, both Companies reducing their price to 12*s.* per 1000 cubic feet. In 1853 the two Companies amalgamated under the style of the "British United Gas Light Co.," which name was subsequently altered in 1891 to "The Bristol Gas Co." The capital of the Company at the end of 1907 amounted to £1,343,002; coal carbonized during last year was 270,051 tons; storage capacity of gas-holders, 15 million cubic feet; total mains laid, 358½ miles; and the public gas lamps number 9,404.

The Company serves an area of nearly 30 square miles, and no better evidence of the public service rendered by the Company could be offered than that 16-c.p. gas is sold to the Corporation, and all consumers using over 500 thousands, at 1*s.* 6*d.* per 1,000 cubic feet. Gas is also delivered over the entire area of the Company's district, to all consumers large and small, for power, at 1*s.* 6*d.* per 1,000 cubic feet, and to all other consumers extending to a distance of seven miles from the works, at a cost of 2*s.* per 1,000 cubic feet.

The Company has three Works. Avon Street and Canons' Marsh have already been named, and the Stapleton Road Works were erected in 1879 to meet the growing business.

The Avon Street Works were erected in 1819, and some of the original buildings still exist in an excellent state of preservation, and are a monument to the enterprise and foresight of the Bristol pioneers of gas lighting. These works contain a total of 520 retorts and are capable of carbonizing over 600 tons of coal per diem. The chief features are the inclined retorts and the modern coal- and coke-handling plants on the "New Side" of the works, the latter of which are worked by internal combustion engines, and are described in Mr. Stagg's Paper (page 565).

The Canons' Marsh Works contain 350 retorts and are capable of carbonizing over 350 tons of coal per diem. The chief features are the mechanical stoking. Two of the Retort Houses are worked by the Fiddes-Aldridge Machine, the retort being discharged and recharged simultaneously. The stoking machines and coke-handling plant are electrically driven by current produced on the works. The electric plant is proved in duplicate.

The Stapleton Road Works are the most modern works of the Company, the site occupying 28 acres of land in what is practically the centre of the Company's district of supply. The works contain 432 retorts and are capable of carbonizing 500 tons of coal per diem. The works have recently been equipped with modern stoking machinery, coal-breaking, elevating and conveying plant. The coke is also removed from the retort house, cooled and stored in the yard by mechanical arrangements all electrically driven. The electric plant at these works is also provided in duplicate.

In addition to these three manufacturing stations, the Company possesses five gas-holder stations, situated in various parts of the district of supply away from the works. The Engineer to the Company is Mr. Daniel Irving.

BRISTOL TRAMWAYS AND CARRIAGE CO., CENTRAL POWER STATION, BRISTOL.

The building of the Company's Power Station at Counterslip was erected on the site of Finzel's sugar refinery, situated on the banks of the Floating Harbour adjoining St. Philip's Bridge and East Tucker Street. It has been arranged in three storeys, the engine standing on the main floor with the boiler room placed directly overhead, whilst the coal-storage bunkers, economiser, and water-tanks are located on the third floor level, the whole forming a very compact and economical working arrangement.

The station building is divided as follows:—The engine-room is 115 feet long by 48 feet wide by 42 feet high; boiler-house 133 feet by 48 feet 6 inches wide by 26 feet high; the basement contains the circulating pumps, lifting pumps, hot-well, etc., and is the same size as the engine-room, but with a depth of 9 feet below the main floor.

The foundations of the Power-House consist of piles about 30 feet long and from 12 inches to 14 inches square, placed about 3 feet apart from centre to centre, finally packed around with concrete, and the heads cut off at water-level, crowns being fixed across the top of each, on which the concrete bed and steel grillage are placed; the columns rest on the steel grillage beams, consisting of three layers of rolled joists under each stanchion. On the top of the columns are the main girders carrying the boiler-room floor with all its machinery; immediately over this are the girders supporting the main flue, coal bunkers, economisers and water-tanks, whilst on the top of these columns are the main roof trusses; attached to these columns in the engine-room are brackets riveted for supporting wrought-steel plate girders on which the travelling-crane runs.

The main engine steam plant consists of five vertical cross compound condensing engines, four of which are 800 I.H.P., driving a Thomson-Houston continuous-current 500 k.w. railway generator; the fifth machine, recently added, is 1,600 I.H.P., driving a 1,000 kw. railway generator of a similar type. These engines were made by the Allis Chalmers Co. of Milwaukee, and they are of the Reynolds-Corliss type. The gear is of the automatic type, with double ported valves for the steam and single ported for the exhaust; there are two eccentrics to the valve-gear of each cylinder, one for operating the steam-valves and the other for the exhaust-valves. Two governors are attached to each engine, one of which operates both the high and low-pressure cylinder valve-gears, while the second or safety governor automatically closes the main stop-valve in case of excessive speed.

The fly-wheels are built up in segments which are fitted to cast-iron centre pieces, the sections of rim being held together by wrought-iron arrow-head connections shrunk in place after the wheel is erected. Between the cylinders there is a reheater receiver with coils supplied by steam boiler pressure.

In the engine-room, parallel with the main engines, are three Bellis vertical compound enclosed type engines, capable of developing 300 I.H.P. running at 400 revolutions per minute, the total capacity of these being 200 kw.; they are all carried on a combined bed-plate. These engines are of the standard pattern with forced lubrication for all the working parts supplied by a valveless pump worked from the crank-shaft; they are used for lighting the Power-House and all the depots.

The condensing plant consists of three Wheeler (Admiralty pattern) surface condensers, having cast-iron rectangular shells, strongly ribbed on the outside, and fitted with water bonnets at each end. The tube plates are of brass, into which the seamless brass drawn tubes are fitted. The condensers are arranged so that either of the main engines may exhaust into them. The circulating pumps are of the centrifugal type, electrically driven; they are placed in the basement and draw their supply from the harbour, returning the discharge to the same. The exhaust steam on its way to the condensers is passed through oil separators of an efficient type, which, with the filters on the low-pressure pipe line, practically eliminate the whole of the oil mixed with the steam. The air-pumps discharge their water to a hot-well placed in the basement, from which it is taken by an electrically-driven pump of the three-throw type, and discharged into the tanks over the boiler-room. The travelling-crane is a 25-ton overhead electrically-driven one, operated by three motors, one each for the hoisting longitudinal and traversing movements.

The generators are direct connected to the engines already described, and the laminations of the armature are of the best quality soft iron, with staggered joints, assembled with ventilating ducts, insulated from one another by a coating of japan; each segment is dovetailed into the iron spider at least twice during its length. The conductors extend from end to end of the armature without a join, and are insulated between the conductors and the iron core. The commutator segments have a radial depth of about 2 inches and are of hard drawn copper, the insulation used being mica, of such quality as to wear evenly with the copper segments. The insulation between the segments and the rings exceeds $\frac{1}{8}$ inch thickness, and there are eighty segments to the pole, which allows groups of segments to be removed without disturbing the remaining ones.

There are five motor generators, constructed so that the field of the generator is put in circuit with one or more of the positive feeders running from the positive bus-bars at the switchboards to the trolley lines, whilst the armature is placed in circuit with the return feeder, one end of which is fixed to the negative bus-bar and the other end is connected to the track rails at a distant point of the system. The generator is thus separately excited, and the current in the armature corresponds with the current in the field. The motor driving this generator is a four-pole shunt-wound machine direct connected to the generator.

The switchboard is arranged in two galleries, and comprises the five main generator panels and twenty-six feeder panels arranged for handling a current of 600 ampères. There are also five booster panels, two lighting generator panels and nine lighting distributor panels, the latter for supplying the current to the Company's various depots.

In the Boiler-House the steam-generating plant consists of ten Babcock and Wilcox boilers, arranged in five batteries. Each boiler contains 3,140 square feet of heating surface and is of sufficient capacity for evaporating 8,000 lbs. per hour, the working pressure being 160 lbs. per square inch. There are three vertical duplex direct-acting boiler feed-pumps, which draw their water from two tanks placed directly overhead. Each tank is of 6,000 gallons capacity and receives its supply from the hot-well in the basement of the station; the feed-pumps are each capable of drawing 6,000 gallons of water per hour. The steam-piping is designed to suit the particular arrangement of the station, there being one header in the boiler-room and another adjacent to the main engines; proper provision is made by the insertion of separators to prevent water passing to the cylinder of the engines. From the lower steam-header risers are taken to the stop-valves of the engines, and the ring main is taken around the basement of the station for supplying steam to the auxiliary plant.

There are ten pairs of Vicars mechanical stokers, driven from a shaft which runs in a passage formed between the girders in front of the boilers; this shaft is driven by an electric motor coupled direct to the spindle of a worm reducing-gear. The coal supply is brought alongside the quay by steamers and is deposited by a steam-winch into the main storage bunker, whence it is transmitted overhead by the conveyor and discharged into the bunkers immediately over the boilers. Attached to the bottom of each bunker is fixed a separate hopper with weighing scale and chute, so that all the coal passed to the mechanical stokers can be carefully weighed, checked, and a record kept.

The ashes are raked from the boilers on to the floor and passed through an opening placed in front of each boiler to the conveyor, which on its return journey carries the refuse to a storage-bin outside the building adjoining the stack; when a sufficient quantity has accumulated it is disposed of through a chute into barges. One special feature in connection with this arrangement is that the coal can be passed to the overhead bunkers at the same time as the ashes are being removed; this forms a twofold advantage in a plant of this description. The main flue for conveying the gases from the boilers to the chimney is placed directly over the rear of the boilers, being connected to them by suitable breeching pieces, in the neck of which a plate damper is fixed. The flue is made of steel plates, stiffened on the outside with angle bars and is lined throughout with firebrick.

The economiser is composed of 560 tubes in fifty-six sections of ten tubes width, and is of sufficient capacity to deal with the water required for the ten boilers. The scraper gear is driven by an electric motor, the speed being reduced by means of belts and a countershaft placed on top of the economiser.

The chimney stack is composed of two parts, one being a brick pedestal and the other the steel shell forming the shaft, this arrangement being necessitated by the extreme height of the boilers and their flue. Advantage, however, has been taken in the design to utilize the interior of the pedestal for a spiral staircase to give access to the boiler-room floor. On the pedestal top is the chimney proper, 200 feet from the base plate or 265 feet from the ground level. The shell is made of steel plates in three thicknesses, namely, $\frac{3}{8}$ inch at the bottom, $\frac{5}{16}$ inch in the centre portion, and $\frac{1}{4}$ inch at the upper end, where it is 10 feet 9 inches in diameter and is finished off with an ornamental cap. The interior of the chimney is lined throughout with specially moulded firebrick.

BRISTOL WAGON AND CARRIAGE CO., BRISTOL.

The works of this firm cover about 12 acres of ground, and provide employment for about 1,000 men. Their productions include any kind of vehicle, from a spring cart to a railway coach, a steam-motor, or an electric brougham. Most of the English and foreign railways have, at one time or another, been supplied with rolling stock from these works. The business, originally a wheelwright's shop, is of old standing, and was acquired by the late Mr. Albert Fry in 1866, when it was enlarged and converted into a company. Since that time numerous extensions have been made and modern machinery with labour-saving appliances introduced.

The timber-yard and drying-sheds hold a three-years' stock of various kinds of suitable woods, valued at over £60,000, the careful drying and maturing of which is a question to which very careful attention is given. The sawmill is equipped with wood-working machinery of all kinds. So exhaustively, and with such exactitude, is the various work dealt with in the sawmill, that little except glueing and fixing remains to be done in the erecting-shops, where may be seen in different stages of construction hundreds of vehicles of all kinds—railway rolling stock for 5 feet 6 inches down to 2-feet gauge, dogcarts, phaetons, omnibuses, tramcars, carts, wagons, vans, drays, etc.

The smithy is a large one, containing nearly 100 fires, together with a good number of steam-hammers. There are two well-appointed foundries and a forge. Practically everything—frames, bodies, wheels, and all accessories except springs and special fittings—is made on the premises.

BRISTOL WATER WORKS:

YEO RESERVOIR, PUMPING STATION, AND OTHER WORKS AT BLAGDON.

Yeo Reservoir.—The construction of this reservoir was authorised by Acts of Parliament in 1888 and 1889, and the works were designed and constructed under the direction of Messrs. T. and C. Hawksley, of Westminster. The area of the watershed draining to the reservoir is 5,300 acres, and the area of surface of water when the reservoir is full is 450 acres. Its capacity is 1,770 million gallons, and the maximum depth of water is 37 feet, the compensation water delivered daily to the river below the embankment amounting to 1,900,000 gallons. The length of the embankment is 530 yards, and its maximum height 43 feet. The puddle trench is sunk through red and variegated marls and a layer of grey dolomitic conglomerate, all of the Keuper Series, on to a bed of watertight red marl. The maximum depth of this puddle trench below the natural surface of the ground is 175 feet. During the construction of the embankment a tunnel, having a diameter of 10 feet, was in use for the passage of floods. In this tunnel were two sets of valves, in tandem, each 4½ feet by 1¾ feet. The length of weir at the head of the by-wash for carrying off flood-water is 180 feet.

Yeo Pumping Station.—This pumping station consists of two Engine Houses, each containing two compound rotative beam engines, each of 170 maximum horse-power, and a speed of 17 revolutions per minute. The high-pressure cylinders are 21 inches diameter by 5 feet 3 inches stroke, and the low-pressure cylinders are 34 inches diameter by 7 feet stroke. The main pumps, of the bucket and ram type, one to each engine, are 30 inches diameter by 3½ feet stroke. Each pump delivers 106 gallons per revolution, or 1,802 gallons per minute, or 2,594,800 gallons per twenty-four hours; and the maximum head, including friction of water in pipes, is about 250 feet. The Boiler House contains six Lancashire boilers, 30 feet in length by 7 feet 6 inches diameter, two sets of Green's economisers, and feed pumps in duplicate. Steam pressure in boilers is 100 lbs. per square inch. There are two coal stores, each with a capacity of 500 tons.

Two receiving tanks are supplied with water from the Yeo reservoir, and by the lines of pipes from the Rickford and Langford springs. Each tank has a capacity of 567,000 gallons, and the water gravitates from them to the pumps in the Engine House.

The fitting shop contains 6-inch and 12-inch lathes, and drilling, shaping, and screwing machines driven by water power, with 15 H.P. Pelton wheel.

The pipe lines are all laid with cast-iron socket and spigot pipes jointed with lead.

There are three separate treatment works for drainage from the villages of Butcombe, Compton Martin, and Ubley, and part of Blagdon, which are situated within the watershed of the Yeo reservoir.

Blagdon Drainage Treatment Works.—Road refuse and other heavier materials are deposited in the grit chamber before the drainage flows into the septic tanks, of which there are two, each 40 feet by 10 feet, by 9½ feet deep, with a capacity of 23,750 gallons. The drainage, partially decomposed, flows from the septic tanks over an aerator, and becomes mixed with air. There are six filter beds, each 20 feet long by 16 feet wide and 4 feet deep, and the capacity of each bed is 8,000 gallons, including crushed clinkers, which is the filtering medium. The effluent passes on to land on which osiers are grown. The moderating tank is 100 feet long by 33½ feet wide and 3 feet deep.

Barrow Reservoirs and Filter Beds, Chelvey Pumping Station, and other Works.

Barrow Reservoirs.—The Yeo reservoir being at too low a level to admit of gravitation to Bristol, the water has to be raised by pumping into the Company's aqueduct at North Hill, whence it gravitates to Barrow, together with the Company's original supply from the Mendip Hills. At Barrow there are three storage reservoirs of a total capacity of about 860 million gallons, and ten filters of a total area of about 7½ acres having a filtering capacity of 18 million gallons per 24 hours.

Other sources of supply to Bristol are from Chelvey Pumping Station, the Sherborne Spring, and the Cold Bath Spring. Of the water supplied to Bristol, some portion is pumped again to the higher levels from the pumping stations at Clifton, Bedminster, St. George, and Knowle.

The original works of the Company, including the aqueduct from the Mendip Hills and two of the reservoirs at Barrow, were designed by the late Mr. James Simpson, Past-President of the Institution of Civil Engineers. Another reservoir and the filter beds at Barrow, the pumping station at Chelvey, the gravitation works from the Sherborne Spring, and various other works of the Company, have been designed and constructed under the direction of Messrs. Taylor, Sons and Santo Crimp, of Westminster. The pumping station and high level water-tower at Knowle have been designed and constructed under the direction of Mr. J. A. McPherson, the Company's engineer.

The Company supplies a population of nearly 400,000, and the average daily supply is about 9½ million gallons. The total length of mains, exclusive of aqueducts, is over 400 miles.

MESSRS. CHAMPIONS, DAVIES AND CO., MANUFACTURING CONFECTIONERS, BRISTOL.

These works have been established about forty years, and are situated in the parish of St. James, the principal entrance being in Lewins Mead, while the side of the factory faces St. James' Churchyard. The goods made by the firm comprise all classes of Sugar Confectionery, and also Chocolates. The number of hands employed is about 200.

THE CO-OPERATIVE WHOLESALE SOCIETY, BRISTOL.

This branch was started in 1884 in a small building in Victoria Street, Bristol, with a staff of six employés. Within a few years the business had grown to such an extent that greater accommodation was required. A large warehouse was accordingly acquired in Christmas Street, and opened in October 1888, and these premises served the Society's requirements until 1905. The business of South Wales was also rapidly increasing, so that a Branch was opened in Cardiff in 1894. At the present time the staff at Bristol numbers 235.

The buildings are situated in the most central position in the City, and adjoin the Floating Harbour. The site is in the form of an island, being bounded by Broad Quay, Prince Street, and Currant Lane, and covers an area of about 2,230 square yards. The premises consist of a basement and six floors above rising to a height of 86 feet from the street, and from the street to the top of the clock-tower the height is 130 feet. About two-thirds of the site has been covered by buildings, but the foundations and basement cover the whole area. The present floor space amounts to 100,000 square feet, which will be increased ultimately to 150,000 square feet.

The principal entrance is at the Quay, with two other entrances from the Narrow Quay, each leading to ample stone staircases which are continued to the top storey. In the centre of the building is an open courtyard which serves as a well-hole for light and a loading-way. The latter is served by four electrically-driven hoists, communicating with every department. The architectural style is a free treatment of English Renaissance. The principal materials used for the exterior are blue pennant stone, which was quarried and worked at Fishponds, near Bristol, and buff terra-cotta from

Tamworth. Internally the construction of the building is fire-resisting, the columns being of iron and the floor of steel girders, filled in with cement concrete and covered with pine flooring. The whole of the power and light is electrical, being obtained from the Bristol Corporation Electrical Department.

Basement.—The greater part of this is allocated to the Grocery and Provision Departments. Particular attention is also given in this space to the green fruit trade, particularly to bananas, and special rooms have been constructed for handling the fruit, the temperature being varied according to its condition by means of Bunsen burners and ventilators.

Ground Floor.—The loading-way previously mentioned runs through this floor, and apart from the necessary space required for the receiving and despatching of goods for all departments, space is devoted to the storing of grocery goods of a heavy description.

First Floor.—On arriving at this floor from the main entrance the visitor is faced by doors in the front leading to the Grocery Saleroom. On the left are the Bank and General Offices in which there is accommodation for 80 clerks. On the south side of the Saleroom is situated the Sundries Grocery Department.

Second Floor.—This is devoted to the Drapery Department.

Third Floor.—Here are stocks of a varied character connected with the Furnishing, Hardware and Carpets Departments. A special room is also provided for the permanent display of crockery from the Longton depot.

Fourth Floor.—The whole of this floor is occupied by the Boot and Shoe Department.

Fifth Floor.—On this floor are situated the Woollens and Hat and Cap Department, also the dining-room for the use of staff and visitors, and the meeting-room, with a seating capacity exceeding 250. The remainder of this floor is utilized by the Grocery Sundries Packing Department.

Sixth Floor.—The kitchens, communicating with the dining-room below, by means of lifts, take up a large portion of the space, and adjacent are the apartments of the resident caretakers, the remainder of the floor being utilized for machinery for self-raising flour, etc.

Bacon Department.—The necessity for a separate building, consequent upon the smoke arising from the smoking of bacon, led to the purchase of two small warehouses on the Narrow Quay, adjoining the depot. These have been adapted for the washing and smoking of all classes of meat, the present output being about 20 tons weekly. Three smoke-houses have been erected, with room for doubling the number. In the same building a specially constructed plant mixes poultry corn, extracting all dust and dirt.

The Head Offices of the Society are in Manchester, and there are branches in London, Newcastle-on-Tyne, and Cardiff, besides numerous other distributing centres and productive works.

MR. EDWARD EVERARD'S PRINTING ESTABLISHMENT, BRISTOL.

This artistic building, situated in Broad Street, was designed and erected in 1901 by Mr. Edward Everard, and is an example of fifteenth-century work illuminated with slab mosaics. The dominant note pervading the scheme is that buildings erected to the Industrial Arts should bear in no uncertain form of expression symbols of their craft or trophies to great originators. To Messrs. Doulton and Co., of Lambeth, was entrusted the general idea, and their principal artist, Mr. W. J. Neatby, formulated an illuminated colour scheme in outdoor ceramics which claims originality. The elevation was treated entirely in ceramic materials of an ivory tone, broken irregularly by deeper shades produced by the natural firing in the kiln. The material is named by the firm as Carrara ware, because of its similarity of texture to Carrara marble, though it has characteristic qualities of its own.

The illuminations in Parian ware give the structure an Eastern tone, associating it with the Byzantine period with which Celtic art is so closely connected. A blue-green plinth is carried about 3 feet above the street line. The ground floor is kept very simple in its general lines, but is relieved by a frieze about 2 feet high of conventional tree forms in colour, with a simple moulding as a cornice. Above this come the two large windows of the first floor, with semi-circular arches. Above the first-floor windows are three spandrils, the centre one having a winged figure representing the "Spirit of Literature," whilst on one side is a life-sized figure of Gutenberg pulling his press, and with his alphabet forming a decoration on the wall space around. On the right is a similar figure of William Morris pulling his press, with his golden alphabet also decorating the wall.

The first floor is crowned and finished by a battlemented cornice, and the upper wall is set back about 3 feet, giving room at each end for an octagonal turret, which is surmounted by domes and finials. The upper part of the building is finished with a gable of quaint form with a large semi-circular arch covering a tympanum, on which appears a heroic-sized figure in slab mosaics, bearing a lamp and mirror in uplifted hands, signifying the symbols of "Light and Truth." The open vestibule is reached by solid steps of opalescent Labrador granite. The gates are of massive wrought-iron, and are designed further to convey the traditions of this age. The walls of the public office are covered with cartoons (in oils) of the Celtic period, and the low colour key gives the office an enlarged appearance.

The letterpress machines on the ground floor are of the Miehle pattern, an American invention constructed upon the "two-revolution" principle of motion. This type of machine is fast superseding the early "stop-cylinder" method, with its cumbersome "brake" arrangement and consequent loss of power. The Miehle is designed for strength and accuracy of work, ensuring that dead "register" required for the three-colour process and the finer classes of colour printing.

The principal machine-room is conveniently placed on the same floor level as the public office; it is in direct lift communication with the composing and lithographic transfer rooms, and for the ready despatch of goods, etc., has egress to three streets. The floor is laid with concrete, and upon this, for the warmth and comfort of the operators, are placed 3-inch pitch-pine blocks. The motive power throughout is electricity conveyed by means of motors, and, with but one or two exceptions, every machine has an independent motor, which being driven direct upon the machine means an absence of the noisy and unsightly overhead beltings. Cableways are formed in covered channels along the floor, and are easily accessible for extensions, the coils being placed in flexible steel tubing.

Printing on the lithographic machines is done by means of aluminium plates. The method is found to be more expeditious and less costly than with the use of lithographic stones, besides effecting the minimum of labour for the operators. The composing-room is essentially laid out for the purposes of display composition, and has an extensive range of old style and modern characters. All type is hand-set, the body founts being cast in the works in single letter from matrices and distributed into type cases.

MESSRS. J. S. FRY AND SONS, SAW MILLS, BOX FACTORY, AND PAPER BAG FACTORY, BRISTOL.

The Saw Mills of this firm are situated in Canons' Marsh, and were built about eight years ago. The machinery is driven by a 50-H.P. compound tandem engine made by Messrs. Bryan Donkin and Clench, and the works are well equipped with circular saws and planing machines. About 80 men are employed at this branch.

The Wooden-Box Factory is situated in Prince Street, and employs about 300 men and girls. All the operations of wood planing, sizing, nailing, hingeing, as well as printing and pasting the covering papers on, are carried out by machinery.

The Paper Bag, Cardboard Case, and Fancy Box Factory is situated in Quay Street. Every operation is carried out by machinery, much of it being of a complicated and highly interesting nature. About 400 men and girls are employed here.

MESSRS. HUMPAGE, THOMPSON AND HARDY, BRISTOL.

This firm was started in 1906, when premises were secured in Jacob Street, within ten minutes' walk from the centre of the City. They comprise a Machine Shop, Fitting and Erecting Shop, Pattern Shop and Drawing Office, with room for extensions as may be needed. The speciality of the firm is the manufacture of high-speed gear-hobbing machines and their accessories. The firm is also building a generating machine for grinding the involute teeth of gear wheels both in the soft state and after hardening. The plant was specially selected for the purpose of manufacturing these machines. It consists of the most up-to-date high-speed machinery, including lathes by five or six of the best known makers, automatic gear-hobbing machines, high-speed planers, universal milling and grinding machines, etc. All the work is carried out with jigs and templates on the interchangeable system. The number of men employed is about 50.

MESSRS. JOHN LYSAGHT, CONSTRUCTIONAL ENGINEERING WORKS, NETHAM, BRISTOL.

These works are situated at Netham, about a mile from the Bristol Joint Railway Station, and cover an extensive area. There is water access by the tidal River Avon on the south, and by the feeder canal on the north. The firm manufactures all descriptions of Constructional Ironwork, comprising bridgework, iron buildings, roofing, pontoons, tanks, etc., as well as timber-framed structures, the capacity of the works being equal to a very large tonnage of finished material per annum. The works are at present busily engaged upon a number of important contracts for the Colonial Office and various Foreign Railway Companies, in addition to structures for erection in this country.

Mention may be made of several contracts carried out in recent years, namely, the construction and erection of the roofing of the Buenos Ayres Produce Market, covering about 9 acres; the whole of the iron and steel work for the new Harbour Works at Gibraltar; the double-deck swing bridge over the Avon at Bristol; widening of the Great Western Railway at Bristol; floating pontoon landing-stage at Bristol and at Barry Dock; extensive shops of the heaviest construction at Messrs. Vickers, Sons and Maxim's Works at Barrow; ore bins and approach viaduct at Dowlais Steel Works.

The extensive shops are equipped with the latest machinery, the whole being driven by electricity supplied by the Bristol Corporation Power-House. The installation comprises twenty-eight continuous current 500-volt motors, manufactured by Messrs. Siemens Brothers; these motors varying in capacity from 10 to 60 H.P. The smaller machines are driven in groups by motors of reasonably high power, individual drives being only adopted with the heavier machines. To economise space, and keep the belting out of the way as much as possible, the motors, where practicable, have been fixed on platforms attached to the roof framing.

The general Machine Shop measures 600 feet by 70 feet. The Girder building-up and Riveting shop 450 feet by 45 feet, covering a Girder erecting shop 320 feet by 50 feet; the last two shops being equipped with 5-ton, 10-ton and 12-ton overhead electric travelling-cranes, by Messrs. Stothert and Pitt. These shops are installed with the latest pneumatic appliances by the Consolidated Pneumatic Tool Co., as well as with high-power electric portable drills; there is also a full equipment of hydraulic riveters.

The Smiths' Shop, 350 feet by 80 feet, has the usual installation of steam-hammers and other appliances, as well as various hydraulic-presses, and there is a Foundry at the north end of the general Machine Shop. The Joiners' and Patternmakers' Shop, 240 by 40 feet, is equipped with the usual type of wood-working machinery.

The works are lighted throughout by electricity, power being generated by a 75-kw. Belliss-Westinghouse generator, taking steam from a boiler 30 feet by 8 feet 6 inches, working at 160 lbs. pressure. This boiler also supplies the steam-hammers, the pressure for this service being reduced to 80 lbs. per square inch.

The Head Offices of the firm are at St. Vincent's Works, Bristol, where the business was established over fifty years ago, and where there is one of the most extensive galvanizing plants in this country. The Black Sheet Rolling Mills are situated at Newport, Mon., and contain the finest machinery and the latest appliances of every description. The Company has offices in London and numerous branch works and warehouses in the Colonies and abroad.

The number of men employed varies from 4,000 to 5,000, o which about 500 are at the Engineering Works above referred to.

MESSRS. PECKETT AND SONS, ATLAS LOCOMOTIVE WORKS, BRISTOL.

These works are situated about ten minutes' walk from th St. George trams and two miles from the Bristol Joint Station They stand on about 5 acres of land, and there are an additiona 8 acres adjoining to provide for further extensions. The work have been in operation since 1864 and have been carried on by th present proprietors since 1880, during which time the works have bee entirely re-modelled and the capacity trebled; they are connecte by sidings to the Midland main line, so that locomotives can be sen to any part of the country on their own wheels. The speciality o production is tank locomotives of all varieties and sizes, of whic over 1,200 have been made; these have been mostly supplied in thi country, although a considerable number have been exported to al parts of the world. All parts of the locomotives, namely, boilers, iro and brass castings, steam fittings, etc., are made on the premises.

The works have a floor space of 101,800 square feet, and the steam power is supplied by three Lancashire boilers, each 30 feet by 8 feet working at a pressure of 130 lbs. per square inch. The Machine Shop with a gallery on both sides is fitted up with all the latest modern tools, and the power for same is supplied by a pair of horizontal compound engines of 300 I.H.P. There are also Smith's Shop, Stores, Coppersmiths' Shop, Pattern Shop, Iron and Brass Foundries, Brass Finishing Department, Erecting and Paint Shops.

The Boiler Shop is 320 feet by 50 feet, and adjoining is the power-house in which are a pair of vertical compound condensing engines of 150 I.H.P. In the same building is a compound air-compressor with receiver, etc., for supplying pneumatic pressure at 100 lbs. per square inch, besides which are hydraulic pumps and an accumulator for 1,500 lbs. pressure for supplying power to riveters, 200-ton flanging-press and cranes. Here is also a separate engine for driving the electric light installation for lighting the works by means of some 70 arc-lamps, together with numerous incandescent lamps. The number of men employed is about 375.

MESSRS. E. W. SAVORY, FINE ART PUBLISHERS, BRISTOL.

The publications of this firm include principally Fine Art Calendars and Christmas Greeting Cards, which are known by the title of the "Clifton Series," together with picture publications of various kinds, including the well-known sporting pictures by George Wright.

The present premises, which occupy a commanding position overlooking the whole of the City of Bristol, were erected in 1906 from the plans of Mr. Mowbray A. Green, and represent the most modern type of industrial buildings, the outside suggesting the appearance of a handsome residential building. The front of the premises is occupied by the Entrance Hall, Offices, Dining Hall, etc., and behind these is the large Central Hall covering a space of 50 feet by 100 feet, in which the principal work is carried on. This rises two stories in height with a teak gallery running all round, the photographic operating studios, printing rooms, etc., being on the floor above. The premises, which are entirely detached and stand in a very elevated position, command a good and uninterrupted light which is necessary for the work. Palms have been placed in various parts of the Central Hall, and workers are clad in blue linen overalls during working hours. Everything has been done that the work may be carried on under the best possible conditions.

In the publications of this firm the prominent feature is the reproduction by various processes of high class original paintings and drawings, the majority of which are commissioned in black and white, and are the work of well-known English and Continental Artists. The processes of reproduction are principally photographic. In the manufacture of the various articles very little machinery is employed, except in the printing department. A large proportion of the publications are in colour, but this work is for the most part coloured by hand, giving a much finer and more delicate result than can be obtained by colour printing. A number of colourists are employed on the premises, but the firm have various studios in the City of Bristol, many of the colourists having been taught in Paris, so as to acquire the style necessary for the Continental trade. Photogravure printing is also largely employed, and the embossing and relief stamping used in connection with the Christmas Greeting Card Publications is of the highest order. The Aerograph brushes are worked with an air pressure furnished by a pump in the engine house.

The Photographic Operating Studio is equipped with the most up-to-date apparatus. The copying camera and easel is of special design throughout, the stand of same being 20 feet in length. The daylight printing rooms are fitted with an arrangement of trays and runners by which negatives can be immediately exposed for outside printing. The dark rooms and gaslight printing-rooms are fitted with all the most recent appliances. A small box-making plant has also recently been installed for the purpose of making the necessary cases and protectors for the firm's own publications.

The "Clifton" Publications are well known throughout Great Britain and are also exported largely to the Continent and America, in spite of the heavy import duties of the various countries. They have invariably received the highest awards wherever exhibited.

The premises are heated throughout by two systems of hot air and hot water, and thoroughly ventilated. A system of intercommunication telephones has been installed throughout the building. The motive power is furnished by a 10-H.P. gas-engine, and a dynamo conveys current for the ventilating fans, a small motor, and a limited number of incandescent lights. Cloak rooms and bath rooms have been provided for both male and female workers, and a Broadwood piano in the gallery of the Central Hall for their use during the dinner hour. The number of workers employed is about 100.

MESSRS. STEPHENS BROTHERS AND MARTIN, ST. PHILIP'S HEMP AND FLAX MILLS, BRISTOL.

Bristol stands in the centre of a district comprising the three counties of Gloucester, Somerset, and Wiltshire, in which a considerable amount of woollen manufacturing is carried on. It has also a large cotton-spinning mill, and for upwards of a century the spinning and manufacturing of hemp and flax yarns and fabrics have been carried on at these mills by the firm of Messrs. Stephens Brothers and Martin, which prior to that was founded in the eighteenth century at Bridport, in Dorsetshire.

The materials spun and manipulated by this firm are sundry varieties of what are known as the soft spinning fibres, namely Russian hemp and flax, Italian and Hungarian hemps, Dutch and Belgian flaxes, Irish flax, and a diminishing quantity of English-grown flax and hemp, the latter having unfortunately gone much out of cultivation in recent years from a variety of causes. Italy has given special attention to the cultivation and subsequent preparation of good hemp; and Italian-grown hemp is the longest, finest, and best-coloured hemp produced in Europe. Indian hemps of many different qualities and grades have in recent years been introduced into this country, chiefly on account of their low price, and to mix with and cheapen the stronger and dearer European fibres.

The advent of steamships during the last half-century has materially curtailed the demand for the best all-long flax sailcloth, which this firm made one of their specialities; but since their present Managing Proprietor, Mr. G. Palliser Martin, joined the firm in 1889 they have so altered and adapted their machinery for the manufacture of other hemp and flax yarns and fabrics, that they have in recent years quite changed the character of the goods they manufacture, which now embrace large quantities of hemp sackings, canvas and sheetings for the Admiralty, War Office, and other Government departments, as well as the spinning of yarn for cable work, twine and cord making, and a variety of other purposes.

The mills were considerably enlarged last year by the addition of a new wing of two floors in the middle yard, about 200 feet long by 50 feet wide, the machinery of which is to be driven by a new horizontal tandem compound condensing steam-engine of 300 H.P. by Messrs. Woodhouse and Mitchell, of Brighouse, at 120 lbs. steam pressure supplied by a Lancashire boiler, 30 feet by 8 feet, recently put in by Mr. John Thompson, of Wolverhampton.

The motive power at present is supplied by a compound condensing beam-engine of the old type, put down in 1835 by the old Bristol firm of Aikerman, originally with only a single cylinder, but compounded by McNaught, of Manchester, about the year 1860. The number of workpeople employed is about 200.

THE BATH CABINET MAKERS' CO., TWERTON-ON-AVON, BATH.

The City of Bath has long been famous for the manufacture of high-class furniture. Thirteen years ago the above Company was formed, and the works, which are reached by tramcar in ten minutes from the Guildhall, were built with the intention of manufacturing furniture on a larger scale than previously attempted in Bath.

The Factory, which was built to the designs of Messrs. Silcock and Reay, of Bath, was specially planned to secure economy in the cost of production: all the recent improvements were taken advantage of, with the result that the works form a very good example of an up-to-date Cabinet-making establishment.

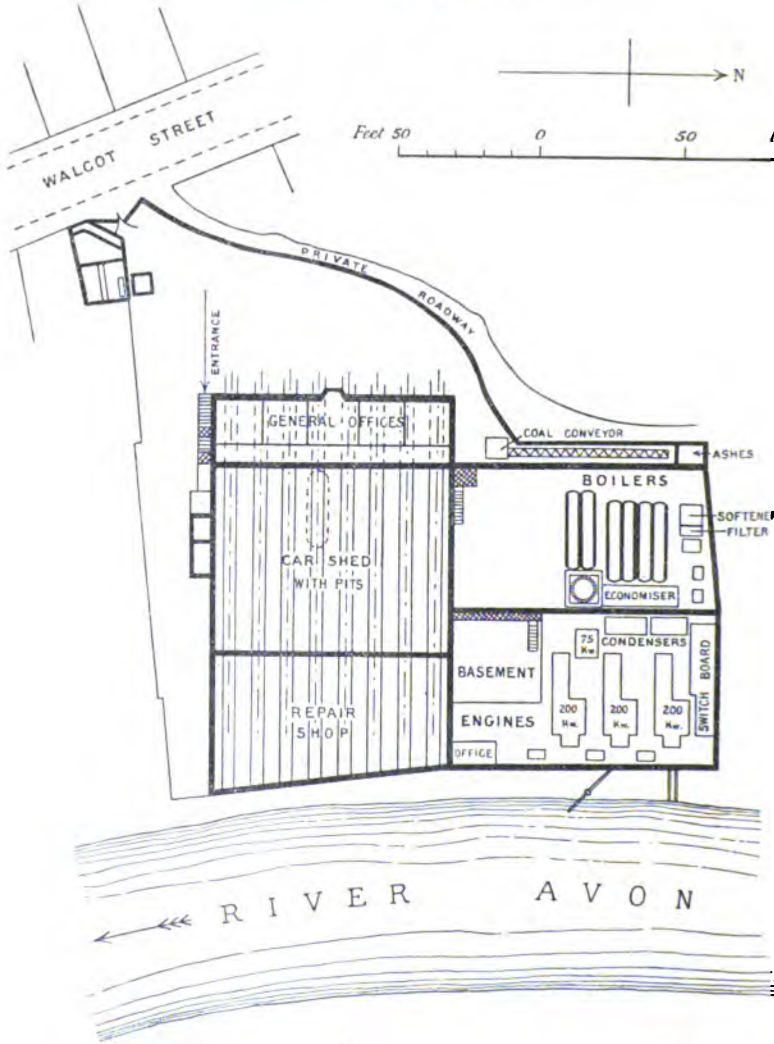
Special attention was given to the Machine Shop, which is of large proportions, giving ample space between the various machines and having an excellent head light. The machines themselves are examples of the latest developments in wood-working machinery. Steam provides the motive power, the machinery being driven by a 50-H.P. engine. The Machine Shop is fitted with a dust and shaving-extracting system, so that it always presents a smart and clean appearance. The refuse is carried to the furnace.

The works have a complete electric-light installation with storage battery, providing light for all the Workshops, Show-rooms and offices. Other features in the factory are the drying stoves, and the well laid-out floors for the various trades. In the Show-rooms can be seen examples of the finest modern cabinet work, designed in the firm's studios, also many faithful reproductions of the best furniture of the Elizabethan, Stuart, Queen Anne, and Georgian periods. Fine Grinling Gibbons carving is also specialized by this firm. Another branch of the Company's trade is the manufacture of all kinds of internal decoration, joinery, including wood mantelpieces, and in this section of the trade they are one of the largest manufacturers in the kingdom. The managing director, Mr. Charles A. Richter, holds a leading position as an expert on all matters relating to the architecture of the home, and the furnishing and decorating of public buildings. The number of men employed is about 250.

BATH ELECTRIC TRAMWAYS POWER STATION.

The combined Power-House and Car-shed of the Tramway Company is centrally situated on the banks of the River Avon, with a frontage in Walcot Street, and about three minutes' walk

Bath Electric Tramways Power Station.



from the Municipal Buildings and Guildhall. Together with the workshops and tramcar repairing depot it occupies an area of practically an acre, and measures roughly 70 yards by 60 yards. The buildings cover about three-quarters of this area, and are built of red brick and reinforced concrete. They were opened in December 1902, and include engine and boiler rooms, repair shop and car-shed, whilst the general offices are conveniently arranged above the car-shed overlooking the main entrance. The engine room and boiler house run parallel to each other, while at right angles to these and across the south end is built the car-shed, underneath which is the repair shop.

ENGINE ROOM.—This room measures 93 feet long and 51 feet wide, and contains three 200-kw. and one 75-kw. compound wound direct-current sets. Sufficient space is left for extensions. The generators are all of British Westinghouse manufacture, and are capable of sustaining a 50-per cent. overload for one hour and a 100-per cent. overload momentarily. The 200-kw. generators are coupled direct to Yates and Thom engines, each of 320 H.P. These engines are of the horizontal tandem compound type running at 100 revolutions per minute, the valves being operated by the well-known Corliss gear with Dobson dashpots. The smaller generator is direct coupled to a British Westinghouse vertical single-acting compound engine of 120 H.P. running at 300 revolutions per minute.

Condensers.—The two condensers are situated in the basement beneath the engine room and are of the ordinary surface type manufactured by the Wheeler Condenser Co., having a cooling surface of 3,000 square feet. The engine for driving the air and circulating pumps is placed directly beneath the condenser.

Oil Separator.—A mechanical oil separator by Messrs. Holden and Brooke is placed in the main exhaust-pipe for the purpose of extracting the oil from the exhaust steam before the same passes into the condensers. The condensed steam is delivered to a hot-well, from which it is fed back into the boilers.

Switch Board.—This is of the ordinary British Westinghouse traction type and runs along the north side of the engine room, the platform being raised about 6 inches above the engine room floor.

Auxiliary Plant.—This consists of three 20-H.P. negative boosters of Westinghouse manufacture. These are coupled to the return traction feeders connected with the outlying districts of the city.

Electric Traveller.—A 15-ton electric traveller, supplied and fitted by Messrs. Stothert and Pitt, of Bath, spans the engine room, and is supported by columns and girders independent of either of the engine-room walls.

BOILER HOUSE.—This house measures 90 feet by 49 feet and contains three double-drum Babcock and Wilcox water-tube boilers fitted with superheaters, each capable of evaporating 10,000 lbs. of water per hour at a working steam pressure of 150 lbs. per square inch.

Coal Conveyor.—The coal, which is a mixture of Ashton Vale (local) and Welsh small, is brought each morning in carts, weighed over the Company's weighbridge, and is tipped into the hopper of the conveyor which is driven by a 5-H.P. British Westinghouse direct-current motor running at 1,100 revolutions per minute. The coal is thence distributed to the storage bunkers which run the whole length of the boiler house, these being placed immediately in front of the furnaces. The storage bunkers have a capacity of about 80 tons, the average consumption of coal being about 60 tons per week.

Feed Pumps.—These consist of two vertical steam-pumps made by Messrs. Hall, of Peterborough, each pump being capable of dealing with 2,400 gallons per hour, working against a pressure of 150 lbs. per square inch at a speed of 14 double strokes per minute.

Water-Softening Plant and Grease Separator.—This apparatus is situated in the boiler house next the feed-pumps, and was installed by Messrs. Masson, Scott and Co., of Bow. The water is treated with soda till a standard of 4° of hardness is reached. The alum is added to condensed water for the purpose of separating out the grease, and the whole passes through a filtering tank which contains pebbles and sand before it enters the hot-well. The whole apparatus is entirely automatic.

Economiser.—The economiser is placed at the rear of the three sets of boilers, and immediately over the main flue and adjoining the foot of the stack. It is of the Clay Cross pattern and contains 240 tubes, having an area of 3,000 square feet. The mechanical scrapers are driven by means of a 3-H.P. British Westinghouse direct-current motor.

CAR-SHED.—Over the Car-Shed is a single span roof of structural steel work covered in with slate and glass. The shed is a commodious building measuring 130 feet long by 82 feet wide, and giving accommodation for thirty-four double and six single deck-cars, also one water-car and track cleaner. Eight lines of pits give access to the under side of trucks for repair purposes. The cars are fitted with the Westinghouse standard equipment, consisting of two 49B motors with 90M controllers and magnetic brake.

As the question of tramcar brakes is very much to the fore at the present time, it may be of interest to call attention to the latest development now at work in Bath. This consists of a mechanical attachment to the magnetic brake, so that the brake can be operated mechanically as well as electrically. The mechanical attachment does not in any way interfere with the operation of the magnetic brake, *i.e.*, the magnetic brake can be used for regular service or for emergency independent of the mechanical attachment, and the mechanical attachment can be put into use either alone or together with the magnetic brake.

Paint Shop.—The painting and decorating shop is an enclosed building of corrugated iron in the south-east corner of the car-shed.

Repair Shops.—Immediately connected to the car-shed by means of a sloping gangway is the repair shop, a building 80 feet long by 40 feet wide, side lighted by means of six large windows overlooking the river. The workshop is fitted up throughout with up-to-date machinery, the whole being driven by a 10-H.P. British Westinghouse motor, and comprises lathes, drilling and shaping machines, air-compressor, blacksmith's forge with fan, also a complete re-tyring plant, together with wheel-press for pressing on or off wheels, and capable of exerting a pressure of 120 tons.

MOTOR GARAGE.—This company has, in addition to the forty cars, twelve motor omnibuses, six having been supplied by Messrs. Milnes-Daimler, and six by Messrs. Sidney Straker and Squire. These act as feeders to the cars, and also form a connecting link between the City of Bath and the neighbouring villages. The garage is situated about three-quarters of a mile from the Guildhall on the main London Road. Together with petrol, carbide and general stores, smithy and tinker's shop, it covers an area of about ¾ acre. The garage proper is a double-span corrugated iron building, top and side lighted, measuring 80 feet long by 50 feet wide, having a concrete floor, and galvanized swing doors to entrance. It has accommodation for twelve omnibuses, with a pit running the whole length of the shed, enabling three omnibuses to be inspected at the same time. The building is lighted throughout with electric light supplied from the company's mains. The garage is also equipped with a lathe driven by a 3-H.P. British Westinghouse motor, also re-tyring plant.

MESSRS. JAMES FORTT,
ORIGINAL BATH OLIVER BISCUIT FACTORY, BATH.

The "Original" Bath Oliver Biscuit was invented by the celebrated Dr. Oliver in 1735, who was at that time physician to the Bath Mineral Water Hospital. The only biscuits then before the public were the "Captain" and the "Abernethy," and, no doubt, the success of the latter in some measure induced the doctor to turn his attention to the production of another first-class biscuit, which should be not only a novelty but a luxury, and an aid to digestion. The doctor, who died in 1764, bequeathed the secret of the composition of the biscuit to his coachman, who took a small shop in Green Street, Bath, and became its sole manufacturer. Eventually it came into the hands of the present proprietor, who for many years carried on the manufacture in the "original" house. The premises, however, had to be constantly enlarged, and a large factory equipped with every modern improvement was added in Manvers Street.

The old method of manufacture was what was known as the staff brake. This was an appliance of the simplest description; merely a staff of wood attached at one end to the side of a table or board, on which the dough was placed in such a manner as to allow of its being freely pressed. The dough was first thoroughly kneaded with the staff in this way, then each biscuit was weighed and moulded by hand, and, lastly, separately rolled with rolling-pins.

The staff brake in time became too slow and cumbersome for the purpose, and gave way to the steel roller. The principle was the same as that of an ordinary mangle, but the time came when it also had to yield to much quicker methods. The place of the old hand-turned mangle was taken by machinery, designed and introduced by the present proprietor. This consists of three sets of rollers driven by power. In addition to the celebrated biscuits, a large variety of cakes, buns and confectionery is produced at the bakery.

THE GRIFFIN ENGINEERING CO., KINGSTON IRONWORKS, BATH.

These works are the outcome of a business started forty years ago by Mr. Samuel Griffin, who is now the managing director of the Company. Originally engaged in general engineering and the manufacture of steam-engines, Mr. Griffin was one of the earliest makers of gas-engines and took out many patents for improvements in principle and detail. Later, the manufacture of oil-engines engaged his attention, and at the present time engines for using the heavy hydro-carbons are a speciality of the Company, which owns numerous patents for these special appliances. These engines have been sent all over the world and are used both for stationary and marine purposes; for the latter various special appliances in the form of starting and reversing gears, feathering and other propellers, etc., are manufactured by the Company.

The present works, covering about an acre with land adjacent for extensions, consist of a main machine-shop fitted with the various machine-tools for making engines up to 200 H.P. The machinery is driven by a Griffin gas-engine in the power-house supplied with gas from a suction plant which has the firm's special fuel-feeder, an improvement which has revolutionized the use of such apparatus, as it ensures a gas of uniform quality giving perfect working at various loads, and without necessitating either constant or skilled attention. With an improved gas-engine to work with this gas, the Company are now making arrangements to supply these plants in various standard sizes, a large additional machine-shop having just been erected for this purpose. Separated from the main shop is a testing-house where the engines are thoroughly tested and finally adjusted. A large pattern store is isolated from the main buildings.

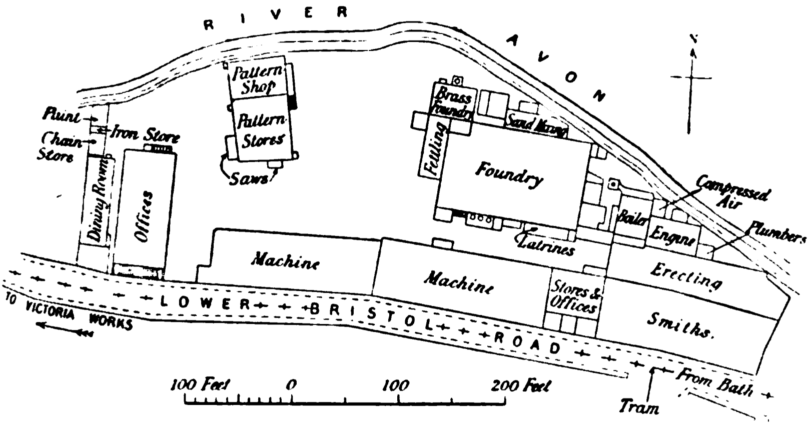
The office block consists of a well-lighted drawing office, clerks' and private offices with the main store, on the ground floor, the upper part being used as a Pattern Shop fitted up with circular and band-saws, lathes, drills, and other wood-working machinery. A blacksmith's shop and various outbuildings, with a workmen's dining-room, complete the works, which are lighted throughout with electricity. This is generated in the power-house from a dynamo driven by a Griffin engine run with suction-gas from a Griffin producer. The number of men employed is about 70.

These works, however, represent only a very small percentage of the whole industry actively engaged in the manufacture and sale of the "Griffin" specialities. Palmer's Shipbuilding Co., of Jarrow-on-Tyne, besides having an interest in the Company, hold an exclusive license for Great Britain for the manufacture of the larger sizes of the marine type of oil-engines from 100 H.P. upwards, and are now actively engaged in making the necessary arrangements for a large output. Recently the firm of Messrs. Weyher and Richemond, of Pantin, near Paris, have secured a similar license for France and its Dependencies, with the further right to sell in Spain, Belgium and South America. This firm alone will employ about 800 men in this department only. Negotiations are also at the present moment being matured between the Company and a large firm of electrical engineers in Germany for the exclusive license to manufacture and sell the "Griffin" system of "Auto-Magneto" ignition.

MESSRS. STOTHERT AND PITT, ENGINEERING WORKS, BATH.

This Company commenced operations as a private firm in the early part of last century, and in the year 1883 was converted into a limited company. The works have in recent years been largely extended, and now consist of the principal or Newark Works and the branch or Victoria Works, both situated in the Lower Bristol Road. Both have access by water, and the Victoria Works are connected by a siding with the Midland Railway. The main works contain the Offices, Stores, Machine Shops, Pattern and

Plan of Newark Foundry.
Messrs. Stothert and Pitt.

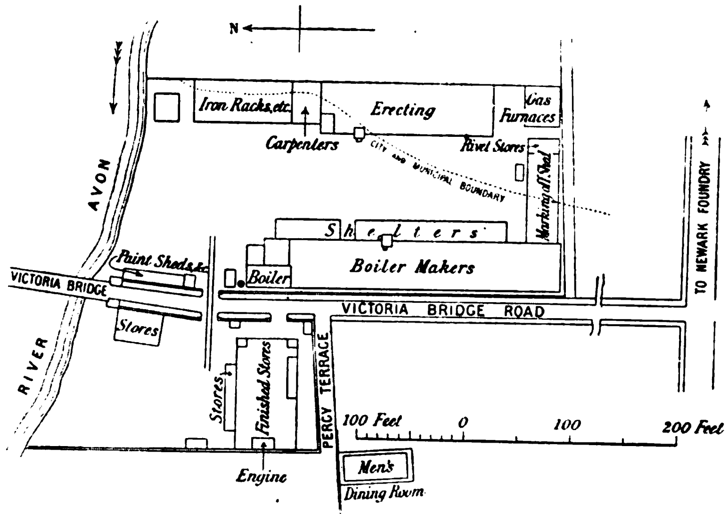


Carpenters' Shops and Foundry, Smiths' Shop, Tool Room, Electrical Fittings Department and a large Erecting Shop and Yard; at the Victoria Works are situated the Boiler and Structural Steel Departments, a large store for standard finished parts, a large erecting shop and two erecting yards.

The offices are a modern range of buildings, and contain on the first floor the secretarial, private offices, estimating and typing departments, and on the second floor a well-lighted drawing office 54 feet by 45 feet, head-draughtsman's office, drawing store and board room; the upper storey is devoted to phototyping.

The large Machine Shop is to the right of the entrance, and is 310 feet long by 50 feet wide; it has galleries for small tools and electric fitting work. Amongst other notable tools may be mentioned a very large milling machine by Messrs. Hetherington, of Manchester, taking work 9 feet 10 inches wide by 20 feet in length by 6 feet 3 inches high; also quick-running planers by Bateman and others and a range of boring mills, the last of which is now being erected to take 14 feet diameter. There are a number of capstan and other

Plan of Victoria Works.
Messrs. Stothert and Pitt.



lathes of heavy modern type, modern radial drills, and an extensive wheel-cutting plant, also bevel gear planers. In the galleries are a range of capstan lathes for bar work and other small tools. The Machine Shop is driven electrically and is served by two electric travellers.

In the North Gallery switchboards, cable drums, and light fittings and other electric details are fitted up. The centre block, which previously contained the stores and offices, is now entirely occupied by stores and tool rooms; in the latter are made milling cutters, gauges and other tools. The gauges are ground up in a Brown and Sharpe precision grinder. At the east end of the works is the Smiths' Shop, 160 feet by 42 feet, fitted with three steam-hammers where much stamping is carried out, also the Erecting Shop, 165 feet by 50 feet, which is served by a 12-ton electric traveller.

Opening out of the Erecting Shop is the Generating Station in which are two Belliss and Morcom-Siemens sets, each of 137 kw. and a small set of 60 kw., steam being supplied by two Lancashire boilers fitted with Bennis automatic stokers and economisers. At the back of the Generating Station is the air-compressing plant.

The Foundry is to the north of the Machine Shop, and is 130 feet by 85 feet. There are two bays, one fitted with a 12-ton electric traveller, the other, for light work, fitted with two 3-ton electric travellers. There are also two 5-ton swing cranes placed on the columns separating the bays, which enable loads to be passed from one bay to the other. There are three cupolas of various sizes, and the usual drying stoves. Behind the Iron Foundry is a Brass Foundry. At the west side of the yard are the Carpenter and Pattern Shops, also a Pattern Store for current work, although the principal Pattern Store is a building separate from the works.

At the Victoria Works the largest shop is the Boiler and Girder Shop, 250 feet by 45 feet, served by a 10-ton electric crane. It contains the usual equipment of plate rolls, plate planing machine, shears, drills, etc., and a pneumatic-riveting plant. The plate furnace is heated by a Dowson gas plant. Opposite the Boiler Shop is a large Erecting Shop 160 feet by 45 feet, fitted with a 12-ton electric traveller and lathes and drill for adjustment purposes. The space between the two shops is occupied by wide lean-to shelters, in which are shears and plate rolls, and by the Erecting Yard. The latter is served by a high 10-ton steam Goliath and by a 12-ton steam jib-crane mounted on a high portable gantry-truck, also two smaller portable steam-cranes. Adjacent to the yard is a smaller erecting yard and large store for finished standard crane parts, also a small Fitters' Shop for assembling concrete mixers. This yard is served by a 12-ton steam gantry-crane. At both works are commodious dining-rooms for the men. The Victoria Works are electrically driven from the Corporation mains.

The work carried on is general engineering of all kinds, but the leading specialities are harbour plant, Titan cranes, concrete mixers, and especially electric jib-cranes mostly for dock equipment purposes and also general cranes of all kinds, particularly railway hand-driven cranes. The number of employees at present is about 1,000.

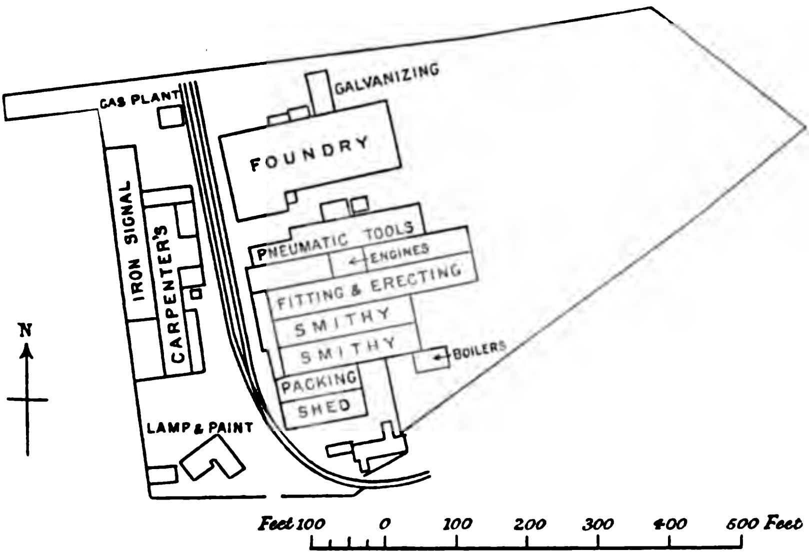
MESSRS. SAXBY AND FARMER, RAILWAY-SIGNAL WORKS, CHIPPENHAM.

These works are situated about five minutes' walk from the Great Western Railway Station, on about 10 acres of land, five of which are at present occupied, the remaining five being taken up with a view to extensions. At the north end of the works is the gas plant which provides power for engines whose total capacity is approximately 370 B.H.P. To the east side of the above is the Foundry with a floor space of 18,800 square feet, having an average output of 50 tons per week, and employing 120 to 140 men. Adjoining this on the south is the Pneumatic-Tool Department, where a large number of up-to-date machines, including automatic lathes, have been installed for the production of high-class pneumatic hammers, drills and moulding machines. The low-pressure pneumatic signalling apparatus is also manufactured here. The necessary power for this Shop is provided by a 100-H.P. Crossley gas-engine and suction plant.

Adjoining the Pneumatic-Tool Department is the Fitting and Erecting Shop for interlocking apparatus, electrical instruments and other signalling gear. A large number of machines for dealing with this class of work are fixed here and are driven by a 100-H.P. gas-engine in an adjoining Engine Room, which contains also a 100- and a 33-B.H.P. gas-engines for lighting purposes and an air-compressor for supplying the pneumatic tools and hoists used throughout the works. Both in the Pneumatic-Tool Shop and Fitting Shop are tool rooms for the distribution of jigs, templets and special tools on the latest methods.

On the south side of the Fitting Shop is the Smithy with a weekly output of about 15 tons. A large quantity of drop stamp work is done in this shop by five steam and five belt-driven stamps with tups varying in weight from 9 to 15 cwts. A Ferguson bar-heating oil-furnace has just been installed. At the south-east corner of the Smith's Shop is the Boiler House, containing two 7½ feet by 28 feet Galloway boilers, draught for which is obtained by a 90-foot stack. On the south side of the Smith's Shop is the Packing Shed, capable of dealing with about 200 tons to 300 tons of packed cases at a time. Next to this are spacious Stores for the receipt of castings, forgings and bought materials.

Railway-Signal Works, Chippenham.
Messrs. Saxby and Farmer.



Returning to the gas plants, on the west side are:—

(1) Iron Signal Shop, where iron signals of all sizes and descriptions are manufactured, pneumatic hammers playing a very important part in the process.

(2) The Pattern and Carpenter's Shops, in which the chief products are wood signals, cabins and level-crossing gates. The plant comprises three circular and two band-saws, planing and morticing machines driven by a 60-H.P. Crossley gas-engine, which also drives a dynamo supplying light for this section of the works.

In the south-west corner are the Lamp and Paint Shops; in the former are manufactured the various signal, disc and other lamps used in signalling work. The Firm at present employs between 700 and 800 men, and was founded by John Saxby in 1856, their first works being at Hayward's Heath. From there the works were moved to Kilburn, where a flourishing business was carried on till 1903, when they were moved to Chippenham.

MONKS PARK QUARRIES, NEAR CORSHAM.

The Monks Park stone mines, belonging to the Bath Stone Firms, Limited, are situated about 8 miles from Bath to the north-west of Wilts, and are in the principal area from which the Oolite (which has gained for itself, under the title of Bath Stone, a high reputation which it has so well deserved) is quarried. The Romans were probably one of the first to use Bath stone for building purposes, and the massive structures at and around the hot mineral springs in the City of Bath (erected nearly 2,000 years ago) are still in a state of preservation, which testify to the wisdom of the Romans and the excellence of the stone. At Box, about three miles from Monks Park, the Saxons excavated large quantities for the erection of Malmesbury Abbey and other monastic buildings, and to this day stone is being quarried from the same neighbourhood, and sent all over the world.

The Monks Park Mines yield a compact, close-grained, even-textured, and very strong stone, suitable for exterior work in any position. It is situated to the south of the village of Corsham on the estate of Sir John Goldney, whose residence was designed by Adam, the famous architect. The mine is reached by a slope shaft, 1 in 2, about 90 feet below the surface of the ground, the system of mining the stone is universal throughout the whole of the district. The coal-miner under-cuts his coal, and the mass may fall and break, but building stone so quarried would make a valueless rubbish heap. The freestone miner or quarryman has to commence his operations at the roof of the stone. This "picking" operation is effected by means of long-handled pickaxes, and the men thus make their driving a distance of 6 to 7 feet back in the rock. The width or span of the workings must of course depend upon the soundness of the rock, but at Monks Park they can be driven a width of 25 to 30 feet without any danger. The removal of 8 or 9 inches of the rock immediately under the ceiling deprives the overlaying strata of the support of this area of stone as effectually as its removal throughout from roof to floor would do, but any tendency to settle or drop is at once detected, and any risk to life and limb thus guarded against.

The next process is the cutting of the rock into blocks of random dimensions, and for this a one-handled saw is used. These saws are worked in lengths of 4, 5, 6 and 7 feet, and are made broad and deep at the head or extreme point, so as to ensure the saw sinking to its work at that point. The rock is thus opened down to the next natural parting and the block is thus separated literally from the parent rock, levers are introduced into the bed or parting at the bottom, and these levers are weighted and shaken till the block is forcibly detached at the back. It is then lewised and drawn out by crane power, the broken end and beds dressed with the axe so as to make the block shapely; it is then placed upon a trolley, pulled up the shaft and taken to the loading wharf. After the first block is removed, the workmen have access by the opening made to the back of the bank of stone, and avail themselves of this to work the saw transversely, which, separating the block from its back or hinder attachment, renders all further breaking off unnecessary.

The extent of the workings in the mines of this Company is something approaching 60 miles. The ceilings are 12 to 15 feet high and there is no inconvenience whatever in traversing the roadways, the air being good, and with a powerful lamp one's way can be easily found. Many large public buildings throughout the country and in South Africa have been built of stone from these quarries, one of the most recent being Christ's Hospital, Horsham.

MESSRS. SPENCER AND CO., ENGINEERING WORKS, MELKSHAM.

These works are situated on the Great Western Railway near Melksham Station, which is about twelve miles from Bath. They were erected about five years ago owing to the then existing works, which were situated about half a mile further from the railway, being much too small to cope with increasing business. The new works were accordingly entirely designed and constructed throughout by Messrs. Spencer and Co. to suit their own special requirements. They occupy a site of about eleven acres, bounded on one side by the railway and on the other by the main road from Melksham to Chippenham. A complete system of railway sidings runs from the Great Western main line through the various shops and yards, so that material can be unloaded from, and finished work loaded into, railway wagons at the most convenient points. There is also a supplementary system of narrow-gauge rails through the various shops.

The offices front the road, and are arranged in the most convenient manner for inter-communication, and the private rooms of the joint Managing Directors are so placed that they command a view from the windows, not only of the general office, but also of the main workshops.

The Drawing Office is on the first floor and provides thoroughly well-lit and complete accommodation for about sixty draughtsmen. There is also a fireproof room for storing drawings and a complete photographic department. The Tracing Department, where a staff of lady tracers are employed, is in communication with the Drawing Office by means of a special lift. All the offices are mechanically ventilated and heated by a system of hot-water radiators, and are electrically lighted. A system of telephones connects the various departments, both of office and works. The Drawing Office also connects through double fire-proof doors with a passage leading to the Pattern Shop and Joiner's Department, which is fitted with complete outfit of modern wood-working tools.

The main shops consist of six bays, each 50 feet span by 260 feet long; of these five form one large open shop containing Machine Tool, Fitting, Erecting and Constructional Steel Departments, while the other, which is partitioned off by a brick wall, forms the principal Moulding Shop. In an annex of the latter small machine-moulding is done, also brass casting, and the cupolas are situated there. Each bay is commanded by 10-ton electric travelling cranes, and in addition to these there is a system of pneumatic cranes in the Foundry.

The Machine Department is fitted throughout with modern and efficient tools and a complete and thoroughly fitted-up tool-room is provided, fitted with special appliances for forging, tempering and grinding the high-speed tool-steel which is exclusively used. The partitions forming the tool-room and also the partitions shutting off the general stores are made of open expanded metal work, so that there is as little interruption as possible to view throughout the shops. The workshops throughout are exceptionally high and the roofs are glazed, so that abundance of light is provided. A complete system of heating and mechanical ventilation is also provided, so that the men can work in comfort and under the best conditions at all periods of the year.

The steel constructional work yards are well commanded by travelling steam-cranes, overhead gantry-cranes and both narrow gauge and ordinary gauge railway lines. They are fitted with modern machine tools and hydraulic and pneumatic plant necessary for the production of all kinds of high class structural work. The whole of the works and yards are electrically lighted, and all the tools are electrically driven from a central generating station which is placed at some little distance from the main shops.

An extensive Pattern Store about 30 feet wide by 250 feet long, in two storeys, has been built some distance from the main shops so as to be isolated in case of fire. The works have their own sewage system of septic tanks. A large mess-room is provided for the men, completely fitted with cooking appliances, and a large bicycle shed provides for those who live at a distance. The whole of the works are specially adapted for the convenient and economical production of elevating and conveying plant for grain, coal, ore, cement and all other materials, and for the various labour-saving appliances with which Messrs. Spencer and Co.'s name is so closely associated. The average number of employees is about 700.

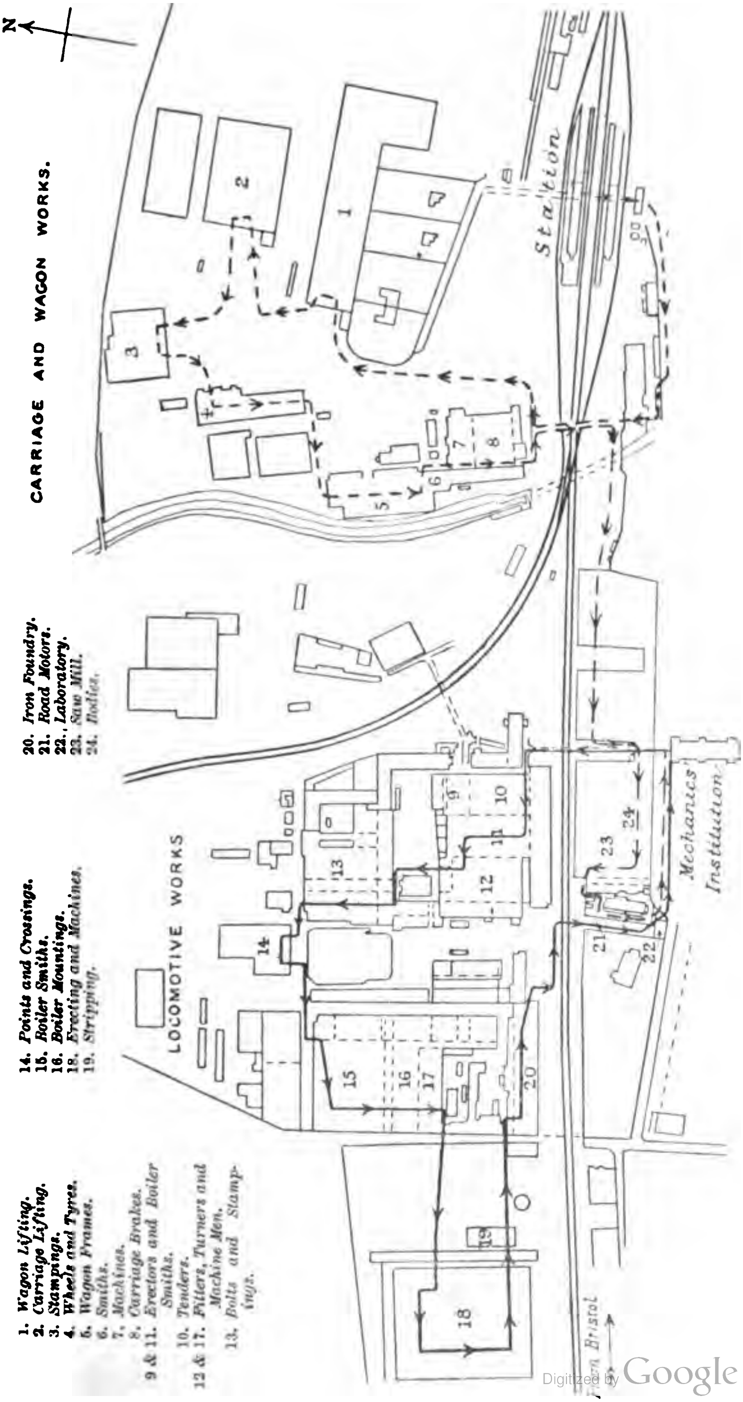
GREAT WESTERN RAILWAY LOCOMOTIVE, CARRIAGE AND WAGON WORKS, SWINDON.

Swindon is the headquarters of the Great Western Railway Locomotive, Carriage and Wagon Department. The works, which have grown with the railway, were founded in 1842. At that time, the old town of Swindon (which dates back some eight centuries, and is mentioned in Doomsday book) had a population of 2,500, and was a mile distant from the works. The population is now nearly 51,000. The original line of the Great Western Railway extended from London to Bristol, a distance of 118 miles. Extensions and amalgamations have brought the total mileage up to 2,878 at the present time.

The Rolling Stock owned by the Company on 31st December, 1907, was as follows:—Locomotives 2,538; Carriages 6,525; Carriage Stock 1,159; Wagons 68,238; Rail-Motor-Cars 99; and Trailer Cars 70. All new carriage and wagon stock (including rail-motor-cars and road vehicles) are built at Swindon, also the greater portion of the locomotives. A few of the latter, however, are constructed at Wolverhampton.

There are branch repairing shops at Wolverhampton, Worcester, and Newton Abbot, but the greater part of the repairs are done at Swindon, where also a great variety of other work is dealt with; rail chairs are supplied to the Permanent Way Department, points and crossings are manufactured, castings and stampings for the Signal Department, and furniture and fittings for stations. The

PLAN OF SWINDON WORKS.



heavy repairs to the large pumping engines at the Severn Tunnel, and to the very numerous hydraulic installations at the Company's stations and docks, are also carried out by the Swindon staff.

The Rolling Mills were erected in 1861, the Carriage Works in 1868, and new Iron Foundries in 1874. In 1902 a large Erecting and Machine Shop was built, very completely equipped with electric power. Large additions have recently been made to the Wagon Works, including a new block of stores and offices. The total area of the works is 254 acres. The number of employees is approximately as follows:—Locomotive Department 8,000; Carriage and Wagon Department 5,000, making a total of 13,000. The shops are large and well lighted, modern methods are in use, electric power is being rapidly introduced, while a special feature is the extensive use made of hydraulic and pneumatic appliances.

LOCOMOTIVE WORKS.

These are situated to the north of the main line, and are approached by a subway (page 775). At the end of the subway are the Locomotive Superintendent's Offices, a three-storeyed building of stone, having two wings 180 feet by 46 feet 6 inches and 148 feet by 45 feet 6 inches. This block also accommodates the Stores Superintendent and his staff.

Drawing Office.—This forms the top storey and consists of two wings 148 feet by 46 feet 6 inches and 148 feet by 45 feet 6 inches. It is one of the most up-to-date in the country, spacious and lofty, and lighted by inverted arc-lamps. In connection with the Drawing Office there is a large studio for photo-printing and photography, built over part of an adjacent shop and having an outside south balcony, thus ensuring the best possible light.

Old Erecting Shop (270 feet by 280 feet).—This shop is now used for repairing tenders and goods engines. It contains two steam traversing and four overhead rope-driven travelling cranes. There are 84 pits, each taking one engine or tender. The original engine shed (480 feet by 70 feet) is the oldest building in the works. It has four rows of pits and is used for finishing off and painting.

Machine Shop (adjacent to the above) is 280 feet by 160 feet, and is chiefly used for repair work. It is provided with 5-ton walking cranes, and a number of automatic machines.

Tool Shop.—This contains machines for the manufacture and repair of all tools used in the works; for cutting spur and bevel wheels and for turning out gauges and templates.

Central Power House is a new building equipped with three Westinghouse 3-cylinder vertical gas-engines. These are of 250 H.P. and are each coupled direct to a dynamo giving 600 ampères at 250 volts, at 200 revolutions per minute. Provision is made for extension at some future date. The switchboard has automatic cut-outs throughout.

Nut and Bolt Shop.—Herein are the usual automatic machines for the rapid production of nuts, bolts, rivets, and pins. Three creosote oil furnaces greatly facilitate rapid production.

Stamping Shop (240 feet by 105 feet).—This shop contains twelve Brett drop-hammers and seven steam-hammers. A great variety of locomotive forgings are made here. The necessary dies are produced in a small shop adjoining. Revolving files, electrically driven by a flexible shaft, are used for finishing dies.

Smiths' Shops.—These have a total area of about 50,000 square feet, and are of the usual type. Many of the special frame angles for locomotives are pressed out in dies by hydraulic power.

Forge.—This contains 9 steam-hammers, the greatest capacity being 5 tons.

Points and Crossings Shop is fitted out with a number of hydraulic presses for bending rails.

Rolling Mills.—These were originally used for making rails, but are now employed in turning out merchant bar sections from scrap, the output being about 200 tons per week.

Millwrights' Shop.—This has a total area of about 20,000 square feet. In addition to the usual millwrights' work, the construction and repair of turntables, pumps, cranes, portable engines and hydraulic plant, chiefly for out-stations, are carried out.

Springsmiths' Shop.—Springs of all descriptions, laminated, spiral and volute, which are also tested to load, are made here.

Tank Shop.—The manufacture of tanks, coal bunkers, and steel-plate work, is carried out here. It is provided with overhead and jib cranes, and some large shearing and punching machines. Compressed air is available at all points. Two steam-traversers afford access to the Tank, Paint, and Boiler Shops, also to the Boiler and Frame Shops.

Boiler Shop (350 feet by 320 feet).—The capacity of this shop is 200 new and 900 repaired boilers per annum. There are two 20-ton overhead travelling cranes, hydraulic cranes for light loads, such as riveters, and a number of jib cranes fixed to alternate columns. There is also a 30-ton fixed hydraulic crane, with racking and slewing gear, provided with a pit. This is chiefly used for riveting barrels to fire-boxes. This shop is well equipped with hydraulic and compressed-air machines of all kinds, available at any point. There is a fixed hydraulic riveter with a 12-foot gap. Among other machines are a special drilling machine for fire-boxes, and two horizontal band-saws for trimming edges of fire-box plates after flanging, also a large hydraulic flanging press capable of exerting a pressure of 600 tons. In this the largest fire-box plates are flanged.

Hydraulic Power House.—This contains three duplex pumping engines with two cylinders 16 inches by 21 inches, and four pumps 4½ inches by 21 inches, built at Swindon, and two "Pearns" duplex triple-expansion pumping engines. There is also a double cylinder 16 inches by 24 inches engine for driving machinery.

Air-Supply Station.—This is situated in an upper storey of the Hydraulic Power House. Equipped with two Ingersoll-Sergeant two-stage air-compressors, with cooling chambers, tandem coupled to compound engines. A spare compressor is also provided.

Central Boiler Station.—This station is situated opposite the Hydraulic Power House. It contains a battery of nine locomotive boilers, and a Stirling water-tube boiler. The latter has a mechanical stoker, and two of the locomotive boilers are fired by special furnaces.

Frame Shop.—The equipment of this shop consists of large slotting, milling, and drilling machines, and two 5-ton walking cranes.

Cylinder Shop.—This is fitted with two 5-ton walking cranes, boring and other machines.

Machine Shop (295 feet by 80 feet).—This shop is driven by a 130-H.P. Crossley gas-engine, and contains slotting, milling, planing and other machines for the manufacture of locomotive details.

Brass Fitting Shop.—This shop contains a number of labour-saving machines. Vacuum-brake injectors, whistles, gauges and other fittings are made and repaired, and steam and vacuum gauges are tested.

Brake Test House.—This is completely fitted up for testing ejectors, brake-valves, steam-valves, and brake-cylinders.

The Brass Foundry has a capacity of 27 to 30 tons per week.

Iron Foundry (400 feet by 80 feet, in two bays).—This foundry is equipped with three overhead electric travelling cranes and several jib cranes. The usual output is about 240 tons per week, and castings up to 20 tons are produced. The capacity of the two cupolas is from 12 to 14 tons per hour each. Hydraulic lifts raise the metal and fuel to the charging floor.

Chair Foundry (adjacent to the Iron Foundry).—It has an output of about 80 tons of chairs per week for the Permanent Way Department, chiefly for points and crossings.

New Erecting and Machine Shops (with Power House).—These are contained in one block, covered with a "weaver" roof with north lights. The stores and offices form a two-storeyed building under the main roof and divide the Machine Shop from the Erecting Shop.

New Erecting Shop (480 feet by 306 feet).—This is the latest and most up-to-date building in the works. It is equipped throughout with electric power. There are two electric traversers and four rows of engine pits holding 80 locomotives. The western row of 20 pits is used for new work, and the others for repairing passenger engines. There are four overhead hydraulic electric cranes, each having two 25-ton lifts and two 2½-ton quick lifts. The heavy lifts are by hydraulic power, worked by 8-H.P. electric pumps. There are independent motors for traversing movements, 33 H.P. and 2½ H.P. Compressed air is available at any point in the shop, and is in general use. The shop is lighted by 700 c.p. arc-lamps, and by glow-lamps at the benches and pits. Gas is also laid on. Capacity—80 to 90 new engines and 500 repaired engines per annum.

Engine Testing Plant.—This is arranged for complete tests of locomotives. Drawbar-pull is measured by a special steelyard dynamometer, and coal and water measuring apparatus is provided, while the speed is shown by indicators. There are five pairs of carrying wheels. These are adjusted to suit different locomotives by racks and pinions driven by an electric motor. The axles are connected by belts and jockey pulleys. The locomotive is run to a table and lowered to the carrying wheels by sixteen motor-driven screw-jacks. The axles of the carrying wheels are provided with band-brakes, water-cooled, and worked by small hydraulic cylinders, which are supplied by a motor-driven return-flow pump. The pressure is regulated by hand and also by a centrifugal governor. These brakes are not dynamometers, but merely absorb power, and are used to regulate speed. Power is measured by the drawbar-pull and speed. The plant is utilised to drive a 2-cylinder air-compressor, for supplying the pneumatic tools in the shop.

Engine Weighbridge.—This was made by Messrs. Pooley and Sons, and has twelve tables weighing up to 12½ tons per wheel. The weights are shown on segmental dials.

Opposite the Erecting Shop, and connected with it by an electric traverser, is a building (163 feet by 60 feet), with ten pits, used as a paint shop. One end of this contains a large caustic-soda tank, provided with trolleys, in which grease and dirt are cleaned from the motion, etc., of engines.

Machine Shop (464 feet by 180 feet).—All machines in this shop are electrically driven; the smaller being group-driven, and the larger machines having separate motors. The shop is served by five 6-ton electric walking cranes, with 5-H.P. lifting and traversing motors. The machines include crank-axle lathes, tyre-boring, wheel and axle lathes, screw-cutting and gap lathes, vertical turning and boring machines, crank-axle sweep-cutting machines, multiple and radial drills, milling and profiling machines (including a very large milling machine), shaping, slotting, and planing machines, key-seating, grinding and lapping machines.

Electric Power Station.—This contains three Westinghouse 3-cylinder vertical gas-engines, each coupled direct to a dynamo giving 600 ampères at 250 volts, at 200 revolutions per minute. There is a 15-panel switchboard, with double-pole switches and automatic cut-outs. An automatic reversible booster brings the accumulators into action when required. These consist of 140 cells, and are placed in a battery room overhead.

Between the Erecting Shop Yard and the Boiler Shop there is a subway under a public road. This has a hydraulic lift at each end, and is used for transferring boilers and other large material.

Testing House.—This contains a 60-ton Buckton testing-machine, and a 100-ton chain-testing machine. Boiler-plate, rails, axles, tyres, copper, wood, cement, etc., are tested; and fatigue, friction and non-conducting tests are made. The drop testing plant for axles and rails is fitted with a steam-windlass working a 2-ton tup to a height of 40 feet. Chains, hooks and lifting tackle for the whole of the system are repaired and tested here.

Chemical Laboratory.—This is a department to which the most careful attention has been paid at Swindon for many years. Twelve chemists are employed in carrying out analyses of water for locomotive and drinking purposes; also of coal, steel, copper, cement, etc.

Pattern Stores.—This is a fireproof building of three storeys, covered by a 230,000-gallon water-tank.

CARRIAGE WORKS.

The Carriage Works are practically wholly situated on the south side of the main line.

Saw Mills (260 feet by 140 feet).—This mill is equipped with six vertical reciprocating log saws, band and circular saws, and grooving, tongueing and planing machines. A special feature is that the shafting is under the floor and the sawdust is drawn away through large tubes and used to feed the boilers for driving the shop. There is a rope-driven overhead crane, also special machines for turning out various body parts, such as pillars and roof sticks. A new saw mill and timber drying yard have recently been provided on the west side of the main line in the direction of Bristol.

Stacking Yard.—The Mill is 195 feet by 52 feet, with one through road. There is a 10-ton overhead electric travelling crane, 50-foot span and 20-foot lift. There is also a horizontal log band-saw (driven by a 60-H.P. electric motor, and capable of cutting 68 super feet of Java teak per minute), cross-cut and other saws.

Timber Drying Shed.—The dimensions of this shed are 410 feet by 100 feet.

Carriage Body Shop (275 feet by 260 feet).—A portion of this shop is used as a machine and fitting shop.

The Gas Fitting Shop adjoins the Carriage Body Shop.

Carriage Repair Shop (230 feet by 225 feet).—There are 15 roads in this shop connected by steam traverser with Body Shop. There are 4 hydraulic drop-pits for changing bogies.

Carpenters' and Finishers' Shop.—The dimensions are 230 feet by 40 feet.

Trimming Shop.—This contains a large number of machines. Female operatives perform the polishing, sewing, etc.

Carriage Paint Shop.—This is 195 feet by 270 feet to 250 feet, with 12 roads. It is connected to Repair Shop by a steam traverser. A novel feature of the Swindon Works is a well-equipped laundry, wherein is done the washing, etc., of the major portion of the towels, dusters, etc., belonging to the Company.

WAGON WORKS.

Although collectively termed the Wagon Works, the shops on the north side of the line, in the vicinity of the station, are responsible (in order to avoid repetition) for a good deal of work for carriages.

Smiths' Shop (524 feet by 44 feet).—Contains (with an annexe), 58 single and 13 double hearths. There are 8 steam-hammers, and the lighter forging work is done here.

Machine Shop and Carriage-Brake Shop (235 feet by 370 feet).—This has recently been extended. It contains the usual machine tools. Carriage bogies are built here, and vacuum-brake cylinders, brake-gear, axle-boxes, draw-gear, etc., are fitted up.

Frame Shop.—Herein carriage and wagon underframes are manufactured. There is a machine section, with shears and other machines, and multiple drills up to 50 spindles for frame members. The shop is well provided with hydraulic riveters, both on jib cranes and overhead runners. They are raised and lowered by light hydraulic cylinders. Compressed air is in general use.

Road Wagon Shop.—This has a total area of about 51,000 square feet. All kinds of road vehicles, such as delivery vans, lorries, omnibuses and carts are made and repaired here. Seven hundred vehicles are repaired per annum, and the output of new vehicles averages about 70.

Wheel and Tyre Shops.—This shop is conveniently arranged for consecutive processes and well supplied with labour-saving devices, and has the usual wheel, tyre and axle lathes and hydraulic presses.

Stamping Shop (240 feet by 185 feet).—This contains 18 hydraulic forging presses; two of 200 tons and seven of 100 tons capacity; also steam-hammers and Brett drop-hammers. There are six large boilers of the locomotive type utilising the waste heat from the furnaces. Here forgings of almost every kind required in carriage and wagon construction are cheaply and rapidly produced by hydraulic presses.

The Power House is equipped with two double-cylinder pumps with 16-inch by 21-inch cylinders, built at Swindon, and governed by the accumulators.

Carriage Washing Shed (350 feet by 60 feet) with three roads. There are raised platforms level with the carriage floors, with water troughs of "pick-up" section running along the edges.

Carriage Lifting Shop (350 feet by 240 feet) with ten roads. This has a machine department, containing wheel lathes and other machines. There are four hydraulic drop-pits.

The Wagon Lifting Shop has an area of 160,000 square feet. Both new and repair work are done here.

GAS WORKS.

These are situated at the extreme northern end of the works and supply all the gas required for the works, locomotive, traffic and stores departments. There is also an oil-gas plant for train lighting. The plant is of the most improved description and has an output up to 1,500,000 cubic feet per day. A special feature is the Methane Hydrogen Plant, which uses oil-gas tar; 25 per cent. of the above output is Methane Hydrogen. A large new gas-holder has recently been erected. This has a capacity of 1,000,000 cubic feet, and is of the three-lift spiral-guided type. The height from ground when full is 114 feet 6 inches, and the lifts work in a steel tank 130 feet diameter by 29 feet deep. A ladder-mast affords access to the holder at any point.

Fire Appliances.—The works are well supplied with hydrants and hose, fire buckets, and patent extinguishers. There are some powerful ejector hydrants, worked from the hydraulic mains, two steam fire-engines and several "manuals," and a trained fire-brigade, which has periodical drills. Numerous fire-pits, or sunk reservoirs, are provided for the use of the engines.

Lighting of Works.—The lighting of the works is in a transition stage. Incandescent gas is being gradually superseded by electricity. Gas-engines are used to drive the dynamos.

MEMOIRS.

Sir George Barclay Bruce was born at Newcastle-on-Tyne on 1st October 1821, being the son of Mr. John Bruce. After receiving his education at his father's school, he, at the age of fifteen, entered Robert Stephenson's works in Newcastle, and served an apprenticeship of five years. On its completion in 1842 he was engaged upon the construction of the Newcastle and Darlington Railway, which was opened in 1844, and formed the last link in the connection of London and Newcastle. At the end of this work he was appointed resident engineer on the Northampton and Peterborough Railway, which was completed in 1845. His next post was as resident engineer on the Royal Border Bridge, which formed the railway connection across the Tweed at Berwick. This bridge, which still stands as a splendid example of masonry viaduct—among the largest in the world—is 2,160 feet in length, with a height from the bed of the river to the top parapets of 126 feet 6 inches, and its successful completion was signalised by its inauguration, in 1850, by Queen Victoria. He next became engineer for the construction of the Haltwhistle and Alston branch of the Newcastle and Carlisle Railway, which included some difficult work over Hurlston Moor. In 1851 he ceased his connection with the North Eastern Railway to go to India, and remained there five years. During this period he did splendid work, which was not without its influence on later railway construction. After spending eighteen months in charge of the Calcutta end of the East Indian Railway, he was chosen to design the railway lines in the Presidency of Madras, being appointed chief engineer of the Madras line in 1853. The work was of an arduous nature, calling for great resource, because there were no satisfactory means of transit or communication; moreover there was a great difficulty in obtaining native labour, owing to the prejudice of the people. The Madras line was about 500 miles long, but his health broke down long before the end of the undertaking, and he returned to England at the end of 1856. On the restoration of his health, he commenced to practise as a consulting engineer in London, and one of his first appointments was that of consulting engineer to what is now the South Indian Railway. Later he became also consulting engineer to the Great Indian Peninsula and the Indian Midland Railways. In addition, he had from this time onwards an extensive Continental and South American practice, and from 1872 to 1879 he acted jointly with Mr. C. W. Homans as consulting engineer to the government railways of New Zealand. His work in England during this period was associated with many cross-country lines, which have since become part of the general systems of the London and North Western and Midland Railways. In 1887–1888 he was President of the Institution of Civil Engineers, and in the latter year received the honour of knighthood. His death, after an illness of some months, took place at his residence in St. John's Wood, London, on 25th August 1908, in his eighty-seventh year. He became a Member of this Institution in 1874.

JOHN DICKINSON was born at Hebburn-on-Tyne, on 4th July 1825. He went to work at the early age of nine years, and in 1841 he was placed in the works of Messrs. John Clark and Co., Sunderland, as an apprentice, and while there, was employed on the construction and erection of colliery engines. The works changed hands shortly after he went, but he remained until 1846, when they were finally closed. After this he went to Consett to work at the mills which were then in the course of construction, but this class of work not appealing to him, he soon had an opportunity of giving it up, and went to Houghton-le-Spring, where he was again employed on colliery work. After a short period he returned to Sunderland, and was employed by Mr. Burlinson, and Mr. George Clark, on repair work of various kinds. In 1852 he started a small repairing establishment of his own, where the repair work was confined principally to the tugs and small colliers and traders then coming to the port, and was the foundation of the present marine engine and boiler works. The work so increased in volume that extensions had to be made, and a move was made to a more commodious site on the top of Palmer's Hill. Gradually the whole of the hill was acquired, extending down to the river, and was cut into terraces on which the present shops were erected. The works now occupy an area of about five acres, with a quay frontage of 600 feet, and when in full swing about 1,200 men are employed. He was the inventor of a crank-shaft, which is well known to engineers, in connection with marine work. His death took place at Harrogate on 3rd July 1908, within one day of his eighty-third birthday. He became a Member of this Institution in 1880.

EDWARD HENRY JENKINSON was born at Walton-on-Thames on 16th January 1857. After receiving a liberal education he was apprenticed in 1873 to Messrs. Holman and Co., engineers, of Mortlake, and in 1884 he entered the office of the late Mr. Oswald Brown, M.I. Mech. E., as draughtsman. In 1886 he was promoted to be assistant inspecting engineer, which position he held until 1891 when his health failed. He then went to Australia, and entered the service of Messrs. G. E. Fulton and Co., engineers and ironfounders, of Adelaide, as works manager, where he remained until the works were closed in 1902. He next joined the staff of Messrs. W. and A. McArthur, of Sydney, first as assistant engineer and subsequently as engineer. This position he held at the time of his death, which took place from pneumonia after a few days' illness, on 4th August 1907, at the age of fifty. He became a Member of this Institution in 1903.

JAMES THOMAS JEPSON was born in Manchester on 22nd December 1867. He received his scholastic education from 1878 to 1883 at the Royal Masonic Institution at Wood Green, London, and his technical education from 1884 to 1890 at Manchester and Stockport Technical Colleges, obtaining first class honours in the City and Guilds of London Institute, and other honours in mechanical construction and drawing, applied mechanics, steam and steam-engines, theoretical mechanics and mathematics. In 1885 he commenced an apprenticeship with the Victoria Engineering Co., of

Stockport, and two years later was transferred to Messrs. E. T. Bellhouse and Co., hydraulic and general engineers, of Manchester, where he completed his articles. He was then engaged as draughtsman by the latter firm, upon hydraulic and general work, until 1890, when he joined the Ashbury Railway Carriage and Wagon Co., of Openshaw, Manchester, as draughtsman in charge of the bridge, roof and general work, and whilst there he carried out a number of important contracts, including bridges over the Rivers Lune, Ribble and Irwell, for the Manchester Corporation aqueduct. In 1895 he resigned his position to take up the post of chief draughtsman with the Leeds Forge Co., where he rendered very valuable assistance in standardising many of the firm's specialities, and introduced improved methods of manufacture. He also invented a self-discharging bogie coal-wagon, large numbers of which are in use on Central South African, Indian, and English Railways. In 1904 he became engineer to the A.B.C. Coupler, Limited, London, where he invented the well-known automatic railway coupler known as the "A.B.C." Coupler, Jepson's Patent. He was distinguished by exceptional mental activity and combined high inventive power with a very practical judgment and business ability. His death took place in the Sudan on 17th June 1908, at the age of forty. He became a Member of this Institution in 1902.

The Right Hon. the EARL OF ROSSE, K.P., was born at Birr Castle, Parsonstown, Ireland, on 17th November 1840, and succeeded to the title on the death of his father in 1867, while in the following year he was elected a Representative Irish Peer. He was of wide scientific attainments, and had conferred upon him, in 1870, by the University of Oxford, the honorary degree of D.C.L. In 1879 Dublin University conferred upon him the degree of LL.D., and the University of Cambridge awarded him the same honorary degree. He was selected, in 1885, in succession to Earl Cairns, for the position of Chancellor of the Dublin University, and in 1890 he received the knighthood of the Order of St. Patrick. In addition to acting as Lord Lieutenant for King's County, he occupied several Government and municipal positions, and was chairman of the committee appointed by the London County Council in reference to gas-testing. He was very popular in Birr, a township which was practically founded by his ancestors, and which he developed largely. He was a Fellow of the Royal Society, and an Honorary Member of this Institution from 1888. On the occasion of the Dublin Meeting held in that year, he entertained the Members at Birr Castle, and at that Meeting he contributed a Paper * on a "Balanced or Automatic Sluice for Weirs." He maintained the observatory established at Birr Castle by his father, including the famous Rosse reflector, and he always took a most active interest in astronomical research. Amongst other matters, he had himself carried out a series of investigations of the temperature of the moon at different periods of a lunation; these investigations were still in progress at the time of his death, and were yielding some interesting results. He was the eldest brother of the Hon. Charles A. Parsons, C.B., F.R.S., to whom the modern development of the turbine is chiefly due. His death took place at Birr Castle on 30th August 1908, in his sixty-eighth year.

RICHARD EDWARD WHICHELLO was born at Lincoln on 30th October 1875. His education was received at public schools and the Lincoln Science and Art School, and he commenced his apprenticeship in 1890 in the workshops of Messrs. Ruston, Proctor and Co., Lincoln. On its completion in 1896 he remained in the drawing-office until 1900, when he went to Calcutta in the interests of the firm and of their agents, Messrs. Martin and Co. He took a keen interest in the technical education of Indian students, and delivered several courses of lectures in a Technical Institute which he assisted in organising. His death took place in Calcutta on 17th April 1908, at the age of thirty-two. He became an Associate Member of this Institution in 1902.

* Proceedings 1888, page 292.

ROBERT STEPHENSON.

(1803–1859.)

President 1849–1853.

Robert Stephenson, son of George Stephenson, was born at Willington Quay on 16th October 1803. He was educated at Newcastle, and was apprenticed in 1819 to a coal-viewer at Killingworth, after which he attended science classes at the University of Edinburgh. On his return he joined his father in the factory at Newcastle, aiding him greatly in the improvement of his locomotives. After the retirement of his father he was regarded as the chief authority on the subject. He developed the construction of wrought-iron bridges for carrying railways across estuaries, rivers, and valleys, notable examples of his work being the Royal Border Bridge at Berwick, the high-level bridge at Newcastle-on-Tyne, the Britannia tubular bridge over the Menai Straits, the Conway tubular bridge, and the Victoria tubular bridge over the River St. Lawrence, Canada. He was also frequently consulted in the construction of foreign railways. In 1847 he entered the House of Commons as Member for Whitby. His death took place on 12th October 1859, and he was buried in Westminster Abbey.

He was an Original Member of this Institution on its formation in 1847, and occupied the Presidential Chair from 1849 to 1853.

From a coloured Photograph 1858, lent by Mr. R. Price-Williams.

The Institution of Mechanical Engineers.

PROCEEDINGS.

October 1908.

The first Ordinary General Meeting of the Session was held at the Institution on Friday, 16th October 1908, at Eight o'clock p.m.; John A. F. Aspinall, Esq., Vice-President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The Chairman announced that the Council had appointed Mr. Arthur Greenwood, of Leeds, a Member of Council, to fill the vacancy caused by the decease of Mr. John W. Spencer. He would retire at the next Annual General Meeting, in accordance with Article 25. The Council deplored the loss of their old colleague, who was not only a typical engineer but had been so instrumental in developing the manufacture and the use of steel castings for ships, locomotives, and other industrial purposes, and had always shown so much interest in the affairs of the Institution.

The Chairman announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following sixty-six candidates were found to be duly elected:—

MEMBERS.

Mills, Charles William, . . .	Huddersfield.
Pack, Albert Edward, . . .	Transvaal.
Spurling, Oliver Cromwell, . .	Hawthorne, Ill., U.S.A.
Wedge, Francis Humphrey, . .	East London, C.C.

ASSOCIATE MEMBERS.

Ablitt, Edward Frederick, . .	London.
Aldridge, Thomas Henry Unite, .	Shanghai.
Bacon, Ernest Leslie, . . .	Darlington.
Bayley, John Parr, ...	Manchester.
Bradford, Percy Richard, . .	London.
Bruce, Charles William, . . .	Bareilly, India.
Carne, Henry, ...	Biggleswade.
Carosio, Giovanni, ...	Buenos Aires.
Chisholm, John, ...	Airdrie.
Cleghorne, William Shaw Hamilton, .	Cape Town.
Crookes, James Hardie, . . .	Sheffield.
Cuny, Terence, ...	Bombay.
Darling, Henry, ...	Oswestry.
Drew, Ernest Henry, . . .	Dunedin.
Drury, Harry James Hutchison, .	Landore.
Dutton, Charles Henry, . . .	Limerick.
Ednie, John, ...	Cawnpore.
Fletcher, Donald Corbet, . .	Hatfield.
Fletcher, Savile Rutter, . . .	London.
Gill, James Stephens, . . .	Whitby.
Hatfield, William Herbert, . .	Sheffield.
Hodgson, Harry Leonard, . . .	Horley.
Homan, Brees van, ...	London.
Johnson, James, ...	Insein, Burma.
Lower, Richard Anthony, . . .	Great Yarmouth.
Mell, Stephen Theodore, . . .	Derby.
Noble, George, ...	Calcutta.
Parker, Robert, ...	Barrow-in-Furness.
Purnell, Walter Henry, . . .	Loughborough.

Rayner, John Merrick, . . .	London.
Robinson, Frederick Harold, . .	Singapore.
Robson, John, ...	Calcutta.
Rolls, The Hon. Charles Stewart, .	London.
Sutherland, Kenneth Wallace, . .	Adelaide.
Tetley, Thomas Reginald Herbert, .	Manchester.
Trimnell, Leonard Charles Boughey, .	Richmond, Surrey.
Walker, Thomas Archibald, . .	Calcutta.
Walter, D'Arcy Joseph, . . .	Tezpore, Assam.
Whitaker, John William, . . .	London.
Willans, George Herbert, . .	Smyrna.
Wise, George Macdonald, . . .	Bombay.

GRADUATES.

Ashmore, John Alfred, . . .	Alfreton.
Bousfield, Reginald Michael, . .	Devonport.
Chaster, Clifford Stilwell, . .	London.
Childs, James, ...	Barrow-in-Furness.
Clausen, Hugh, ...	Stafford.
Copping, Gilbert Lloyd, . . .	London.
Curry, Angus Downes Mathwin, .	Devonport.
Fedden, Alfred Hubert Roy, . .	Bristol.
Gort, Albert Henry, . . .	London.
Keiller, Clifton Macnee, . . .	Swindon.
Krönig, Heinrich Hermann Gustav, .	Doncaster.
Lee, Lionel James, ...	Devonport.
Maclean, Alan Douglas, . . .	Hartlepool.
Mehta, Framroz Dhanjishaw, . .	Bombay.
Napier-Hemy, Hubert John, . .	Devonport.
Newman, Reginald Bodman, . .	Bath.
Saxelby, Fred Albert, . . .	Loughborough.
Scott, George Herbert, . . .	Devonport.
Thoms, Alexander Keay, . . .	Dundee.
Toner, Joseph, ...	Slough.
Wallace, Robert Alfred, . . .	London.

The Chairman announced that the following ten Transferences had been made by the Council:—

Associate Members to Members.

Briggs, Ernest Reynolds,	Glasgow.
Browne, William Ruddle,	London.
Bryan, Bernard William,	Romford.
Codd, Thomas James,	London.
Duncan, John,	London.
Fulton, Norman Osborne,	Glasgow.
Garratt, Ernest Albert,	London.
Gee, Thomas John,	Buenos Aires.
King, Henry James Hubert,	Nailsworth.
Symons, Diogo Andrew,	London.

The Chairman announced that the Council had awarded the Water Arbitration Prize for the best Paper on "Filtration and Purification of Water for Public Supply" to Mr. John Don, *Associate Member*, of Maybole.

The following Paper was read and partly discussed:—

"Repairs, Renewals, Deterioration and Depreciation of Workshop Plant and Machinery"; by Mr. James E. Darbishire, *Member*, of London.

The Meeting terminated shortly before Ten o'clock. The attendance was 159 Members and 82 Visitors.

PROCEEDINGS.

30th October 1908.

An Extra General Meeting was held at the Institution on Friday, 30th October 1908, at Eight o'clock p.m.; T. Hurry Riches, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The Discussion upon Mr. James E. Darbishire's Paper on "Repairs, Renewals, Deterioration and Depreciation of Workshop Plant and Machinery" was resumed and concluded.

The Meeting terminated at Ten o'clock. The attendance was 88 Members and 31 Visitors.

REPAIRS, RENEWALS, DETERIORATION AND DEPRECIATION OF WORKSHOP PLANT AND MACHINERY.

By Mr. JAMES E. DARBISHIRE, *Member*, of London.

Most of the details of the management of an engineering establishment have, within recent years, been systematized. Systems now govern the General Office, Drawing Office, and Works, from the filing of correspondence onwards; and no modern business can be economically carried on without them. They are the result of careful study of the requirements common to all engineering establishments, and the fact that they are *systems* points to a general consensus of opinion that what is good for one, is good—with modifications—for all, and that certain definite principles are applicable to all cases.

It therefore appears strange that the method of dealing with the wear and tear, repair and renewal, and depreciation of plant and machinery, has escaped attention, and that there seem to be as many different ways of treating this question as there are engineers, or perhaps it should be said, as there are accountants.

Possibly a discussion of the subject by the Institution may tend towards some approach to uniformity of practice amongst the mechanical engineers having control of manufacturing works; and the author has therefore endeavoured in this Paper to bring forward the points which govern the question, and to make some suggestions for a system which shall provide for the proper upkeep of machinery, and for its replacement when no longer useful. This is a matter so vital that he hopes it may be found of sufficient interest for discussion, although the subject differs somewhat in character from those generally treated at these meetings.

The matter is very far from being, as many seem to believe, merely a matter of accountancy; in fact, the first reform would be to transfer the control of the Machinery Stock Book, and everything connected with it, from the accountant to the engineer. While this Paper was in course of preparation, the subject of depreciation was treated in a leading article in an engineering journal, upon which comments were made by correspondents. This appears to indicate the recognition of the fact that the subject is an engineering one, and that our attention may with advantage be directed to it, while the correspondence also indicated diversity of opinion as to how it should be dealt with. The article in question, however, did not treat specially, as it is now proposed to do, with the plant and machinery of engineering workshops, which are not by any means under the same conditions as the rolling stock of a railway, or the generating plant of an electrical power station, if only because the *quality* of the product in the one case depends upon the condition of the plant, whereas it does not in the other.

It is beyond dispute that the efficiency of a manufacturing establishment depends upon the quality and condition of the plant and machinery therein, and that any neglect to maintain this equipment in the highest working condition promptly results in a falling off in both quality and quantity of output. The first question, therefore, to be considered is:—What is the best system to be adopted for maintaining the whole factory equipment in proper repair, and for discarding obsolete or worn-out machines, and replacing them with new machines when necessary? The second question is that upon which opinions differ so greatly, viz.:—How is the necessary financial provision for the maintenance and renewal to be made? Needless to say the two have to be considered together.

Maintenance.—The maintenance of the plant and machinery of a manufacturing establishment is generally one of the duties—and not the least important one—of the works manager, and much depends upon his judgment in deciding upon and executing the necessary repairs and renewals from time to time. It is, however, very unusual for this official to have any concern with, or knowledge of, the money value of the plant he is dealing with, and there would be an obvious advantage in the introduction of the reform previously indicated; namely, placing the control of the repairs and renewals and of the valuation in the same hands, and limiting the accountant's duty in this connection to the use of the valuation provided for him by the engineer for the purpose of his profit and loss account and balance sheet.

The following system is suggested for adoption with the object of ensuring proper attention to upkeep of machinery and plant, which in a manufacturing establishment will consist of boilers, producers, furnaces, steam or gas-engines, electric generators, transmission (pipes, cables, shafting, etc.), possibly hydraulic and air-compressing and other machinery, together with cranes and similar gear, all only indirectly productive; with machine tools, steam-hammers and similar machines which are directly productive. The quality of the output is absolutely dependent on the quality and condition of the latter; the quantity and the cost, on the whole equipment. Besides the above, there are "loose tools," which are, in modern establishments, controlled by the "tool room" and may be left out of the present consideration.

Under the suggested system the control of everything would be vested in the works manager, or, in the case of large works, in a special official. The limit of his powers, as regards incurring expenditure, would be defined by the general manager, directors or partners, according to circumstances; he would be responsible for the upkeep of the whole of the machinery and plant, and it would be his duty to report his requirements when he found them to exceed his financial limit; but it is essential that he should have considerable latitude in incurring expenditure on repairs, because obviously time is of the utmost importance in most cases, and he ought not to be bound by too much red tape; in machinery repairs "a stitch in time" often saves many times nine. There is no doubt whatever that, if the right man be appointed, there will be no difficulty on this point.

His first step must be to prepare a proper schedule of the plant and machinery in his charge, entering each item in the Machinery Stock Book, with its distinguishing number. Against each item there should be entered its present value, calculated according to its age, in the manner to be explained later. Also a figure representing its *probable life* in years; this second figure will be required when provision for depreciation comes under consideration. (*See* Appendix I, page 809, showing the system of posting the Machinery Stock Book for new works. The method of determining the depreciation *class* will be explained later.)

Probable life must always be a matter of opinion, but the development of mechanical engineering is now so rapid that it would certainly be unsafe to anticipate for the machinery of today the life of that of fifty years ago. For example, machine tools fifty years old may be very interesting and still capable of doing work, but their use is not conducive to commercial success, and it will not do to look forward to following the practice of previous generations in keeping old machinery at work.

The importance of properly estimating probable life will be apparent when depreciation is considered, and it is in this that the engineering skill and experience of the works manager or the special plant engineer will have their opportunity. The matter seems to have had no consideration whatever in the past; but a short time will suffice to produce plenty of men with the experience necessary to form a sound judgment on the probable life of any machine, that is, on the chances of its becoming obsolete by the arrival of new methods of working, and also of its wearing out in use.

The next step must be to make provision for proper care of the various machines, and for repairs being executed when required without delay. To ensure this, each attendant or workman in charge of a machine or group of machines, being the actual attendant or operator, and not a foreman, would be made, in the first instance, responsible for its being maintained in the highest possible condition, the fireman for his boilers, the turner for his lathe, and so on. It would be his duty to report immediately to his shop foreman any defect becoming apparent, and to enter on a card the description and number of machine, nature of defect, date, and his (the attendant's) name.

The foreman's duty would then be to inspect the machine, and if in his opinion the repairs are necessary, to initial the card, and submit it to the works manager for final authority, the works manager initialling and dating the card and assigning a Works Order No. to the job. The repairs would then be executed at once, and on their completion the machine would be inspected and passed by the works manager, and their execution certified (with date) on the card; to which would be also added the cost incurred. This system would ensure proper care by the attendants of every machine, and would prevent ill-usage, which used to be one of the workshop troubles, though in this respect the modern workman is a great improvement on his predecessors, and the care of machines—especially machine tools—now leaves very little to be desired. It would also afford the works manager the opportunity of deciding when the time has come to replace instead of repairing—and it will be remembered that this official would have before him the Stock Book valuation of the machine under consideration, and therefore would know how far the cost of renewal had been provided for. He would see the whole situation at a glance, and decide whether to replace, thoroughly repair, or partially repair.

In addition to the workman's or attendant's daily watching of each machine, periodical inspection should be made by the works manager as a check upon workman and foreman, and each such inspection recorded.

A suitable form for the card is given in Appendix III (page 811).

In the first space, the workman or attendant reports the defect noticed by him. In the second space, the foreman and the works manager record their inspection, and the latter his authority for the repair. The works manager, having assigned a Works Order No. for the repairs, can through that order authorise any further repairs necessary to the machine; there will generally be other defects to remedy, besides that originally reported by the attendant. In the third space, details are given of all the repairs when finished, this being signed by the foreman responsible for the repairs, who may, or may not, be the same as the foreman of the shop to which the machine belongs. In the fourth space, the works manager records his authority for the machine to be set to work again, and the foreman gives the date of re-starting. Finally, the cost is added in the fifth space, and the record is complete.

Depreciation.—It is sometimes argued that if machinery be maintained as indicated above, it does not depreciate, and that, so long as its output does not fall off in quality or quantity, it is as valuable to its owner when ten or twenty years old as when new. This, however, is absolutely incorrect, for although a machine could of course be kept "alive" for ever, by renewing its parts one by one as they wear out, supposing that it never grew obsolete, its value at any given time would depend upon the state of deterioration of its various parts at that time, because since each part has a "life," the effluxion of the life of that part is proceeding from day to day. But machines do grow obsolete, and are not renewed in this way; and the depreciation now to be considered provides for that effluxion of life of each machine as a whole which actually takes place, the amount depending upon the time during which a machine can be profitably used for the purpose of producing the output required by the works in which it is installed—this being its "life."

It is therefore absolutely necessary to make provision for a fund by means of which the various items of a workshop equipment can be renewed from time to time—which provision obviously has to be made without any reference to the profits or losses of trade. It must be made as part of the working expenses of the business, and in this respect the author protests against the system frequently adopted by accountants of showing a so-called "profit" out of which so much is set aside for depreciation, the amount apparently being at the discretion of the directors or the accountants, and frequently depending upon the amount of the so-called "profit." It is clearly wrong to make the provision for depreciation a charge on profits, for depreciation is really a loss of the capital assets, which has to be made good out of income, and is just as much a charge on revenue as rent or taxes; there is no escape from its incidence, and there is no profit until adequate provision for depreciation has been made. That the provision should be adequate goes without saying; the amount must be determined without reference to the result of trading, but must be an absolute charge, so that the depreciation may be truly representative of the loss of value of the machinery, which occurs whether trading is profitable or not.

When therefore a machine is new, the probable life having been estimated, the depreciation on that machine can be determined, the sum of the loss during life being the new value less the scrap, or ultimate value. This has to be written off during the life in gradually decreasing increments by fixing a percentage to write oft each year from the last year's value, this percentage being such that at the end of the life the depreciated value shall equal the scrap value.

It must be noted that the ultimate values of machines expressed in percentages of their new value vary considerably, because an expensive special light tool will probably have a lower scrap value than a much less expensive heavy tool, such as an ordinary planing machine or a heavy lathe.

It is clearly impossible to foresee either probable life or ultimate value with absolute accuracy, and it would be a refinement of detail to treat each machine on a basis of its own, even if it were possible; but having estimated the probable life and ultimate value individually, each machine may, for depreciation purposes, be assigned to one or other of the classes indicated by the curves on Fig. 1 (page 805), the class selected being that giving the nearest resultant scrap value at the end of the probable life.

Such a provision as the foregoing is sufficient to cover loss due to deterioration beyond that made good by repairs; because in estimating probable life, the chance that a machine may wear out before it becomes obsolete is taken into consideration.

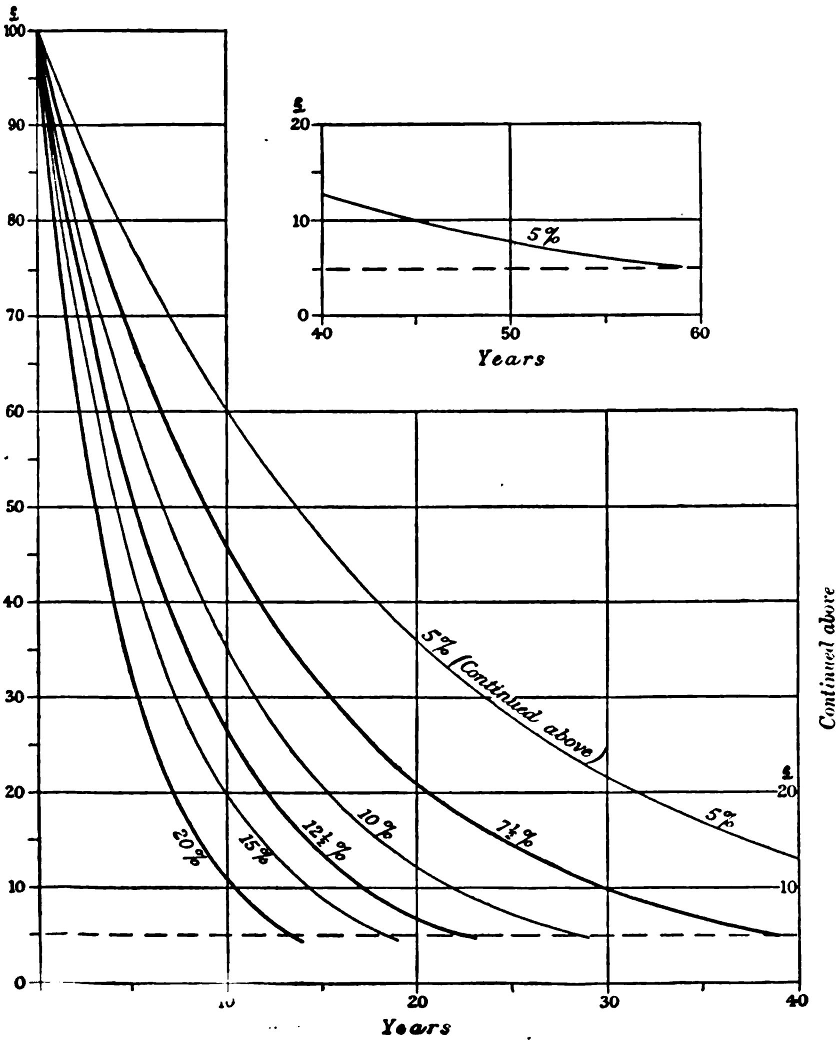
It must, however, be borne in mind that special conditions apply, in the case of leasehold premises, to certain machinery which passes with the hereditament; and when the period of lease is shorter than the probable life of any such machinery, it becomes necessary to apply a rate of depreciation which will *entirely* extinguish the valuation at the expiry of the lease, not even scrap value remaining. In such a case, it is simplest to write off an equal instalment each year, dividing the present value by the number of unexpired years of the lease.

The amount of depreciation on each item being determined, the total on the whole plant must be charged against the income of every year, if the balance sheet is to show truly the value of the plant, and consequently the actual profit or loss of trading.

The author believes that it is essential to schedule every item, and to write off the depreciation separately, so that the Stock Book may show the actual present value of every machine. It may prove, in the course of a machine's career, that for some unexpected reason it is found that its life is likely to fall short of, or to exceed, the estimate to some considerable extent. In such a case there is no reason why it should not be considered on its merits, and the rate of depreciation increased or reduced from the time when its unexpected weakness or vitality became apparent. This would provide against the absurdity of a useful machine standing in the Stock Book at scrap value—but any changes in depreciation should only be made with authority; accurate judgment in estimating probable life will prevent such cases occurring.

When a machine is replaced it disappears from the Stock Book, and its successor takes its place at its new value, being paid for out of the accumulated funds. Thus the valuation would be unchanged in the event of new machines replacing old ones to the exact extent of the total sum set aside for depreciation in any year.

FIG. 1.—*Curves showing Depreciation of Machinery, assuming a probable life and scrap value.*



There is still a provision to be made for the cost of repairs, which is usually met out of income, as it is incurred each year. This is perfectly sound in works which have been established for some time, but in the case of new works equipped with entirely new plant—as the repairs for the first year will be practically nil, and for the next few years very slight, whereas they will fall heavily on some later years—it is wise to set aside a sum during each of the early years to provide for this. After a few years, the requirements for repairs equalize themselves, owing to the varying rates at which the different items require expenditure.

Increase in the productive power of works due to the installation of additional machinery warrants a charge upon capital, and such machines appear in the Stock Book as additions to plant, although no additional capital may have been raised to pay for them.

If additions to individual machines increase their productive capacity, the cost of such additions may fairly be added to their Stock Book value, but they must then be depreciated at such a rate that the additions are written off by the end of the life of the machine.

Appendix II may now be compared with Appendix I. It shows the same plant ten years later, the items having been dealt with in the manner previously indicated. It will be noticed that the planing machine has had an addition to its productive capacity; also that the slotting machine, which was second-hand when the works started ten years before, is now at a figure which permits of its replacement by a more modern machine.

The results of unsound finance in dealing with depreciation are so serious that it may surely be said that every establishment ought to be put on a sound basis, the actual present value of the machinery and plant determined, and systematic provision made for depreciation, so that when renewals become necessary, their cost is provided for. It is often stated that when a business is working at a loss, there can be no provision for depreciation, which in a sense is true; but depreciation is going on all the same, and the accounts ought to show the loss fairly and squarely—that is, the depreciation sum should be written off, whatever the results of trade. If a recovery takes place, the position is sound; if not, continued losses mean the end of the business, and the valuation of the plant at its right figure will not affect this.

The danger of under-provision for depreciation, and especially of allowing the amount to depend upon the results of any year's trading, is that in lean years what ought to be set aside for depreciation may be entirely or partially distributed in dividends, which is nothing more or less than paying dividends out of capital. This may be done in the expectation of better times to come, when the depreciation deficiency may be made up; but it is quite unsound, and in many cases has brought about the results which might have been expected. Even now, there are too many works equipped with machinery which is so out of date as to be a serious handicap in manufacturing, but which cannot be thrown away and replaced because past years have not provided the means to meet the expense To raise fresh capital for this purpose, even if feasible, is absolutely unsound finance, for the new machinery has to produce sufficient to provide interest on the lost capital as well as on the new.

In fact, over-valued machinery is one of the most dangerous enemies to financial safety; it would be far better to distribute less and set aside more for depreciation, than to live in a "fool's paradise," and awake to find that the time has come when machinery must be modernised to meet competition, and that the funds to do this are non-existent.

As a matter of accountancy, in order that the balance sheet may show the true value of the plant, this should be entered at its depreciated value; the depreciation should not be treated as a separate or "Reserve" fund, though if this separate fund be sufficient, the financial position is quite sound. The essential thing is that it should be sufficient, and that it should be provided for before the word "profit" is as much as thought of. This means that the statement or valuation must show the real value of the plant and machinery. However fascinating mechanical engineering may be, the aim of all manufacturers is to work at a profit, and no true profit is shown if the valuation of the plant is incorrect.

Depreciation as a charge against revenue is admitted in principle by the Income Tax authorities, and in rating valuations an allowance is made in the difference between gross and rateable values for a sinking fund for renewal of plant and machinery at expiration of life, which is, in another form, a depreciation fund. This, however, is a somewhat thorny question, and although the author feels that it should not pass unmentioned, it is perhaps hardly one for consideration in connection with the present subject, which is that of workshop practice as affecting the effective maintenance and the true valuation of machinery and plant.

The Paper is illustrated by 1 Fig. in the letterpress, and is accompanied by 3 Appendices.

APPENDIX I.

The .... *Engineering Co., Ltd.*

MACHINERY STOCK BOOK.

Date: 31*st December* 1897.

No. of Machine.	Description.	Depreciation Class.	Present Value.
	Machine Shop A.		£ s. d.
1	18-inch Sliding, Surfacing and Screw-cutting Gap Lathe, with 24-foot Bed, Driving Apparatus, etc., complete. (By A. B. & Co. New; probable life 30 years) . . .	2 (7½%)	400 0 0
2	4 feet 6 inches square by 15 feet long Planing Machine, 2 Tool-boxes on Cross Slide, Driving Apparatus, etc., complete. (By C. D. & Co. New; probable life 30 years) .	2 (7½%)	500 0 0
3	Special horizontal Milling Machine for light work, Vice, Set of Mandrels and Driving Apparatus, etc., complete. (By E. F. & Co. New; probable life 20 years) . . .	5 (15%)	100 0 0
4	10 inch Stroke Slotting Machine, with Driving Apparatus, etc., complete. (By G. H. & Co., second-hand from X. Y. & Co.'s Sale. Was new (£100) in 1885; probable life 25 years)	3 (10%)	28 0 0
	Carried forward . .		

APPENDIX II.

The............................*Engineering Co., Ltd.*

MACHINERY STOCK BOOK.

Date: 31*st December* 1907.

No. of Machine.	Description.	Depreciation Class.	Present Value.
	Machine Shop A.		£ s. d.
1	18-inch Sliding, Surfacing and Screw-cutting Gap Lathe, with 24-foot Bed, Driving Apparatus, etc., complete. (By A. B. & Co. New in 1897)	2 (7½%)	184 0 0
2	4 feet 6 inches square by 15 feet long Planing Machine, two Tool-boxes on Cross Slide, Driving Apparatus, etc., complete. (By C. D. & Co. New in 1897) . . .	2 (7½%)	230 0 0
	Two Tool-boxes on Uprights added in 1905, then cost £50	4 (12½%)	38 0 0
3	Special Horizontal Milling Machine for light work, Vice, Set of Mandrels and Driving Apparatus, etc., complete. (By E. F. & Co. New in 1897)	5 (15%)	20 0 0
4	10-inch Stroke Slotting Machine, with Driving Apparatus, etc., complete. (By G. H. & Co. New in 1885)	3 (10%)	10 0 0
	Carried forward . .		

APPENDIX III.

The............................Engineering Co., Ltd.

REPORT ON DEFECTIVE MACHINE.

Department..

Machine No....................... *Description*......................................

Defect noticed

Attendant's name............................ *No.*......... *Date*..................

Repair recommended..Foreman.

Date..............

Approved..Works Manager.

Date.............

Works Order No..........................   Date.............

Report of Repairs completed.   Date.............

Particulars.

....

Foreman responsible for Repairs.

Passed for Work...Works Manager.

Date.............

Re-started...Foreman.

Date.............

Cost of Repairs.

Remarks.

Discussion on Friday, 16th October, 1908.

The CHAIRMAN (Mr. John A. F. Aspinall, Vice-President), before calling on Mr. Price-Williams to open the discussion on the Paper, desired to accord a hearty vote of thanks, on behalf of the Institution, to the author. While in a certain sense the Paper dealt with a question which was a little outside actual engineering, it was essentially one of those questions without which manufacturing engineers could not exist if they intended to keep their business on a sound basis, and to make those legitimate profits for which their works existed. Therefore he was sure the Institution was greatly obliged to the author for the Paper.

Mr. R. PRICE-WILLIAMS had read the Paper with very great interest, and, as it was a subject to which he had devoted a considerable amount of attention, he was pleased to have the privilege of opening the discussion. He was quite at one with the author when he said that it was a subject purely of an engineering character, and not as it had hitherto been treated, too much of a mere accountant's work. The author stated (page 798) that the subject was not of the same character as that of rolling stock, a subject with which he (Mr. Price-Williams) had had a great deal to do; but with all deference to the author he was bound to say he considered that the subjects were really the same. He had had to do chiefly with railways, and of course every railway had its workshop. It had been his privilege on more than one occasion, notably in the case of the Irish railways, to examine and value, not only the rolling stock but the workshops; and as a workman himself, having served his time in locomotive shops, he saw no difference in the principle affecting the repairs and renewals of machinery, wherever it was and for whatever purpose it was used, whether in the workshop or in the wheels of a railway carriage.

He had had in his time to value three Government Railways, and to estimate the wear and tear, not merely of the rolling stock and the permanent way, but of the workshops also. In estimating the amount of wear and tear—he would not use the word "depreciation—he had followed very much the lines indicated by the author, with whom he quite agreed that it was essential it should receive the closest attention from engineers, and a most careful examination should be made of every machine in the way the author so graphically described. The author dealt correctly with the workshop and all its equipment in its entirety containing a great variety of machines and appliances which had a common source of power and a common purpose to fulfil. As an illustration, he might mention the case of the Irish railways in particular, where he adopted exactly the same method of dealing with the workshop repairs and renewals as in dealing with those of the whole undertaking of the railway. He ascertained whenever he could the age of the machines, and the amount of labour and the amount of material expended upon their renewal; and he might add that if the author's suggestion had been adopted thirty years ago, namely, of keeping accounts showing the amount of labour and material expended upon the large number of machines to be found in large undertakings, a more correct valuation could have been made. He mentioned thirty years, simply because the author stated that there was undoubtedly very great difficulty in assigning an average serviceable life to all classes of operative parts of machinery; so much so that, taking the respective lives of the different parts of a very complicated machine, it would be almost impossible to arrive at an exact average, but that difficulty did not occur in the method which he adopted. With Mr. Ramsbottom's approval, and that of his successor, Mr. Webb, in the case of the valuation of a London and North-Western Railway locomotive, a serviceable life of thirty years—an arbitrary period—was adopted, during which it was calculated that the cost of the numerous renewals of over 2,000 different parts subject to wear and tear of the traffic would be the equivalent of the total amount expended in the case of the serviceable life of a single locomotive machine during a period of the longest life portions. The results of actual experience during that period of thirty years conclusively established the fact that thirty years might be considered as the serviceable life period, and, what was more important in connection with this Paper, that the *average*

Mr. R. Price-Williams.)

annual expenditure in labour and materials, in repairs and renewals of machines subject to incessant wear, during a period of thirty years would be the true measure of the annual expenditure per engine. And in fact that, where no time limit existed for the cessation of machine work, there was no need of any sinking fund in any well-administered manufacturing business. There was, in fact, during a period of years a constancy and a sufficiency in the average aggregate annual expenditure in the maintenance and renewals per machine in a large number of machines (differing as they might do in character) which constituted the equivalent of a sinking fund, as in that period a number of them had been entirely renewed; and the effect of these complete renewals was manifestly to reduce the depreciation, if not to enhance the value of the undertaking considered in its entirety.

He was very much interested in the Paper, believing it to be a step in the right direction. Without crossing swords with the author on the subject of depreciation, he was bound to say he thought depreciation was very much exaggerated; and that where for a number of years the machinery of a large equipment had been repaired and renewed in a thoroughly efficient condition, there was no real depreciation, yet there was great need to have the subject ventilated, and he thought the author had done a great service by drawing timely attention to a very important subject. [*See* page 879.]

Mr. H. Sherley-Price was sure the members were all very much obliged to the author for bringing so important a Paper before them. On page 797 the author said that the subject had escaped attention, and on page 800 that the matter appeared to have had no consideration whatever in the past. He was rather surprised at such a statement. For years past the technical and other papers had teemed with writings and correspondence on the subject of depreciation. A few years ago a Joint Committee of the House of Lords and House of Commons sat on the very subject, except that it dealt chiefly with Municipal Trading, the alleged inadequate provision made for depreciation in the accounts of municipalities, mostly relating of course to power stations, electric lighting, and such like. The Blue Books published included his own evidence on the subject. He therefore thought it was strange for anyone to say that the subject was a new one or had escaped attention. Personally he had been calling attention to it for years, and he did not at all disagree with the author on the necessity of labouring the subject, because it very badly required attention being drawn to it, especially amongst old firms, private ones, those who still adhered to the legend that "What was good enough for my father is good enough for me." But in up-to-date concerns, those whose accounts were regularly audited certainly made provision for depreciation in some form or other; hence it could not be said that the subject had not been dealt with. Whether that depreciation was adequate or not, it was not for him to say.

He cordially agreed with the author that the man who was not competent to dictate a percentage of depreciation was the accountant; that was self-evident. On looking through the system the author proposed, he feared it was much too complicated ever to become general. It involved chiefly the card system, but first it was necessary to have a Machinery Book in which every machine in the works had to be entered and numbered, each machine having its present value put in, its probable life in years, and its rate of depreciation. He believed every modern firm already had a Machinery Book, and every modern firm—and by modern he meant not more than thirty years old, which was going back far enough—had a number on each machine. There were very few works in existence whose machines were not numbered. He quite agreed with the suggestions that a Machinery Book should be kept and the machines numbered.

He was quite certain everyone agreed that there was depreciation, and depreciation not merely from wear and tear but from obsolescence, a term only used in recent years. A well-known illustration of that was to be found in the recent introduction of high-speed steel. Engineers would like to adopt high-speed steel, and it had been and was still being adopted by many firms, but the old machines would not all stand the high-speed working of the new steel. It had been tried, and breakdowns had followed. Therefore steel had to be used instead of iron for the gearing, with the result that the tool was

(Mr. H. Sherley-Price.)
much more substantially built. That was a very good illustration of the obsolescence alluded to by the author. Where he joined issue with the author was in the proposed remedy; in that connection it was necessary to refer to the diagram which the author had constructed. In his own view no one could fix the rate of depreciation upon a machine to cover any long periods of years. The author mentioned thirty years and twenty-five years, but to talk of such a life as that assumed that finality had been reached in mechanical design, and the diagram further assumed that the maintenance would be always alike and fairly regular. As an illustration, two works might be taken alongside of each other, both of the same size, of the same cost, and with the same machines. One shop manager would work his machines for all they were worth, his object being to get a good output and make a profit without counting the cost. The other manager was perhaps shop-proud, and would keep his machines right up to the mark. The life of the one might be ten years and the life of the other might be twenty. Under those circumstances how would the diagram work? Who was to fix it?

On the question of fixing the values, the author said that the shop manager should be the one to do it. There was not one shop manager in a hundred who knew the cost of his machine tools, much less the value, and he was not interested in knowing the cost. What he wished to know, if possible, was the best machine for the work he had in hand, irrespective of cost. The cost was no business of the shop manager. Certainly in not one case in a hundred was that man in a position to fix the values of the machines, because he did not know the values. The rates which the author had fixed were such as would appeal to accountants, who liked a nice curve that would last for many years.

He knew of only one reliable method of fixing depreciation, a method which was becoming more and more extended every year. It was no stretch of imagination to say that the majority of the best, largest, and up-to-date engineering firms had adopted or were adopting it. An outside, independent, competent valuer first fixed the figure at a certain date, and then put the price on each machine; the machine was numbered in the Machine Book, and the valuer fixed, so far as he possibly could, the rate of depreciation which would last for a short period—no prudent man would fix it for a long one—a period varying from one year to seven. He knew of no period longer than that. Then the valuer re-valued every year, every third year, fifth year, or seventh year, the seventh year being an unusually long period. He was not speaking without knowledge, because he was familar with instances of the kind that ran into many millions sterling. It was easy to see that by such a method as that the shop manager certainly had no need for a card system.

The card system was an excellent one, if it were not done to death. In the case under discussion there was a tremendous amount of it. When a lathe or a drill or a slotting machine or any other machine became damaged, the man had a card and made a report; the foreman had a card and came and examined the machine, and made a report; and the manager came and initialled the report. Then it went to someone else who repaired the machine, and someone else came and inspected the repairs to see that they had been done properly, and then someone else came and put the cost into the books. The manager of a large works would be driven crazy if he had to go through all that procedure every time a machine required repairing. He was quite certain that in a high-speed establishment no shop manager would undertake such a job. The method he had just outlined entirely did away with the necessity for anything of that sort.

Mr. H. F. Donaldson, Member of Council, said he held the same view as both speakers who had preceded him in considering that the Paper was one dealing with a subject of enormous interest, and he thought also it was a subject the value of which had not received the attention it deserved. He agreed with the author as to the principles laid down on pages 803 and 807, which went to show that there were no profits in fact until provision had been made for depreciation, and he presumed for maintenance as well, seeing that the two items were stated by the author to go together. He agreed that they should go together. But he did not agree, he was afraid, with some of the details by which the author arrived at his

(Mr. H. F. Donaldson.)
conclusions, nor did he agree that it was the best thing to leave the decision as to wear, the incidence of the charges, the depreciation and maintenance charges, until the balance sheet had been almost entirely made up. He was strongly of opinion that it was very much better to make each piece of work which was done on a machine bear the charges of that machine, whether maintenance, or depreciation, or power. The whole of them, in his opinion, should be charged against the work which was done upon the machine.

He was surprised to learn that it was very unusual for a works manager to be concerned with, or have knowledge of, the money value of the plant he was dealing with; it was certainly extraordinary if true. According to his belief it was not true; there were a great many who *did* know. He admitted there might be a good many who did not know, but it was the man who knew, who made the best of his job. He thought the manager should know a great deal more than the mere wages cost of the job which passed through his establishment.

The author said with regard to machinery repairs that a stitch in time often saved many times nine. That was perfectly true, but he could not but think the system the author suggested was so tightly bound with red tape—a proceeding deprecated by the author—that the stitch in time would be non-existent if, in an establishment, for instance, like the one with which he himself had the honour to be connected, dependence had to be placed upon a workman initiating suggestions that his machine required renewal or repair. Of course if anything went wrong, it was undoubtedly the workman's duty to draw attention to it, but, equally undoubtedly, in his opinion, not to write about it. The workman should draw the foreman's attention to it, and the foreman should take the necessary action. The system propounded by the author appeared to start with a suggestion from the workman, and he did not think that could be sound, as it presupposed a want of knowledge on the part of the foreman of what was going on in his own shop. The necessity for the repair of a machine—*a* machine, not a set of machines—should be capable of being seen from the records in the office. That was a big thing to say, but it could be done, because it was being done.

The author expressed the desire to have a Machinery Book or Ledger, and it was impossible to see how such a Ledger could be avoided; it was absolutely necessary. But he failed to see that there was any necessity for dealing with each machine separately, so far as its life was concerned. It would interest him very much indeed to see the whole of the Ledger, of which sample sheets were given in Appendices I and II (pages 809–810). If the whole Ledger were gone through and the depreciation leviable on each machine added together, he would expect the average to be about 10 per cent. He would quote actual experience to show that 10 per cent. machinery depreciation was not far from correct, as an average. He had examined the results of sales of old machinery extending over about three years and had found that, in order that the sale value of the old machinery should agree with the depreciated value of the machines sold, the levy for depreciation should have been 11½ per cent. instead of 10 per cent. Some of the machines sold were disposed of on advantageous terms, and some were very old and consequently stood at a correspondingly low figure in the Machinery Ledger.

He agreed that the Machinery Ledger should include each machine separately, that it should show the value of each machine with its depreciation written off each year, and that it should show any additions to the value of the machine; but it appeared to him unnecessary to show individual repairs which came under the head of maintenance. It might be interesting, but after all, the accounting should be a means—perhaps an indirect means—of saving money. If accounting were not useful for administrative purposes and was only wanted for balance sheet purposes, the accounts need not be nearly so elaborate as they had to be when used for both purposes. He thought, therefore, it was unnecessary to elaborate the attempt to place a life on each machine. The author admitted that it was an empirical process at the best, and the example given by the last speaker of the introduction of high-speed steel seemed eminently suitable, because numerous machines were today of very much less value than they were seven years ago, after allowing for the lapse of seven years, owing to the introduction of high-speed steel, which demanded more from the machine.

(Mr. H. F. Donaldson.)

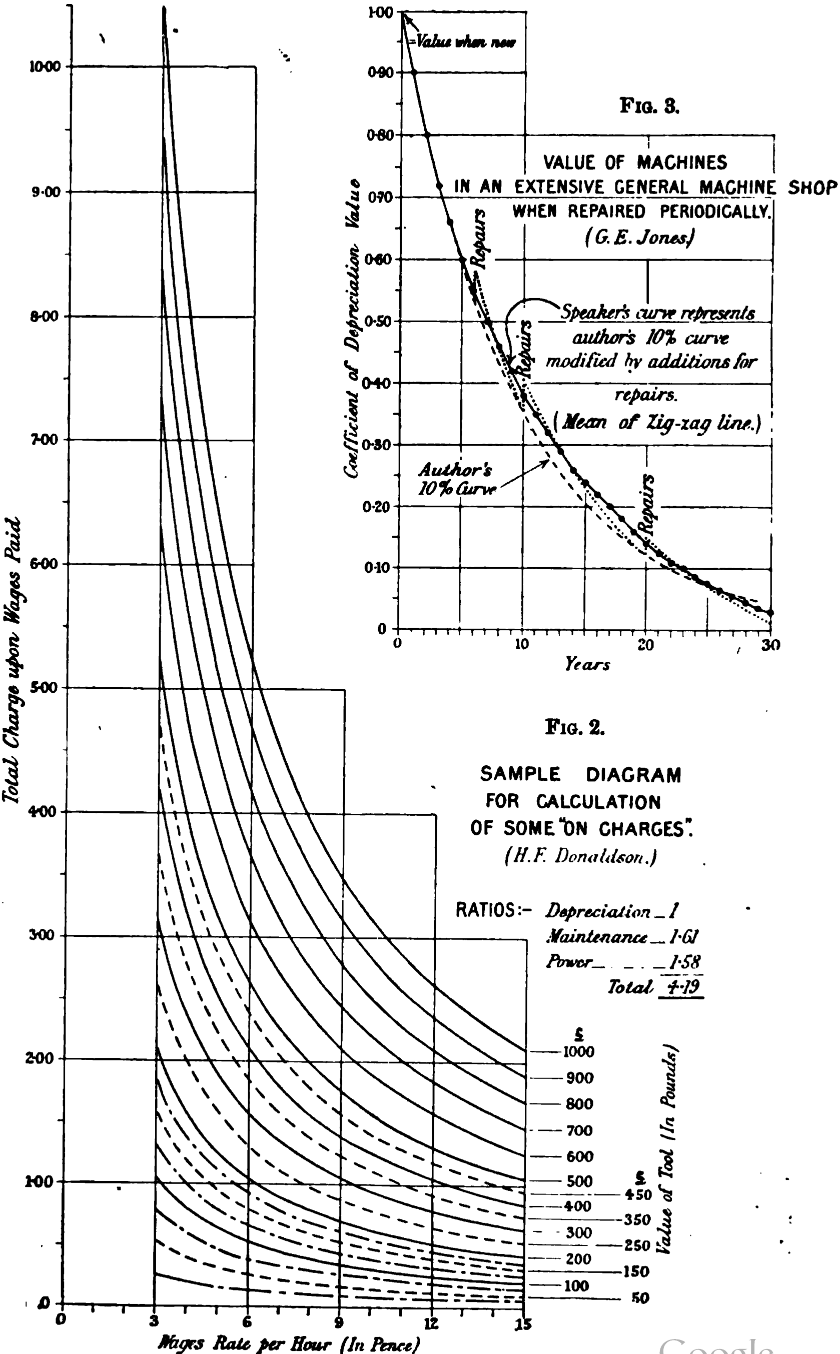


Fig. 3.

VALUE OF MACHINES IN AN EXTENSIVE GENERAL MACHINE SHOP WHEN REPAIRED PERIODICALLY. (G. E. Jones)

Fig. 2.

SAMPLE DIAGRAM FOR CALCULATION OF SOME "ON CHARGES". (H.F. Donaldson.)

In a passing mention of loose tools, the author referred to tool rooms. He would like to know whether he meant the tool room or the tool store? If he referred to the tool room, he thought it would be quite erroneous to leave loose tools at the discretion of the tool room, but if he meant the tool store, then he was heartily in agreement with him, because tool stores, where tools were kept ready for use and for issue to the workmen as required, were a means of saving money and therefore making money. If they were left entirely in the hands of the tool room, there might be a tendency to make and keep too large a stock of loose tools, which would tend to waste money.

With regard to depreciation, as he had said, he preferred direct charges on to the work, and it was really that point which had led him to join in the discussion that evening. He felt sure that the members were willing to grant that 10 per cent. was a fair amount of depreciation, taken all round. He was not very much concerned whether it was allowed or not, because it did not matter much to his argument what sum was taken, provided the principle were adopted. He had prepared a diagram, Fig. 2, which he hoped would be of some use.

To start with, he might say that the 10 per cent. was adopted as an amount that ultimately had to be provided against the balance sheet, and in order to get the proper charges with regard to the job done, it was necessary to go through a process of calculation. The diagram showed ratios—depreciation 1, maintenance 1·61, and power 1·58, making 4·19 as a total. That was arrived at in the following manner. If there were a varying amount of depreciation, as there must be, every year, the depreciation to each machine was not a constant 10 per cent. but a diminishing 10 per cent., 10 per cent. on the value last year. The system, he might say, was applied to something like 7,000 machines—not the particular diagram shown, because each shop had one peculiar to itself, on account of the difference in the power and the difference in the maintenance. The depreciation was levied against the shop, and in order to save the enormous labour of working out every year the charges for every individual machine the system had been evolved. An empirical life of about fourteen years was taken as an average, to make allowance

(Mr. H. F. Donaldson.)
for a good many of the machines being of considerable age, some of them being even of antiquity, though a good many of them were new and up-to-date. After careful consideration it was thought that a reasonable and fair thing for four, five, or six years would be to take a $7\frac{1}{2}$ per cent. flat rate for depreciation and to work from that basis.

Then the maintenance was arrived at by taking the accounts. He noticed in the discussion there was a little tendency to run down accountants, but personally he had found them very useful—at times. To take the accounts, a three or four years' maintenance in the shop was taken as a basis and a percentage worked out for each machine. The ratio shown, 1·42 of the maintenance, was thus arrived at, and the power required to drive the machine was also worked upon the same basis, that is, a period of years and an average were taken. That was worked out for the use of the accountants and he understood they liked it very much.

The diagram showed also the value of the machines, and at the bottom gave the wages of the man employed upon the machine, and the vertical line gave the total charge to be levied upon the work. It would be much simpler if the general system allowed of obtaining the hours that the machine was employed, readily, without a large increase of cost. It would be much simpler to work it out at a rate per hour for the use of a machine, but it did not happen to suit the system that was in vogue at the time, and it was necessary to make a charge against the earnings of the man working the machine; the diagram allowed that to be read off with very great ease. Supposing the machine were of the value of £100 and the man were earning a shilling an hour, the diagram showed 0·25, and therefore 1·25 of one shilling was the charge for the labour and the machine against the job, supposing it to be for an hour. If the man earned 6*d*. an hour on the same machine it would be 0·5. The same amount of money was written off to both men as the charge for the machine, but the ratio made it possible to use the men's earnings instead of the actual hour's work. Therefore the man having worked for a whole week it was only necessary to multiply the whole week by whatever figure appeared on the vertical line on the diagram, corresponding to the value of the machine obtained from the Ledger, to say what the proper charge was. Incidentally there was a very considerable administrative gain in getting the charges. The system suggested, if properly used, made it possible to know how long it paid to use a machine; the shop manager, by examining the results of working the system, was in a position to say when a machine did not pay him to use. Before the charges were made direct on to the job the shop manager perhaps was not quite so much concerned—perhaps he did not know. Now he knew, and he clamoured for machines which would let him do his work a great deal cheaper. That was a distinct gain, because it was necessary to make production at the lowest price consistent with good quality. Also by the same process knowledge was obtained as to when a machine, having ceased to be properly productive, ought to be scrapped. Those were two gains which he thought it would be agreed were very real.

Mr. Max R. Lawrence agreed in the main with the general principles of the author in the necessity for the true valuation of plant, but he felt that the author did not give sufficient credit to the amount of care and attention which this subject had been receiving during the last few years. He thoroughly endorsed Mr. Donaldson's criticism. He had not personally been able to give very much time to the matter, having had other work to do in connection with his duties as works manager of a factory for the last nine or ten years.

At the commencement of that period he felt very strongly that this matter was not treated in the proper way by the accountants. He therefore got out a Plant Book on somewhat similar lines to that advocated, which would provide for an annual valuation of the plant by engineers as a means of arriving at its true depreciation. The accountants, who were very able people, could not see their way to adopt this method. At that time he could not thoroughly understand their reasoning, but now he was quite convinced that the method they had adopted, although perhaps a rough and ready one, was not far away from the actual facts of the case, and that on the whole it was a very good and true way of dealing with the matter. Taking a particular instance, he (the speaker) said that he wished to purchase a Gisholt lathe of a particular size. At that time delivery of a new

(Mr. Max R. Lawrence.)
machine could not be obtained, so eventually a second-hand machine of this size was found. This was bought at a figure slightly in excess of the list price for a new machine, but they were very glad to pay it and get the machine to work. Today a similar machine in about the same condition could be bought at a considerably cheaper rate. Such fluctuations in the market value it would hardly be fair to take into consideration in dealing with the matter. He had always found that the true depreciation of machinery was a thing carefully considered by the persons responsible, whether they were directors of the company or accountants. It seemed to him wrong to presuppose that such people did not understand their business. They might perhaps arrive at their figures by some rough and ready rule-of-thumb method as an aid to their judgment, but to assert that their judgment must therefore be wrong was hardly fair.

At the present time his firm was moving a considerable quantity of machinery from one factory to another, and on looking at their Plant Book he found that the value of the plant as it now stood in this depreciated form was very near its present value as a means of producing the products of the factory. There of course always would be anomalies—such as machines that had fallen into disuse standing at a good value in the books, and other machines still in use standing at a lower figure than their actual worth, but taken all in all the total was about correct. The plant now being moved had been and would be used for manufacturing motor cars, and consisted mostly of machines up to the value of £300 to £350, with only a few above the purchase value of £400. He had no experience to show whether this method of depreciation at so much per cent. per annum would suit another factory differently equipped, but in this case depreciation at the rate of 2½ per cent. per annum had been about correct.

In the factory he controlled seven years ago (which was also a factory containing machinery for the manufacture of motor cars) a Plant Book on the lines suggested by him was prepared, and Fig. 4 showed the ruling of this book.

One page was allotted to each machine-tool, and contained its description and price, and the estimated rate of depreciation, which,

Fig. 4.

No. 3345.

Description: 8-inch Herbert Capstan Lathe, with Taper and Chasing Attachments; 6-feet Bed.
Rate of Depreciation (Class 2): 10 per cent. per annum.
Probable Life of Tool: 10 years.
Scrap Value: £1.
Machine-Tool Rate: 5*d.* per hour.
Initial Cost: £300.
Capacity: 16½″ diam., $1\frac{9}{16}$″ hole in head, 23½″ length of Traverse.

	Particulars.	Repairs, etc.	Stock Value.
		£ *s.* *d.*	£ *s.* *d.*
1900. Jan. 4.	Fixing	1 10 0	
Mar. 20.	Repairing cross-slide (accident) .	3 10 6	
1901. Feb. 2.	Moving machine	0 7 6	270 0 0
Sept. 10.	Repairing turret	0 15 0	
Dec. 9.	Do. Do.	1 10 0	
1902.	Repairs	Nil.	240 0 0
1903.	Repairs	Nil.	210 0 0

No. 3350.

Description: 12′ 0″ Sqr. Planing Machine, 24-feet Stroke; Price £3,500; Foundation, etc., £250.
Rate of Depreciation, Special: 5 per cent. per annum.
Probable Life of Tool: 20 years.
Scrap Value: £250.
Machine-Tool Rate: 8*s.* 6*d.* per hour.
Initial Cost: £3,750.
Capacity: Width, 12′ 0½″; Height, 12′ 0¾″; Stroke, 24′ 3″.

	Particulars.	Repairs, etc.	Stock Value.
		£ *s.* *d.*	£ *s.* *d.*

(Mr. Max R. Lawrence.)

as previously explained, was not endorsed by the accountants. Also a space was left for the rate per hour and a space for the maximum capacity of the machine-tool. The rate per hour was got out for each machine-tool (which might be styled machine rent), and made up from rough and ready figures estimated for as the proportion of rent, rates, taxes, lighting, heat, power, shop room, etc. In estimating this figure it was necessary to estimate a useful life for the machine tool, and in order that this might be recorded a space was left and filled in with the number of years it was assumed the tool would be useful. The reason for doing this was that conditions changed, and it gave a means of reference as to what was in the mind of the man when the machine rate was fixed. In estimating the amount of this rate it was assumed that a machine costing £300 would take three times as much driving as one that cost £100.

At the bottom of Fig. 4 (page 825) was shown the ruling of a book for a large planing machine, a very different tool from the other. He did not know what the actual cost of such a machine would be, but he had put it down at something like £3,500. The foundations for such a machine would cost a considerable amount, and he reckoned that considering everything, a fair rate for such a tool would be 8*s.* 6*d.* per hour quite irrespective of wages paid to the operator. There might be some criticism of the actual figures, which were only guess-work, but it served to illustrate what he had in his mind in considering such a plant book seven years ago. The probable rate of wages on the £300 tool instanced would be from 5*d.* to 7*d.* per hour, and probably on the planing machine 1*s.* or more per hour. This Plant Book proved of considerable use in the works which he managed at that time, not for the purpose for which it was designed originally, but in the estimating department and keeping a proper check on money spent on repairs.

Mr. Edward B. Ellington, Vice-President, was very glad that the subject had been brought forward, because it was extremely important to all engineers who had control of works. There was the question, first, as to what *was* the depreciation of machinery. That was entirely an engineering question, and could be solved only through experience. Detailed information on this point would be most valuable. There was then the further question as to the best way in which depreciation—which everybody agreed necessarily took place—should be shown in the accounts. That, as the author had said, was a matter for accountants to advise upon. But the point which he wished specially to refer to, was that the system that had been proposed by the author would, as a matter of accounts, really fail of producing the effect which he desired.

The author stated (page 804) that, under his scheme, when a machine was replaced it disappeared from the Stock Book and its successor took its place at its new value, being paid for out of the accumulated funds. According to the system set out in the Paper, there were no accumulated funds from which that replacement could be made, and he might illustrate that by some figures. Take a case of new works with, say, £100,000 spent upon them; the accountant when he prepared the balance sheet put on one side £100,000 as the cash that had been invested in those works. The other side had to show what that £100,000 had been expended upon, and he would assume that £50,000 had been expended on plant. Before any actual work was done in the new works the £100,000 would be made up of various items, land and buildings, stock and cash, and, say, £50,000 worth of plant (*see* Table 1, page 828). In the next year the sum of all the estimated depreciations would reduce that £50,000 by some amount which might be taken at £5,000, so that the value of the plant in the books would be £45,000 at the end of the first year. Supposing those works had been carried on so that they had just paid their expenses and the depreciation, and without further capital outlay or improvement or increased stock, there would be £5,000 more cash (or net book debts) in the business. That was a reserve sum which would not be dealt with in the accounts; it would simply appear as cash.

Supposing the process to go on from year to year, the time would arrive when that cash, not being wanted in the business (there being assumed to be enough to carry it on without addition), would have to be invested in some other undertaking. Of course, repairs would be executed as part of the ordinary expenses of the works. In five or

(Mr. Edward B. Ellington.)

TABLE 1.

Balance Sheets illustrating Mr. Ellington's remarks.

Dr. | *Cr.*

—	Year 0 to 7.	Alternative Year 6.	Alternative Year 7.	—	Year 0.	Year 6.	Year 7.	Alternative Year 6.	Alternative Year 7.
	£	£	£		£	£	£	£	£
To Capital . . .	100,000	100,000	100,000	By Land and Buildings .	30,000	30,000	30,000	30,000	30,000
				Plant . .	50,000	30,000	35,000C	40,000	45,000C
				Stock . .	10,000	10,000	10,000	10,000	10,000
Reserve for Depreciation . . .	Nil.	10,000A	5,000B	Net Debts .	Nil.				
				Investments	Nil.	30,000	20,000	30,000	20,000
				Cash . .	10,000				
Profit . . .	Nil.	Nil.	Nil.	Loss . .	Nil.	Nil.	5,000	Nil.	Nil.
	£100,000	110,000	105,000		£100,000	100,000	100,000	110,000	105,000

A. The accumulation of years 1 to 6.

B. The amount of the previous year's reserve *minus* £5,000 plant scrapped and written off.

C. Valuation of previous year *plus* £10,000 expended on new plant *minus* £5,000 plant scrapped.

six years later it might be assumed that the value of the plant would be reduced to £30,000 and the accumulated fund would be £20,000 in the business or in investments. Something now came along which necessitated the destruction of a lot of the tools; for instance, quick-speed steel was introduced into the works, and a number of the tools had suddenly to be renewed. It was no doubt the author's idea that the accumulated fund of £20,000 could be used for that purpose, but it would be found that that was not the case. Supposing it was necessary to spend £10,000 on the new plant, it was perfectly true there was the accumulated fund out of which the *new tools* could be bought, but the old tools would still stand in the books at, say, £5,000. As, however, they had been scrapped, £5,000 would have to be written off, and there would be no reserve to debit the loss with. Though £10,000 had been paid for the new tools out of accumulated revenue, as a matter of accounts a loss of £5,000 would still have to be shown, because the ordinary depreciation could not be suspended for that year, as there would be the same depreciation as before going on from year to year.

His own view was that, in dealing with this question, every machine must not be depreciated by a fixed amount every year. Care must be taken that the total amount provided for depreciation was sufficient, according to the best judgment, to cover the average annual depreciation over a term of years. While, in the case of boilers and things of that kind, it was known there must be depreciation going on each year, and therefore with some certainty a correct provision could be made for replacement, it was not possible to tell what outlay would have to be made or what amount written off in certain years on account of particular items which, under special circumstances that could not be foreseen, had been overvalued in the Stock Book. Therefore the right course to take in his judgment was to put a large portion of the fund on the other side of the account as a reserve fund for depreciation. Supposing, in the case assumed, £40,000 was retained on the one side as the estimated value instead of £30,000, and that £10,000 out of the £20,000 depreciation fund was placed on the other, one was still prevented from distributing in any way that fund, but one was able to

(Mr. Edward B. Ellington.)
accommodate the provisional estimate of depreciation to the facts of the case. In the case assumed the loss of £5,000 on an early renewal would reduce the reserve fund by £5,000, and the difficulty would be overcome.

All accounts ought to show facts, and in the ordinary method of preparing balance sheets facts were not shown. Taking new works on which he had assumed £100,000 had been spent, what did the valuation of £100,000 mean, in which was included the £50,000 for the plant? Properly considered, the latter sum did not show the value of that plant; it showed that that money had been expended in that way and showed nothing else. The real value could not be ascertained; it could only be found by experience. Supposing a mistake had been made and it was desired to realise, the £50,000 paid for the plant could not be obtained. The fact of the matter was that the valuations of capital outlay in the way proposed by the author were extremely hazy. What had to be done was to take care not to pay money out of the business, either in dividends or to partners, or in any way, unless it had been earned after making ample allowance for depreciation. One could do really little more than see that it was not paid out, and to take care that the accounts showed it. Having to deal with the facts as they arose, one might find that, owing to a mistaken system of accounts, difficulties would arise which might easily have been avoided.

What happened when a business was successful? The old-fashioned ideas of valuing as a going concern and of capital being sunk in business were absolutely true. The difference between valuing as a going concern and valuing simply at a break-up value was really that in the former a portion of the goodwill of the business became represented in the value of the plant. Directly the plant of a business became profitable, the plant had a value which might be many times the real value, that is, the selling value as plant apart from the business. The old-fashioned way of buying a business was certainly to estimate the return on the whole capital in the business, and how many years' purchase the profits were worth, and that old-fashioned way continued sound. He wanted simply to call attention to what seemed to be a defect in the proposed arrangements, and he would ask the author when he replied, to explain how the accumulated funds were to be dealt with in the case of having to replace perfectly good machinery by new machinery owing to general improvements in manufacture. The author's fund provided for replacement at the end of the natural term of life, but not for early renewals due to accident or incapacity.

Mr. E. J. Chambers said he had thought Mr. Ellington was going to render it quite unnecessary for him to speak, but he had never yet found a man he entirely agreed with, and therefore he did not entirely agree with Mr. Ellington. On the question of depreciation the author's main point was that he desired to get actual values. If actual values were wanted, it was unwise to try and form a fund which immediately it was formed proved that there were no actual values. He quite agreed that the works manager was the only man who could really value the machinery. There might be a managing director who had been works manager in years gone by, but he was speaking of a works manager who knew the works thoroughly. The finest and best known firms of engineers' valuers in the country might be called in, but he did not hesitate to say from a good many years' experience, that if the works manager happened at that particular time to have a month's holiday, the value of that machinery would not come before the directors until he came back. Suppose that for a particular process he designed a machine and made it himself and knew the cost of it all the way through; how was an outside valuer to know anything about the value of that machine? It was quite impossible. The works manager ought to know the value of every machine in the place, and to know its state even if it was one of 5,000 machines, because as a rule in such cases there were generally about fifty machines alike, and he had a corresponding number of men on whom he could rely to keep him on the right lines, so that he had not to attend to too much detail. The whole object was to get the correct value of the machinery in the books, and it was necessary to separate obsolete machines from machines that had suffered wear and tear.

(Mr. E. J. Chambers.)

Obsolete machines came under a totally different heading from ordinary machines that had to be repaired and kept in working order. A machine might be a first-class machine to-day, worth its full value, but some process might be adopted to-morrow which would render that machine obsolete. It was impossible to talk about the life of that machine. It had to be dealt with straight away if it was really obsolete, but his advice was never to be in too much of a hurry in saying when a machine was obsolete. He had had cases when he thought the machine was done for, but another turnover came and it was found that the work in another department could be done with that particular machine, and therefore he always advised people not to be in a hurry to scrap a machine. If it was perfectly evident that the machine would become obsolete, say, in ten years, then a certain life of ten years might be taken, but should not be put down as absolutely unalterable. In the following year if there were any cause to alter from ten years, it could be done.

It was perfectly well known that there were lathes in the shops to-day that were there twenty-five years ago, and in spite of the high-speed steel and new lathes, there would be found perhaps 25 per cent. more weight in the old lathes than was to be found in the lathes of the present day. He could call to mind a great many first-class workmen who had charge of their tools in years gone by, and he would give a great deal to get their equal at the present time in taking care of the machines. He had read a great deal about the scrapping that went on in America, but if dividends were to be paid the scrapping must not be too much. It was astonishing what could be done to machines in the way of repairs; by putting in new mandrels or stronger bushes, much could be done in speeding up the machines and holding one's own with the best of them.

The question of depreciation should be dealt with by itself. He did not admit for a moment that the auditor was the man who could say how much he was to depreciate his machinery. If one required to form a fund for depreciation of machinery, it had nothing to do with the works manager or the actual valuation of the machines in the Machine Book; it had to do with the directors or the partners, who had to decide, with the actual figures before them, whether they would set aside a sum for special depreciation or for protection. The first duty to the partners and to the shareholders was to have the books state absolute facts as near as they could be arrived at, and the machines had to be valued on a judgment of how long they would last. If the repairs were made out of revenue the machines as a rule were as good at the end of the year, and very often better, than they were at the beginning. He remembered a lathe in his possession which had 8 feet more bed than a change of business made him require, and he conceived the idea of cutting it in half and making two lathes. He did not cut the bed in half, but simply put some head stocks in the middle, and obtained two good lathes which at present were standing in his books at about the same value as they were before, although they were really worth more than the one old lathe. That had been done out of revenue. His advice was to get the values absolutely correct, and let the directors do just as they thought fit as to funds. When he heard a mention of 10 per cent. depreciation it frightened him. It was said that certain machines attached to the freehold had to die with the lease, and therefore it was necessary to write off the full value of the machine up to the date of the end of the lease. But supposing the directors renewed the lease the next morning, what a nice position one would be in. There was no value and the shareholders had been robbed! It was making a man sell his shares because the value had been artifically reduced when there was no right to do it. It was as bad as having an inner reserve. If he had a knife in his pocket and broke the blade, he had a new blade put in; if he smashed the handle, he had a new handle put on; and he would reckon that that knife would be as good ten years hence as it was now.

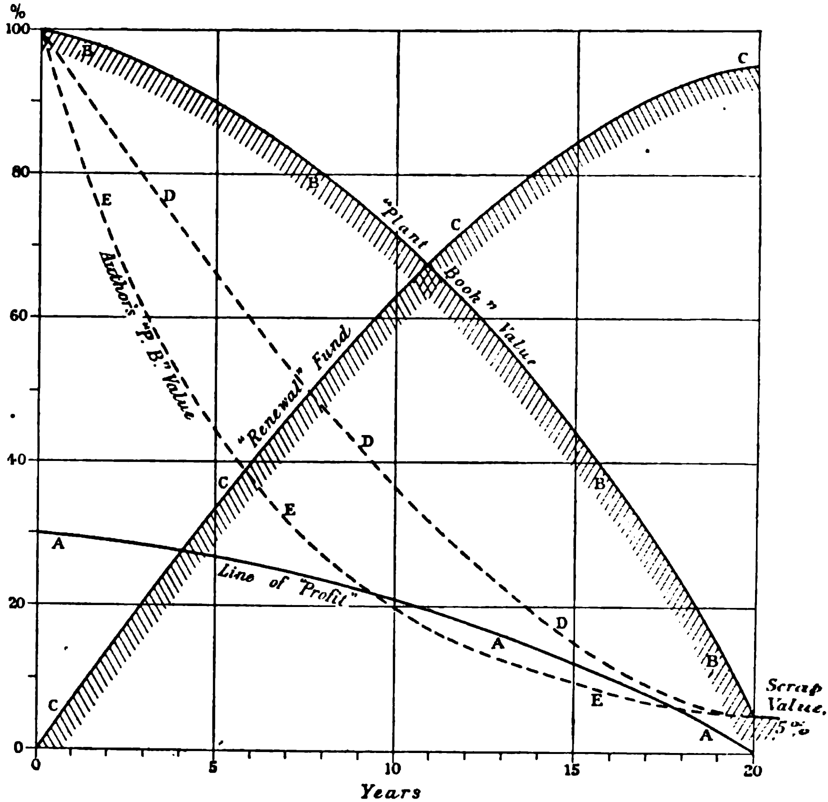
Mr. Charles Pendlebury referred to the "writing down" of machines, and quoted the milling machine (No. 3) mentioned in Appendix I (page 809). The value of this was given at £100, which in ten years' time was reduced to £20. (*See* Appendix II, page 810.) He thought that such a figure was not correct for a machine which had a life of twenty years, and could not agree that a machine lost so much of its value in half its life.

(Mr. Charles Pendlebury.)

Fig. 5 was an outline diagram, showing that that machine would not lose much in value in the early part of its life, and at the end of ten years would be worth about £70. The real value of the machine

Fig. 5.—*Plant "Depreciation" and "Renewal" Diagram.*

Estimated Life, 20 years.



was measured by the profit it would make each year, and he considered it would be as shown on his diagram. (*See* line BB.) He also advocated a separate renewal fund which would not follow the same line as that for depreciation, but would arrive at exactly the same amount at the end of the machine's life. (*See* line CC on diagram.)

With regard to the difficulty of keeping a Stock Book showing the value of each machine, he knew of a large works where this had been done for some years, but the small repairs were not shown separately. They were done on a General Repair Order, and only large repairs were shown against each machine.

The following is an explanation of the diagram, Fig. 5. A machine will give its maximum profit when new, but this will gradually fall off until at the end of its life the real profit will be nil, or so small as to render the machine of no value. Taking this profit for the first year at 30 per cent. of the machine's value gives the "*Line of Profit*" (AA), showing a gradual reduction to the end of the twenty years. This line may vary somewhat from the diagram, depending upon the machine or group of machines being dealt with.

"*Plant Book Value*" (Line BB) shows the real value of the machine each year, and is calculated in proportion to the profit it will make as shown by the "Line of Profit." For example, when the profit is only 15 per cent. of original machine value, the machine itself is only worth half its original value.

"*Renewal Fund*" (Line CC) shows the amount to be taken from revenue each year to replace the machine when worn out, and is taken at a fixed percentage of the "Plant Book Value." For the conditions of the diagram it is about 7 per cent. This line is also shown reversed by dotted line DD, for comparison with line of "Plant Book Value" and the author's Machine Stock Value (dotted line EE).

Discussion on Friday, 30th October 1908.

Mr. George E. Jones remarked that, in general practice, such curves as were shown in Fig. 1 (page 805) were perhaps the most convenient for the purpose, as an approximation. But they were arbitrary, and exhibited the defect that the rate of depreciation kept diminishing as the machine got older, though the greater rate for

(Mr. George E. Jones.)

the first few years when the machine was comparatively new was reasonable, as it brought the value more rapidly down to an intrinsic one; still, it was not quite true that it should go on decreasing. Considering, too, the very varying relations between first cost, cost of repairs, probable life, and scrap value, of different classes of machines, and the variation of duty required from them, with all those uncertainties, and the objection there was to load up the works manager with more or less complicated account-keeping, it seemed to be needless labour to elaborate the process by using various rates of depreciation. He suggested that the 10 per cent. curve, modified to account for important repairs necessary to keep a machine up to the mark, represented fairly well the average depreciation which might be taken all round for the machinery throughout an extensive general machine shop, until the machine was valued down to scrap value. With the object of simplifying such operations, he had prepared a Table of Coefficients for valuing such machinery derived from such a curve, which he had found from experience covered fairly well the cost of periodical repairs to the machines. From this Table of Coefficients the value of a machine at any date could be estimated, by simply multiplying the original cost by the coefficient of the required year. Fig. 3 (page 820) represented the curve.

TABLE 2.

Age of Machine.	Coefficients of Depreciated Value.	Age of Machine.	Coefficients of Depreciated Value.	Age of Machine.	Coefficients of Depreciated Value.
Years.		Years.		Years.	
1	0·90	11	0·35	21	0·13
2	0·80	12	0·32	22	0·11
3	0·72	13	0·29	23	0·10
4	0·66	14	0·26	24	0·09
5	0·60	15	0·24	25	0·08
6	0·55	16	0·22	26	0·07
7	0·50	17	0·20	27	0·06
8	0·46	18	0·18	28	0·05
9	0·42	19	0·16	29	0·04
10	0·38	20	0·14	30	0·03

Table 2 also afforded a very fair guide as to when an engine or machine should be condemned, as if the estimated cost of repairs required at any time, multiplied by the coefficient, exceeded the original cost of the machine, it was generally time to break it up.

Mr. W. G. Cooke said there were one or two points in the Paper, but merely of detail, upon which minds might differ; upon the general principles, however, of putting an engineering enterprise into a safe financial position he did not think there could be two opinions as to the value of the Paper. First, with regard to the title, he noticed it was "Repairs, Renewals, Deterioration and Depreciation." For himself, he thought he should have left out the words "Deterioration and Depreciation," because they were dependent upon the amount of repairs which had been done. He cordially endorsed the opinion which had been expressed by the author as to the necessity of keeping the matter entirely in the hands of the engineer, apart from the accountant, because any valuation, whether of the renewal fund or of anything else, was dependent for its value upon the one who made it. Anyone could make a valuation; the question was what it was worth when it was made, and he maintained that an educated mind rather than one which might be nimble at figures was the proper one to deal with a purely technical question such as this.

He noticed a remark (page 800) with regard to treating each item in the schedule by itself. That, in his opinion, was the right method, and not to put them all together, taking off a percentage, and calling the result the Depreciation Fund. Then under the head of Depreciation (page 802), the statement occurred that sometimes it was suggested depreciation under certain circumstances did not occur He thought some present might call to mind a judicial decision which had been given as to depreciation, and the same principle, though not the same words, occurred in the Rating Acts, to which many had in the course of their practice to give attention. The words were that there shall be allowed from the gross value the "probable annual average cost of repairs, insurance and other expenses, if any, necessary to maintain the hereditament in a state to

(Mr. W. G. Cooke.)
command the rent." That was rather a long description, but it was soon reduced as meaning "repairs, renewals, and insurance." A case came before the High Court many years ago as to what insurance meant, because a renewal fund was in a sense an insurance. Ultimately it was agreed on both sides that fire insurance only was intended by that word. Then it was left to be decided the meaning of the word "renewals," and the judgment of the Court was to this effect, that as both sides were agreed that an allowance had to be made for fire insurance, although a fire might never happen, it was manifest that however sufficiently for working a machine might have been kept up, it was slowly but surely going to its death, and the time must come when no repairs would ever put it into an effective and working condition.

In this way the renewal fund came to mean that a certain sum had to be laid by each year which, accumulated at compound interest, would equal the value of the machine at the end of its estimated life. Having arrived at the life, the question was what percentage was to be allowed. It was customary twenty-five years ago to work on the 4 per cent. Tables, but, owing to the depressed state of the money market and other conditions, first 3½ per cent., and now the 3 per cent. Table had to be used, and one did not know whether in a short time it might not come to the 2½ per cent. Table being adopted. The principle was, that if in a factory a new machine was installed which cost, say, £500, having an estimated life of twenty years, then on the 3 per cent. Tables a sum of £18 10*s.* would have to be put by every year, as that amount, accumulated at compound interest, would equal £500 in twenty years.

Then, with regard to the so-called profit mentioned on page 803, the amount of depreciation was certainly a debt which had to be discharged first. It could not be called profit, if no provision had been made for the full maintenance of the property. A reference was made (page 806) to the results of unsound finance in dealing with depreciation. There was probably not a company or undertaking where a proper maintenance fund was allowed for. Railway companies, with which he had had most to do, were not required by statute to put by a renewal fund. They kept their properties up to the highest state of perfection, but the half-yearly report was silent as to any renewal fund for the permanent way and so on. It was, therefore, found when any rating valuation had to be made that, in addition to the repairs which were shown in the books of the company, the cost of construction of the permanent way and works, and the number of the years they were likely to last, having regard to the traffic, were factors that had to be taken into account. With reference to rating valuations (page 808), the arithmetic in the Paper was not quite the same as that which would be adopted in a rating valuation, but the principle and effect were the same.

Professor ROBERT H. SMITH thought there was hardly any subject more useful for engineering societies to discuss than that of depreciation, and he was therefore very glad to welcome the author's excellent Paper. There were probably many minor details in it to which objection might be taken. For instance (page 801), the author could hardly mean that a fireman could be made responsible for the discovery of the necessary boiler repairs. The defects of a boiler were hidden, and it required a skilled inspector to discover what was necessary. Then, again (page 798), where the author referred to a difference between ordinary machine-tool depreciation and railway-plant depreciation, he (Professor Smith) entirely agreed with Mr. Price-Williams in saying there was no difference in principle at all between such classes of plant, although of course the circumstances of the life and the wear and tear were entirely different, and therefore the data of the calculation of the depreciation were different.

He had long been of the opinion that the American craze for scrapping was economically unsound; but in the Paper (page 807) it was suggested that the propriety of scrapping out-of-date machinery was dependent on the fact of money provision having been made for its replacement. He could not admit that argument. He thought the propriety of scrapping was not in the least dependent upon whether provision for replacement had or had not been made in past years. Again, he did not see at all that raising fresh capital for replacement was always and necessarily unsound finance; in fact,

(Professor Robert H. Smith.)
replacement was desirable if the total increase of profits, including, for instance, saving in power, space and wages, &c., were greater than the total costs of new expenditure required. The replacement would be desirable if that condition were fulfilled, whether or not any cash provision had been made for it in a reserve fund. But passing from those smaller points, it was notorious that on the subject of the Paper very great differences of opinion existed.

He found that there were at least six points upon which all of those present would probably agree, and an agreement upon six points was a very good basis for coming to some further agreement than actually existed in practice. In the first place, he thought they were all agreed that depreciation was very often, unfortunately (some, including Mr. Price-Williams, would say fortunately) not recognised as essential. Secondly, the notions as to the real meaning of depreciation were very vague and various, and it resulted from that state of things that the methods of dealing with it differed very greatly. The third point, upon which he thought all were agreed, was that the evaluation of depreciation was not a matter which non-technical accountants could deal with properly and safely. He thought Mr. Sherley-Price would entirely agree with that, because he was emphatically a technical accountant.

Again, they were all agreed that depreciation depended upon repairs. He wished to point out, however, that it did not simply depend upon the cost of the repairs but upon the degree and efficiency of renovation. It would not do simply to fix upon what was considered a proper amount for depreciation and repairs together, and then subtract from that the money that had been spent upon the repairs in order to arrive at the proper depreciation. For instance, a serious accidental breakage might be very costly, or it might not cost very much; but if the repair was perfect in the one case and in the other, the resulting value of the machine was the same, whereas the two costs of the repairs had been utterly different. Again, as Mr. Cooke had said, perfect repair did not result in zero depreciation. For instance, there was antiquation, or as Mr. Sherley-Price termed it, obsolescence or the pattern of the machine (page 815). But there was beyond that the change of market demand. A good many years ago, for instance, the weaving-plant in Coventry went down very greatly in value because of embroidered silk ribbons going out of fashion; and, at a later period, the Nottingham lace plant went down enormously in value simply because ladies gave up using so much lace, and the demand for lace became almost extinguished for a time. Then, again, as had been already said, a well-patched-up machine was not equal to a new machine. In addition, a change in the market demand for the products of the plant might result in appreciation, in an increase of value. That was illustrated by the two instances which he had just mentioned. There had been within recent years a resuscitation of the fashion for old Coventry embroidered silk ribbons—they were much more in use now than they were ten years ago; and again, there had been a resuscitation in the use of lace, which had put the Nottingham machinery much more into profitable use than it was.

Fifthly, he found they were all agreed that the estimate of the life of plant was quite an uncertain estimate and often a mere speculation. It followed from that that it was reasonable to change the data for the calculation for the depreciation from time to time, and he thought the data became in several respects more certain as the years passed, that is, one could judge of the proper depreciation and of the proper future life very much better two, three or four years after the machine had started working than at the start.

The sixth point on which he thought they all agreed was, that a distinction had to be made between what he called intrinsic depreciation due to wear and tear and such-like causes, and extrinsic depreciation due to market variations, antiquations and so forth. Those were the six points on which he thought all engineers must agree.

In the first paragraph on page 803 he thought a confusion of ideas had arisen, there being a vacillation between two ideas: firstly, the provision for repayment of the capital outlay; and, secondly, the decrease of earning capacity. The provision for repaying the capital outlay was, he thought, a matter for accountants' estimation, guided, however, and modified by agreement how to distribute the repayment over the years of life. With regard to the second idea, decrease of earning capacity, he thought there was often a neglect of what

(Professor Robert H. Smith.)
constituted the real initial total cost, that is, of several items of that cost; for instance, foundations and housing, and, still more, time and skill spent in the selection of the plant, which was surely of great value and had to be paid for, and with which value the machine became endowed. There was also the appreciation beyond all these money costs due to the fact of the installation as an earning machine as part of a going concern.

The author mentioned (page 804) with approval the very common system of allowing for depreciation by writing off annually equal amounts, each being the difference between the first cost and the scrap value divided by the number of years which it was estimated the life of the machine would last. But, as had been pointed out by Mr. Cooke, that was really a very absurd system, because it made no allowance at all for the accumulation of each of those equal parts according to compound interest. He had calculated two examples which were not at all out of the way. For twenty years' life, at 4 per cent. interest, the ultimate value would be $29\frac{3}{4}$ times the $\frac{1}{20}$th part of the difference between the new value and the scrap value, that is 50 per cent. more than the reserve fund which they had set out to provide. Even if the life were only ten years, at 4 per cent. the excess was 20 per cent.

The other law that was recommended on page 803 and was often followed, and which had been recommended also by several speakers in the course of the discussion, namely, that of writing off each year a definite percentage of the remaining value, was still more absurd in that respect, because the curve of value fell more rapidly during the first years than subsequently, so that the initial amounts written off were larger than according to the straight-line law, and they had a longer time in which to develop by accumulation at compound interest. He had not seen the algebraic law given in any books, so he thought it would be of interest to add it to the report of the discussion.

[This system is represented algebraically by the following equations:—

N = new value;
S = scrap value after n years of life;
i = rate of compound interest;
d = rate of depreciation;

then $$N(1-d)^n = S, \text{ and } \therefore d = 1 - \left(\frac{S}{N}\right)^{\frac{1}{n}};$$

and ultimate accumulated value of amounts written off

$$= N \frac{d}{d+i}(1+i)\left\{(1+i)^{n-1} - (1-d)^{n-1}\right\};$$

while actual loss in value

$$= N - S = N\{1-(1-d)^n\}.]$$

As examples, if the scrap value were taken at $\frac{1}{5}$th of the new value, and the life of the plant as twenty years, that gave $7\frac{3}{4}$ per cent. as the annual percentage of the remaining value that must be written off in each of those twenty years. If 4 per cent. interest were taken for the accumulation of the amounts so written off, the ultimate value at the end of twenty years would be 30 per cent. more than the new value, that was to say, as much as $1\frac{5}{8}$ times the difference between the new value and the scrap value—a perfectly ridiculous result. Again, under the same data, with only ten years to run, the percentage of remaining value to be written off each year was $14\frac{7}{8}$, and they had the ultimate value 22 per cent. more than the sum that they were supposed to be providing.

In "Feilden's Magazine" for March, 1900, he had explained a method of approaching the question from the point of view of the earnings of the machine. What he called in that article depreciation was the annual decrease of the present capitalised value of all future earnings of the plant. Of course an estimate of the life of the plant had to be assumed, and one must also assume a knowledge of the future earnings of the plant during that life.

Mr. Pendlebury's diagram, Fig. 5 (page 834), had in one respect a considerable resemblance to his results. If P_n were the present capitalised value of the future earnings, then $P_n(1+i)^n$, where i was the rate of interest, and n, the years that had to be run to the death of the machine, gave what he called the ultimate value of the future earnings. This ultimate value was equal to the sum of a number of terms, each of which was the excess of the revenue for the year over the working costs multiplied by $(1+i)$ raised to the power equal to the years still to run.

(Professor Robert H. Smith.)

He considered the plant as burdened with the debt of its first cost C to be repaid at its death, so that finally this first cost of the machine had to be subtracted from the sum of these accumulated earnings. The equation,

$$P_n (1 + i)^n = (R - W)_{n+1} (1 + i)^n + (R - W)_n (1 + i)^{n-1} + \cdots + (R - W)_2 (1 + i) + (R - W)_1 - C,$$

gave the present value P_n of those future earnings. Taking the difference between the present values at the beginning and the end of the *n*th year before the death of the machine, the depreciation or decrease of the earning value was simply $D_n = P_n - P_{n+1}$, those two being calculated according to similar formulæ for two different years, $n + 1$ and n. This difference was easily found to be $D_n = (R - W)_{n+1} (1 + i) - P_n i$. Thus, if the present value had been calculated for one year, knowing the net revenue for the year, the formula gave the depreciation and the present value a year later. That form of formula allowed complete and perfect freedom for change of data from year to year as to the estimate of the life of the machine, and also as to the estimate of the future earnings of the machine. The working costs W included the interest upon the first cost. In the special case of the yearly earnings being maintained uniform, the depreciation of earning value reduced to the following simple expression: $\frac{R - W^1}{(1 + i)^n}$, where W^1 did *not* include interest upon the first cost.

He showed two diagrams illustrating the results of the calculation for two different cases, the data of which were shown on the diagrams, Figs. 6 and 7. In Fig. 6 the future earnings were supposed to be uniform all through the life, and in Fig. 7 they were supposed to go gradually down at a uniform rate during the life of the machine to 60 per cent. of the original value. The drooping curve gave the present value; it was a curve very similar to the one to which Mr. Pendlebury referred (page 834). The rising curve showed the annual depreciation. The yearly depreciation was small at the beginning of the life of the machine, and rapidly rose to quite a large amount towards the end; but the rate at which it increased was not nearly so great in the second case as in the first.

He wished to mention a peculiarity of the diagram. The zero of the scale for present value was at mid-depth of the diagram, and its final values were negative. In the first case, the present value was negative throughout about one-third of the length of the life of the machine, and in the second case throughout half of that life. That simply meant that the calculations were made taking the present value as burdened

Annual Depreciation of Present Intrinsic Value.

Fig. 6.

First Cost, £1,000. Rate of Interest, 5%.
Nett Revenue after deducting Interest on First Cost, £100, maintained uniform throughout term of 20 years.

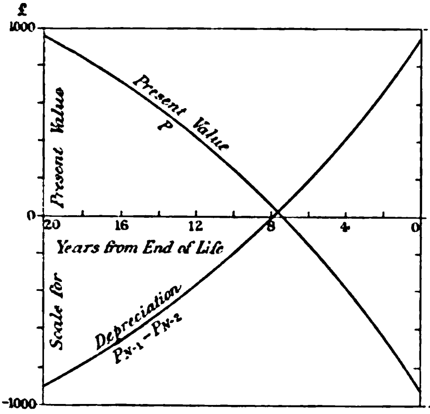
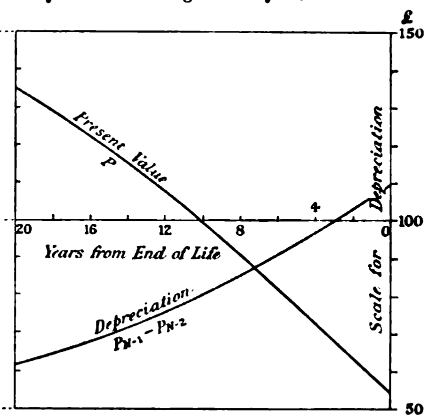


Fig. 7.

First Cost, £1,000. Rate of Interest, 5%.
Nett Revenue after paying £50 Interest on First Cost, £100, during 21st year from end of life and decreasing by £2 per year to £60 during the last year.



with the debt of the first cost of machine; they provided for the repayment of the debt. He had only one thing more to say, namely, that this calculation of D_n was really the decrease of total earning capacity. Now dividends or other forms of profit were paid out of these earnings. Therefore D_n was not what is ordinarily termed depreciation. It was the sum for the year out of which both profit and depreciation had to be provided. It could be spent in paying dividends, in subscribing to a renewals fund, or in fresh additions to capital, which were none the less profits because they were reserved. It therefore left the distribution of the total earnings as between profits and depreciation to be fixed by other considerations.

(Professor Robert H. Smith.)

He thought that it was considerations of business prudence and forethought, and willingness to forego immediate advantages for the sake of future safety, and no hard-and-fast mathematical law, which ought to, and actually did, determine the distribution between profits and the contribution to the renewals fund to provide for depreciation from year to year. The full depreciation must be written off during the life of the machine, but he did not think any mathematical calculation could solve how that depreciation should be distributed over the life. In the same article in "Feilden's Magazine" there was a formula shown giving the sum of the intrinsic and extrinsic depreciations in two separate terms, so that the one could be easily distinguished from the other and allowance made for the very different circumstances under which the two occurred, the data for the intrinsic depreciation being fairly steady from year to year, and the data for the extrinsic depreciation having to be frequently revised according to changing market conditions.

Mr. A. K. Bruce said it seemed to him that the Paper divided itself into two distinct topics, one touching manufacturing efficiency, and the other financial stability. It struck the more or less engineering mind as rather curious that the author dwelt so much on "systems," and he certainly thought that, so far as the first paragraph of the Paper was concerned, it could hardly be said that systems "governed" general office, drawing office, and works. They might assist in governing, but if they were looked to as governing purely and simply, he thought trouble was likely to result. He did not know of any system that would grind a milling cutter or save a decaying business from ultimate disaster.

One of the really practical points touched on in the Paper was the choice of a man to look after the works and their equipment. Of course the accountant would not look after the plant; and the difficulty was to get the man who could. He remembered that in the American works where he served his apprenticeship, they had what was called a "Plant Engineer." The difficulty with such an official was that he had to be a general engineer, and a general engineer could hardly be expected to be conversant with, say, the intricacies of a full automatic machine. Here the author left one consideration quite out of account, namely, the tool-room, and it was the tool-room foreman who, so far at all events as machine manufacture went, might be utilised to considerable advantage. It was further to be noted that such items as the jigs, fixtures, gauges, milling-cutters, taps, dies, drills, reamers, &c., were all neglected in the Paper under discussion.

In those American shops with which he was acquainted, valuations were not made by the works manager, but by an altogether independent man, and it seemed to him that the outside valuation referred to by Mr. Sherley-Price (page 816) was about the most sensible scheme that could be devised. If he were buying machinery or works he did not think he would take the works manager's valuation; he would rather have the valuation of somebody who had had as little to do with the given works as possible.

The first word in the title of the Paper was "Repairs," surely an all-important consideration. He remembered hearing a successful and well-known electrical engineer remark that he was always pleased to see a big repairs bill. It seemed rather a surprising thing to say, but the contention was that expenditure incurred with a view to preventing disaster was small in proportion to that necessitated in making good its effects. If, as the author very pertinently remarked on page 800, it was possible to put in "a stitch in time," a great deal of delay and loss might be avoided. He remembered working in an American machine shop where trouble was experienced with certain heavy machines which were continually breaking down. They did not break through any inherent defect; but because they were not "fool proof." Men operating the machines apparently forgot that if heavy work carried on the table ran up against, say, a tool-post, something was bound to break. In this case a certain bevel pinion invariably stripped. It was ultimately decided to devise means whereby the danger might be obviated, and various arrangements of shearing pins and slip frictions were accordingly experimented with. They never succeeded in actually making the machines "fool proof," and the various safety devices employed had a proclivity for taking effect under normal loads, but they managed

(Mr. A. K. Bruce.)
to devise ways and means of working the machines so that failure became comparatively infrequent, and possible causes of breakage were eliminated. It would always be found that the loss due to the disabling of a machine was directly proportional to its usefulness, which was fairly obvious; hence, the best machines should be carefully looked after. He remembered visiting in Germany a very large establishment where they had an official nicknamed the "astronomer." The man was so called, not because he was versed in astro-physics, but because he was always looking up at the belts, shafting, and counter-shafting. He had nothing to do but to see that these details ran well, and if anything went wrong with them he was asked to explain the reason. Such a provision saved a great deal of delay and tended to the efficiency of the plant.

With regard to the question of depreciation, in common with many others he had been rather frightened by the formulæ presented by Professor Smith. *Apropos* of these, he recollected a certain afternoon when his firm received an order from a large firm of locomotive builders to send off all the boring-mills they had in stock. That was a pleasant sort of message to receive, and they were not long in loading up a couple of carloads of machines. The locomotive builders sent the tools to their tyre-boring department, where they were used for boring and turning locomotive tyres made from the hardest possible description of steel. The machines were not designed for such work, and naturally did not last long, so that when the rush was over they were practically valueless for their legitimate work. In such an instance how were depreciation allowances to be plotted on a curve? It seemed to him that depreciation values might range comparatively, from zero to infinity. That was a difficulty which accountants were doubtless better able to deal with than engineers. The keynote of the Paper seemed to be that there must be vigilance. The celebrated Italian patriot Mazzini once made the very wise observation that "The price of liberty is eternal vigilance." He thought that, with regard to machinery and machine shop practice, the price of efficiency was eternal vigilance—certainly vigilance would be a great deal more serviceable than any mere "system."

Mr. W. Tetley Stephenson said the first point he wished to emphasise, which had already been taken up, was that there was no appreciable difference between the depreciation, repairs, and renewals that took place in connection with a machinery workshop and any other implements that were used to carry on an industry. There might be a difference in time, but old tools, whatever they might be, whether railway rolling stock or anything else, equally interfered with the quality as well as with the quantity of the work. The work of locomotives might be instanced. Eight or ten years ago the punctuality of many of the express passenger trains to Scotland was far from good. The trains had grown in size and weight, and the locomotives which existed were unequal to hauling them at the speeds laid down in the time-tables. In other words, the quality of the work of the locomotives was not what was wanted. For the work the locomotives were obsolete. The interference with the quality of the work was no monopoly of machine-shop practice.

The next point he wished to mention was the question of what the engineer should do and what the accountant should do. In connection with engineering work generally, the accountant had, in the majority of cases, undoubtedly been allowed to do far too much. He had done his own work and the engineer's work too, and had frequently done it rather badly in regard to the matter of depreciation. It seemed to him, however, that the author desired that the engineer should now do the accountant's work as well as his own, and in his (Mr. Stephenson's) opinion that would be equally wrong. That the engineer should give advice as to what the probable life of a machine should be and what was likely to be the average cost of repairs were quite right and proper, but might not it be left to the accountant to then work out on that information in pounds, shillings and pence what the proper charge for depreciation should be? It was rather a large undertaking to expect that workshop managers should become, in addition to being first-rate workshop managers, first-rate business men. Some did become so, but it would certainly limit the choice of men for appointments if that were requisite. It seemed to him very much wiser that the accountant should be left to do the proper

(Mr. W. Tetley Stephenson.)
portion of his business, and that the engineer should content himself with the problem of estimating the probable life of the machine, including taking into consideration the possibility of the machine becoming obsolete.

He would like to raise the point as to whether there was any definite reason that could be assigned why such difficulty occurred in the engineer getting his proper place in the question of the valuation of depreciation? There was a reason, he thought, which was being recognised in many branches of industry at the present time, namely, that whilst provision was made for thorough technical training in nearly every profession, men were left to pick up administration as best they could. In a great many classes of work an effort was being made nowadays to deal with training in administration; and it seemed to him essential that, if the engineer was to obtain the place that he should hold in the matter of depreciation, the work of administration should have a definite place in his training. Then he might expect generally, and be admitted by accountants and by other business men to be able, to take his proper work without any fear that the result might be a loss of financial stability.

Mr. Mark Robinson, Member of Council, said he would only refer to one or two points which he had noticed in the Paper and which had cropped up in the course of the discussion. First of all, he objected to the use of the word Stock Book which had been used by the author. He preferred Plant Ledger. Stock was a different thing altogether, as was pointed out previously in the discussion. He was also inclined to quarrel with the title of the Paper, "Repairs, Renewals, Deterioration and Depreciation"; he wished the Paper had referred to depreciation only. It ought to be taken for granted that repairs were done properly, and that the plant was not allowed to deteriorate so far as necessary renewals and necessary repairs of it were concerned. By giving the word "repairs" a place in the title of the Paper, the author seemed to him to give some encouragement to what he believed was a dangerous view, namely, that repairs which had to be carried out might be looked upon as something which could be done or left undone, or which one was at any rate entitled to claim some credit for doing, as in a sense an act of thrift. The essence of success in a manufacturing business was to keep the plant at all times up to the highest state of efficiency.

With regard to the expectation of life, Professor Robert H. Smith had given a formula which he (Mr. Robinson) thought the shop engineer was very likely to say the accountant might have been paid to understand, but not himself. No doubt it was a valuable formula, and it might be possible by it to get at the probable falling off in the efficiency of the tool later on. The shop manager could only make a rough guess at that. He could perhaps form an opinion, from the class of tool, as to how far it was likely to become obsolete in the course of a few years. There were tools of which one could say there was very small probability of their being obsolete in twenty years, and there were others of which one could say it was more than possible they would be superseded in five years, so that the rates of depreciation must be varied according to the individual cases. It did not seem to him of very much importance whether the tools were divided into classes, on some of which 5 per cent. was written off, and on others 7½ per cent.; or whether they dealt with each one by itself. But whenever anything turned up in the history of a tool which showed that it was going to give trouble by and by, or that it would have to be turned out sooner than other tools, there ought to be a special writing off, and then a fresh start made with it. He did not think there was any difficulty in practice in carrying out that principle. That brought him to the point on which a great deal had been said, namely, the division of duties between the engineer and the accountant.

He was one of those who thought it was very important that the engineer should have at least an acquaintance with the principles of book-keeping and the principles of finance, but he did not think that the engineer wanted more than that. Mr. Tetley Stephenson had put that point admirably before the meeting. He (Mr. Robinson) intended to have said what Mr. Stephenson had said very much better, namely, that the accountant was the man who ought to work out the financial results flowing

(Mr. Mark Robinson.)
from the information which the engineer gave him. The practice of a large firm, of whose proceedings he was well conversant, had been, for a quarter of a century past, for what he might call the accountant heads of the company to consider the depreciation of tools one by one, but they always did it in concert with the works manager. The works manager was asked, "Is this tool giving trouble? Is it costing overmuch for repairs? Do you think its production is falling off? Are we likely to have to scrap it before long?" The answers served to fix the rate of depreciation, though he himself did not actually fix it. There was no difficulty in bringing the accountant and the engineer to work together in that manner.

A suggestion had been made that the rate of depreciation should depend upon the repairs. If that meant that the more a tool needed repairing, the faster it should be written down, he agreed; or if that when it had been thoroughly repaired, it might commence a new and lower rate of depreciation, he also agreed. But repairs and depreciation must be kept rigidly separate. One speaker had referred to the trouble taken over the selection of the plant as an element in its cost which ought to be charged to capital, but he thought in almost all cases that expense would have been charged already to the "general charges" of the works; it was head work done by people whose salaries were not chargeable to separate jobs, but must be treated as a general charge. He believed the Paper to be a very valuable one, and it had elicited a most interesting discussion.

Mr. Harold J. Ping did not think there was very much fault to be found with the principles underlying the Paper, but the methods of applying those principles to practice must depend upon the people who were controlling, and whether they were fond or not of the use of red tape. Whilst the card shown in Appendix III (page 811) was very simple, he thought it might be more simplified, and for that reason be made better. Bearing on this point, he believed that in these later days the use of the words "card system" had something like the same effect on a man as a red rag waved to a bull. He thought, however, with proper careful use a card system was much better than having a haphazard system by which a man reported to a foreman (who was attending to other things) when he had a bad machine. In all probability the foreman forgot all about it, and the defect dragged on. As an instance of that, he knew of a large concern where two machines were lying idle for two or three months, and were not earning a penny, although they cost a large sum to build.

The members had been told that a locomotive might live to be thirty years old, as long as it was constantly repaired according to the latest up-to-date practice, and that there was no need to allow for any depreciation. Although perhaps it was not necessary to allow so much for depreciation, he thought the method was quite wrong. A locomotive or any other machine was essentially an earning machine, that is, it had to earn a living. If it was constantly laid up for repairs, it must be very expensive if it was repaired with the latest pattern parts instead of old pattern parts; and all the time it was laid up, perhaps for some months, it was not earning a penny of revenue. He therefore thought that if, instead of thirty years, a machine were written off for a life of, say, fifteen years, they would be able to replace that machine in fifteen years largely out of the sum saved by repairing quickly and cheaply with old pattern parts, or the then standard parts; and by the sum saved, which was represented by the difference between the revenue *gained* owing to the machine being in running a greater aggregate time, and the revenue *lost* by its being laid up for longer periods owing to the more expensive repairs due to up-to-date parts; and the necessary modifications and fitting required to "bring them in." Thus in the case of a machine or locomotive now thirty years old, it would have been possible to replace it twice on modern lines, so that at the present time a third machine would be at work.

What appeared to be wanted was a happy medium between American "building for scrap" and our system of building for one's lifetime and the next man's too, plus the advantage of having paid for the replacement out of the earnings of the machine itself, that is, by a fair system of allowing a depreciation fund on any given machine *before profits were calculated.*

(Mr. Harold J. Ping.)

The next point he wished to refer to was that the members had been asked to say how they knew when a machine was obsolete. That was not a very difficult question to answer, and he thought it was easily answered in the following way. If a machine were written down for a life of fifteen years, and after eight years it was found there was another machine on the market which was capable of doing either better work, more work, or cheaper work, it was comparatively easy from those three functions to find out what that machine would save. Assuming the old machine had worked eight years out of an estimated life of fifteen, he thought the saving that the new machine should effect ought to be equivalent to saving its own capital cost in the next seven years, its own depreciation over a period covering the term of its own estimated life, and the balance of the depreciation on the old machine for the remaining seven years, minus the accumulated depreciation on the old machine and the then value of that machine—whether it was scrap value or whether it had more value. If the machine could not save that, then he thought the time had not quite arrived for replacement. The time might come another year hence, or it might not come at all, because if it could not do that within seven years the old machine was still turning out useful, that is, paying work, and at the end of seven years there would be a fund for replacing the machine on the most up-to-date lines. This covered the contingency created by the advent of high-speed steel and the consequent scrapping of machines. If a machine did not turn out work calculated to save that amount of money, the old machine should not be replaced, because so long as the old machine's output was satisfactory in the sense he had described, it was safe for the next seven years, or whatever time might remain on its estimated life for the purposes of a depreciation fund.

Mr. W. Steele Tomkins wished to emphasise the fact that he did not speak as a critic, because he was in accord with the principles upon which the Paper was based; and he had nothing to find fault with. But one of the principles suggested in it was so useful and it was so necessary to repeat it continually, that he wished to draw attention to it. The principle was that, as the Paper said, depreciation was an "absolute charge." Those present would not treat that as a novelty, because all who had had to do with the production of machinery knew that depreciation was an absolute charge on the cost of producing any machinery, just as much as the payment for the material and for the labour upon it. But, as he had already said, it required to be continually repeated, because not a week passed but a prospectus of this, that, or the other undertaking appeared, in which statements would be found as to what the accountant either called "Gross profits" or "Profits" unqualified by any adjective. Only a few days ago he saw such an instance in the prospectus of a Canadian company in which the statement was made that the profits amounted to so many hundred thousand pounds, he thought, before deducting, amongst other expenses, depreciation. The principle which ought to be adopted was that depreciation was one of the items of the first cost.

It seemed to him that in days gone by the amount of depreciation was calculated rather upon the assumption of the natural ageing of the machine in the course of years, than on any apprehension of its being superseded. Nowadays the consideration was wholly changed. The machine did not depreciate, so far as its wearing-out qualities were concerned, any faster, but it depreciated enormously faster owing to its being superseded, or to the probability of its being superseded. He thought he was perfectly correct in saying that, in certain works which he knew well, not more than 10 per cent. of the existing machinery was there ten years ago. That was a fair proof of the rapid deterioration that took place nowadays. The period of the usefulness of a machine was evidently in many cases very much shortened. There was no doubt it varied enormously with different classes of work, and it was extremely difficult, if not impossible, to lay down any hard-and-fast rule; that must be determined in each works according to the necessities and the practice. Adverting to a remark which had recently been made in the course of the discussion, he confessed that, valuable as the work of the accountant was, the engineer of the works, and perhaps those who were above him, ought together to supply the figures on which the accountant made his statement, and not the other way about.

Mr. H. Kelway-Bamber, M.V.O., said he would have hesitated to add anything to the able discussion on the Paper, had it not been that he spoke from personal experience of Indian railway practice. He was surprised to read that allocation of maintenance and depreciation charges had not, according to the author, received adequate attention. That was not the case so far as main Indian Railways were concerned. There the matter had been very carefully considered. He agreed with the statement that the matter was not one of mere accountancy, but he thought the services of the accountant were useful in keeping the manager posted on the progress of maintenance and renewal expenditure during a given period. It was quite true that any neglect to maintain equipment in the highest working condition promptly resulted in a falling off in both quality and quantity of output; but the human element of the worker must not be overlooked. With the best of plant, results to a great extent depended upon the efficiency of the workmen.

The author asked what was the best system to be adopted for maintaining the whole factory equipment in proper repair. That, the speaker thought, could be summed up as follows:—The provision of a thoroughly capable and vigilant millwright foreman with suitable staff and plant, continuance of services being dependent upon working results. The provision of a certain supply of spares to replace wearing parts was most essential, and a competent millwright foreman would see that his supply of spares was such as prevented any undue loss of time in dealing with machines out of order.

As to the system for discarding obsolete machines, in the speaker's opinion a machine became obsolete as soon as a better one appeared on the market, and continuance of the use of obsolete machines meant loss of revenue. He did not mean that superseded machinery must necessarily be scrapped. It was the engineer's duty to see if there was any other suitable work for which the machine might be modified so as to give an adequate output. As an example of this in the works with which he was connected, a number of electrically-driven wheel tyre-turning lathes were installed, the old lathes being modified and converted for the repair of journals requiring re-turning or polishing.

He thought that the control of maintenance should be in the hands of the works manager, who should keep in close touch with the accountant and superintendent on a question of expense. A forecast of probable expenditure on maintenance and renewals should be made at frequent intervals, at least annually, any proposed excess of the estimated amount being brought to the notice of the superintendent before the money was expended. In the works he controlled there was a machinery and plant list, in which every item in the shop was entered with its price, date of commencing work, and the makers' name. With that list the works manager and the accountant were in a position to settle the amount of depreciation of machinery, which, under Government orders, was for accounts purposes fixed at 8 per cent.

No remarks had been made by the author upon the cost of foundations. In the works with which he was connected he had to put down a steam-hammer on water-logged soil, where it was necessary to excavate 20 feet and to pile 20 feet below that, the excavation being filled in with rails, timber, and concrete, forming a bed for the hammer and its block. Under such circumstances the relation of the cost of foundation of machinery or plant might be very large, and if neglected a considerable sum remained to be made good when a different type of hammer was put down. That also applied to heavy machinery. The introduction of high-speed tool steel had had a wonderful effect on the output of work in India, and had, in some cases, more than doubled the capacity of a shop and its machinery.

Mr. Darbishire thanked the members for the cordial reception they had given to his Paper. In reply to the discussion, he thought it was desirable that an understanding should be arrived at as to what a depreciation fund was intended to provide for. It would be seen from the Paper that he meant it to provide for a means of replacing machinery at the end of its life, whether that life was ended by wear and tear, or by obsolescence, and that it was essential to the success of any depreciation system that the probable life should be, at any rate, closely estimated. He quite admitted that it

(Mr. Darbishire.)
was difficult to estimate probable life, but it was better, if there were any doubt at all about it, to make it too short than too long. Professor Smith had mentioned six points upon which he thought all the members were agreed. Certainly there was one point on which there could be no doubt, namely, that depreciation must be set aside before profits could be mentioned. Mr. Tomkins had spoken very fluently upon that point, and had absolutely voiced his (the author's) views. But if the Reports of many of the companies which traded in this country were inspected, it would be found that very frequently depreciation was treated as if it were something which it is quite optional to set aside from the profits, or to leave alone, as the managers thought fit.

Mr. Price-Williams suggested that he would deal with the machinery of a railway workshop exactly as he would any other machinery. He (the author) would do exactly the same, the remarks he had made in the Paper applying to any workshops. Of course, however, the neglect to allow for depreciation in a railway workshop would not necessarily have the same disastrous effect as in a trader's workshop, because it would only affect the company's profits to a very slight extent; nevertheless depreciation ought to be provided for. Then Mr. Price-Williams referred to rolling stock, a question that was outside the scope of his Paper, which only related to workshop machinery.

Mr. Sherley-Price had a misconception of the second paragraph of the Paper in which the statement was made (page 797): "It therefore appears strange that the method of dealing with the wear and tear, repair and renewal, and depreciation of plant and machinery, has escaped attention." Mr. Sherley-Price thought that he (the author) said that depreciation had escaped attention. Of course it had not; it had been treated of over and over again. What had escaped attention was the desirability of arriving at some sort of common agreement as to how depreciation was to be dealt with.

The card mentioned in Appendix III (page 811) had been criticised by several speakers, amongst others by Mr. Sherley-Price. That gentleman, however, had evidently not understood the card, because the words he used in the course of his remarks were, "The man had a card and made a report; the foreman had a card and came and examined the machine, and made a report; and the manager came and initialled the report" (page 817). That was not a description of the card method at all. The method of using the card was fully described in the Paper. The reason for the workman attending the machine being the one to notify the need for repairs was that he was naturally the first man to see it. He must see the necessity for the repairs before the foreman or anyone else, and though perhaps, as Professor Smith said, the fireman was not a likely man to know when his boiler wanted repairing, he was certainly likely to find out when, for instance, one of the mountings wanted attention, or something of that kind. In any case, the man who was actually operating the machine would see that something was wrong, and it was right he should report it at once, otherwise the machine would continue in operation and turn out defective work, and the foreman would not find out the trouble until defective work had been issuing from the machine. Mr. Sherley-Price made the remark that the card described would turn any shop manager crazy. He (the author) had had the pleasure that afternoon of an interview with the shop manager of a very large establishment, who came and told him that he had read the Paper and wished to show him the card that he used in his shop. The gentleman showed him a card which was almost identically the same as the one he had described in Appendix III (page 811), and said that he used it for some time, and that he had never had the slightest difficulty in getting the men to understand it—in fact, it was absolutely successful. He (the author) therefore could not possibly see what was the difficulty about the card. The whole thing would only take a very few minutes to fill up by the foreman of the shop and the workman. The works manager most certainly ought to know when a machine was requiring repairs, because the machinery in a shop was under the control of the works manager, and it was for him to say definitely what repairs were necessary. If he thought the machine was so old or obsolete that it was not worth repairing, that was his opportunity for saying that it must be scrapped and a new one put in its place. He had in his

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mind a case where a works manager knew nothing whatever about the Plant Book, and he was told that the tools generally in the shop had better be repaired. There were about six old slotting-machines in the shop of a very ancient pattern, which were made in the year 1843, while the incident he was narrating happened in 1880. They were, in fact, no use at all except as curiosities, and they each stood in the Plant Book at only £5. The works manager spent about £20 apiece on the repair of those tools, and when they had been repaired they were really worth nothing at all. It would have been far better if those tools had been scrapped, and replaced by new ones, and all that expenditure saved. He thought the card could perhaps be modified and improved upon. He did not see any objection to the alteration of the card, but he strongly held to the principle of it.

Mr. Sherley-Price spoke about how the value should be fixed, and said it was no business of the shop manager to know the cost of every machine in the place. He (the author) thought it was, and Mr. Donaldson and other speakers had agreed with that view. Then Mr. Sherley-Price had raised the question as to whether the valuation should be periodically made by an outside expert. It seemed to him it was rather a question of convenience whether the valuation was made by an outside expert or by one of the staff; but the principle of revaluing every year, that is, of taking into consideration anything in the nature of a fluctuation in the market values of machinery was dangerous. One year a very large sum could be added to the valuation if the market value of the machinery was taken into consideration, or it could be knocked off another year; but he thought that a depreciation curve should be formed on some lines entirely irrespective of fluctuations in market value.

Mr. Donaldson had shown some curves (page 820) which he (the author) thought were very useful. They were intended not only to show the depreciation by means of a curve, but also to show how the depreciation, and also the cost of maintenance and power required to drive the plant, could be charged to each particular job through the tool that was doing the work. That was a question of the Cost Book, and it was useful and very complete. Mr. Donaldson said, further, that he dealt with depreciation very much as he (the author) did; he either deducted it from the book value of the machinery, or set it aside as a reserve for depreciation—he did not say which, but either one way or the other. Charging the cost to the job did not affect the fact that the depreciation had to be taken off in some form in the balance sheet. Mr. Donaldson made the remark that repairs ought not to be added to the value of the tool. He (the author) certainly should never add the cost of repairs to the value in his Plant Book, because he did not think it was right to charge repairs to capital.

Mr. Lawrence showed some pages from a Plant Book which were very complete indeed (page 825). For instance, he showed in the margin every time money was spent in repairing a tool, and the amount of those repairs, though of course he did not add it to the value, so that a most complete record was made in the book. Mr. Lawrence's Plant Book contained more than the suggested Plant Book he (the author) had shown. It was simple and it was useful; in fact, he thought Mr. Lawrence's pages might very well be adopted.

Mr. Ellington spoke about the system failing to produce the effect which was expected. He did not think Mr. Ellington quite understood what he (the author) contemplated by the system, which was the renewal of machinery supposing that it had lasted the life which was originally assigned to it. It was perfectly obvious that if a machine died exactly at the anticipated moment, the amount of the accumulated fund, plus the scrap value, would exactly replace that machine. But that system, and any other depreciation system, did not pretend to provide a means of meeting a revolution or earthquake such as the introduction of high-speed tool steel, necessitating the destruction at once of a lot of machines which were practically new. Mr. Ellington gave an example (page 828) of a machinery works in which he started with a capital of £100,000, of which £50,000 was spent on plant, and at the end of a certain time that amount had been depreciated until it had come down to £30,000, with £20,000 in hand. At that moment, five or six years from the beginning of the undertaking, there was a revolution, and £5,000 worth of the machinery had to be thrown away. All would

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admit that that was a very unlikely case, but it was a possible one; and he admitted at once that his system would not provide for that contingency, unless he had originally estimated that one-sixth of his plant was going to fail at the end of five years. The case, however, was quite unlikely, and he did not think it would be expected that any depreciation system should provide for a revolution. If revolutions happened very often, they would have to devise some means of meeting them by an insurance fund or something of that kind; possibly Lloyd's would do it for them. He desired to point out, as mitigating the shock of the revolution, that the machinery which was displaced, although it might have no value in those particular works, if it was good machinery—and it ought to be after only five or six years' use—would have a sale value very much above its scrap value, and that would help to some extent. He had had an opportunity of considering the figures with Mr. Ellington, who, by adopting a system which combined some of the points which he (the author) had adopted with another system which set aside a Reserve for depreciation, had shown a method which he considered had advantages over the system he had proposed in the Paper. A combination of the two would create what he might call an accumulator or a fly-wheel which would be an elastic sum. The Reserve for depreciation, the second line of the diagram, gave an elastic sum upon which one could draw. The reason it was elastic was that if a loss had been made upon some of the tools by their life having been under-estimated, no doubt a profit had been made in the course of a few years upon others which had exceeded the estimated life, and in that case the benefit of it would be obtained by having a fund which would suffice to replace all the machinery that it had been necessary to displace, and would not show a loss, whereas the book-keeping of his system would, for the time; it would show a loss until the difference between the machines replaced and the machines put in to take their place was recouped.

Mr. Chambers (page 832) spoke of engineers not being in too great a hurry to say machines were obsolete, and Mr. Kelway-Bamber said exactly the same thing. They were both absolutely right. When milling came into fashion about twenty-five or thirty years ago a great many slotting, shaping and planing machines were displaced. There were some large works which had some very excellent, strong, heavy planing machines, and it was seen that those tools would be put out of action in the event of milling machines being introduced to do the work that was then done with planing machines. The managers therefore put their heads together, and eventually decided to convert a number of the planing machines into mills, which was done at a very moderate expense indeed, and they made most excellent milling machines. They were, he believed, running to the present day—they certainly were four or five years ago. That showed that a machine was not necessarily obsolete because of the advent of a new process; it might be converted into something else, or at any rate it might be made useful to some other user.

In reference to machinery in leasehold works, which point had been entirely misunderstood by Mr. Chambers (page 833), the machinery would include certain machinery passing with the hereditament. This machinery would cease to be the tenant's and become the landlord's property at the end of the lease. Even if the lease were renewed, this machinery would not belong to the tenant, and he must take no credit for his landlord's property, hence the necessity of completely writing it off. There was no question of robbing shareholders or inner reserve; but to leave any value in the books for this machinery would be to take credit for something belonging to another. In the renewal of the lease, the landlord would include rent for the machinery.

He did not quite agree with the two curves that Mr. Pendlebury gave (page 834), because it would be found that the depreciation of a small sum in the first year, getting larger year by year, made a very heavy charge towards the end of the life of the machine, at the time when the machine was least productive. The usual habit had been to use the curve in the other form, the larger depreciation being made when the machine was new and at its best, and gradually toning off as the machine got older; this curve always left a residual value. Everything had a residual value, even if it were only scrap, and that was why he thought his form of curve was generally adopted. Personally he thought it was the right one to use.

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Mr. Cooke, who spoke from the point of view of a rating surveyor, agreed with him (the author) that it was a good thing to value each machine separately (page 837). When he was a young man he kept a Plant Book for ten years in a very large works, and it was his habit to write down each machine separately, which he thought was a useful thing to do. It gave one more idea as to what the machine was worth, than if an all-round figure of 10 per cent., or whatever it worked out at, was taken off the machinery. But either plan, he thought, was perfectly sound from a financial point of view, and if it were more convenient to ascertain what the average of the depreciation would be on the various machines and use that figure, it certainly saved trouble, and there was no possible objection to it from the point of view of financial soundness. As a rating surveyor Mr. Cooke was familiar with renewal funds. That was a perfectly sound way of dealing with the depreciation of any machinery—to set aside so much a year and let it accumulate at compound interest, but for some reason that had never been adopted by engineers. He did not think any works he had heard of had adopted such a system, because, as a matter of fact, it was all theory and not practice; nobody really did take the money and invest at 3 or 4 per cent. That was why he thought it had never been used.

Professor Robert H. Smith had given some very elaborate figures, which he confessed at the moment he could not understand. The result of the figures was shown in a curve (page 845), while a curve was also shown making the depreciation increase during the life of the machine. He (the author) had already said that he preferred the other, and he had given his reasons for it.

Mr. Bruce gave some information as to the practice on the other side of the Atlantic (page 846). He wished to explain that when he said the systems "governed" the work, he meant that they were applied to the works and were used throughout the works. Mr. Bruce also remarked that any consideration of loose tools had been omitted. The Paper did not deal with loose tools, and therefore he had not touched on them. They were not, as a rule, depreciated in exactly the same manner as machine tools.

Mr. Tetley Stephenson alluded to the question of the quality of the work (page 849), which he said in every case depended upon the quality of the machinery. What the author meant when he said that the quality of the product in the case of the rolling stock of a railway or the generating plant of an electrical power station did not depend upon the condition of the plant was, that it did not matter in the slightest degree to a passenger what an engine was like as long as it took him from, say, Manchester to London; and it did not matter to a householder what sort of machinery there was in a power station as long as the electricity came in and lighted the house; but it mattered a great deal to the railway company or the electric light company which owned the engines what sort of a condition they were in. The cost of production was the factor that varied. There was a great difference between that and the lathe which, if it became defective, at once began to put out defective work. At the same time there was no reason why the depreciation, because the machinery happened to be in a railway, should be treated differently from what it would be if it were in a manufacturer's shop. There was one point on which he was heartily in accord with Mr. Stephenson, namely, that engineers ought to be taught administration. As a rule, engineers were taught technicalities, and if they learned administration it was purely owing to the circumstance of their getting the chance of going into some works where there was an opening for an engineer in the Administration Department. It was seldom that young men obtained that chance; as a rule they were advanced in age before they got into that department. He thought that administration, book-keeping, and a few other things of that kind could very well be taught to engineers. It had been suggested that he had proposed in the Paper that the engineer should do the accountant's work. He did not suggest that he should do the actual figuring, but he thought the Plant Book might very well be kept in the works manager's office, and the actual writing and figuring done by a clerk under his supervision. Of course nobody expected him to do it with his own hand.

Mr. Mark Robinson had suggested the term "Plant Book" instead of "Stock Book," which he agreed was a far better term. He had mentioned "Stock Book," because when he was young he found it

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already termed "Machinery Stock Book" in the works he was at; but "Plant Book" was correct. He quite agreed with Mr. Mark Robinson that repairs should always be executed, irrespective of the value of the tool in the book or anything else. A tool must always be kept up to the mark. It was not his suggestion that the depreciation was in any way dependent upon repairs, which should be done altogether irrespective of depreciation, and depreciation went on notwithstanding repairs. In other words, the cost of repairs to machinery must not be added in any case to the Plant Book valuations.

Mr. Ping (page 852) had generally agreed with the principles laid down in the Paper, and said very properly that the methods, whatever they were, depended upon the people who used them. If they got hold of a man who would not use the card, it would be a failure; if they got hold of a man willing to use the card, it would succeed; and that applied to every other method. With regard to the question of obsolescence, he did not think he could improve upon the definition he had given on page 802. It was "the time during which a machine can be profitably used for the purpose of producing the output required by the works in which it is installed—this being its life." Obsolescence depended upon the time when it could be profitably used in those particular works. A machine might be obsolete in his works, but it might be very useful indeed to his neighbour. Mr. Ping also remarked that in looking at the obsolescence of a machine it was necessary to take into consideration whether it would pay better to keep it going or to throw it away and waste its remaining life—to sell it for what could be obtained for it—in order to introduce another machine which would earn more money than the machine which was being thrown away.

Mr. Kelway-Bamber gave some very interesting information as to how he dealt with things in India. There was one thing which showed how differently things were done by a Government Department in India to what they were in this country, namely, that the Government stepped in and said that the depreciation was to be at a certain rate. He did not think the Board of Trade would like to say to the engineers of England, "You must depreciate all your machinery 8 per cent."

Communications.

Mr. W. Stanley Bott wrote that the author was to be congratulated on having pointed out the great importance of providing a fund for plant maintenance and renewals without any reference to the profits and losses of trade. In Appendix I (page 809), a list of machines was given, and three different rates of depreciation; no doubt, from the author's experience, these rates were correct, but if he could enlighten the members as to his method of procedure in deciding what rate of depreciation a machine should bear it would be interesting. Did he consider it would be possible to formulate a set of questions which, when answered, would assist one in estimating the life of a machine? The ultimate scrap value was probably not difficult to estimate, but the life must depend on so many factors. It would surely be most instructive if he could enumerate these factors.

On page 802 the author defined the life of a machine as, "the time during which a machine can be profitably used for the purpose of producing the output required by the works in which it is installed." He (the writer) was not quite clear as to the meaning of this statement. If two machines, identically the same, were taken and installed in two different factories at the same time, one was kept fully occupied, and the other for only half its time. Yet both were necessary, and producing work cheaper than it could be produced by other means. Would the estimated life of the two machines be the same?

With reference to the number of hours a machine was likely to be at work, he would be glad if the author could furnish figures to show to what extent the depreciation rate was affected by this factor. Under the heading of maintenance (page 799) the author suggested "placing the control of the repairs and renewals and of the valuation in the same hands," and in the second paragraph on page 807, "over-valued machinery is one of the most dangerous enemies to financial safety." Now, surely there was much more danger of the man who had advised the purchase of a certain machine or recommended improvements, over-valuing his own work than if an independent person's valuation were accepted. In many manufacturing works

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nowadays, there was a Works Order Department, and the head of this was probably acquainted with the machinery in use, and would also be likely to know the amount of work coming forward for any particular machine; also, all orders would pass through his hands, and costs he could easily have to record also. It should be his duty to value the plant, subject to the works managers' final approval.

With regard to alterations and additions to a machine tool, it had always seemed to the writer a difficult matter to decide whether the full value of such should be added to the value of the machine to which they were made, as frequently such were made to accommodate special jobs, and yet there was a chance of them being found useful on future work. Would the author reckon the value as equal to the works cost? In this case would the author add the full value of the addition to the value of the machine, or part only, and part be charged against the job or jobs they were made to accommodate? He was sorry the Paper did not deal with loose plant repairs and maintenances, as it was frequently difficult to distinguish between plant repairs and plant additions, and the average foreman was quite unable to do so. He thought it would be well if a special committee were appointed to thrash out the subject.

Mr. E. H. Chambers wrote that there was a good deal to be said for the system of keeping machinery up out of revenue, and letting it stand at its original value in the Plant and Machinery Book. In the works over which the writer had control, a great many small machines were used, say of a value of £40, many of which had been made in the works; these machines had stood at their original figure for more than ten years, and were today as valuable as they ever were. They had been altered and improved in some cases out of all recognition; these alterations were noted, but the value in the Stock Book was not altered, unless some entirely different machine was built on the bed of the old machine, when, of course, the old one disappeared and a proper value was assigned to the new one.

With regard to larger and more expensive machines, he always depreciated these by a certain amount each year down to a fixed limit, which was certainly not scrap price. The reason for doing this was, not that the machine had actually depreciated, as it was always kept up out of revenue, but, being a high-priced machine, it was thought advisable to reduce its price gradually in the Stock Book, so as not to affect unduly the accounts of any one year should it, for any special cause, suddenly become obsolete and have to be scrapped. He maintained that it was just as bad to deceive one's shareholders by writing down their property to scrap prices as it was to inflate its value. The price at which a machine stood in the Stock Book should be its present value to the owners, while their firm was a going concern. Any other system of depreciation bristled with difficulty, because, for instance, one might give £600 for a machine in 1908; and if it had to be sold in 1909, one would be fortunate in getting £300. He would like to put the following questions to the author for consideration :—(1) A machine was bought for £30, and afterwards one was made like it for £5, what value should each machine stand at in the Stock Book? (2) A machine was bought for £100, and in the next year an exactly similar machine was purchased for £80, what value should be assigned to each?

Mr. Frank Edward wrote he felt certain that, if the ways of dealing with the wear and tear on plant were a little more seriously thought out, and the Machinery Stock Book brought to show the true value of various machines, it would go a long way towards helping the accountant to show the true standing of a concern, and also help the works manager, as many obsolete machines might be written off as scrap, which otherwise were expected to do good work, and earn good profits. He was afraid, however, that any uniformity of practice could only be made use of when repetition work was the order of the day, and this was not always the case. For instance, in a general and repair shop, a milling machine of moderate dimensions might be in use to take what would be considered a fair sized job for the shop. How long would it be before that machine was expected to do work beyond its capacity? and it might be permanently disabled from doing very accurate work afterwards owing to a strain, perhaps after it had only been in use a few years; and yet the same machine in a repetition shop would jog along for

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years on half power. Would it not be a very difficult question to judge the probable life of that machine in the general shop? Perhaps one would say, "Why was the machine put to this heavy work"; but those who had run a shop of this kind knew it was not always policy to lay down heavy machinery for a few jobs and perhaps have it standing idle for nine months out of twelve.

As far as the usual run of machines went which were not overworked, the writer thought that allotting them a "probable life" was a very sound system, but in cases such as he had just mentioned, it seemed to him the accountant must give way to the engineer who knew what sort of use the machine had had, and who was in a position to assess the depreciation. This was only one of many similar points that might crop up. There was no doubt that the works manager should have the Machinery Stock Book at his disposal whenever necessary, and in setting out this book plenty of room might be left for each machine, so that a complete record of repairs, cost of repairs, etc., and any information worth recording might be entered there. A loose-leaf book was very suitable for this purpose, as in that case all machines of a type or size might be kept together, and scrapped ones removed. Thus, if a 7-inch lathe of a certain make were purchased and numbered 30, and later on this order were repeated, the new machine might be numbered 30A, and a leaf could be inserted next to machine 30; then the machine's complaints, etc., could be compared at a glance, also the cost of repairs, etc., compared.

With reference to the repairs of plant, it was usual to add this account to the working expenses of a business; but in the case of a new concern starting with a new plant, it seemed to the writer that a fair allowance should be made for this on the first year or two's trading, otherwise it would be found that this item in the expenses would suddenly go up with a big bound; in other words, the cost of repairs for the first three years' trading would all come on to the fourth year's expenses. What everyone was aiming at now was the biggest return for his money, and if one had a machine taking up valuable space and earning say £1 per week, which could be replaced by a new one with double the earning power, then he thought it was time to wipe out the remainder of the old machine's probable life, and install the new one, even if it had yet a few years to run. In a case of this kind it would be interesting to know just how to deal with the financial side of the question. The accountant would no doubt say that a certain number of years' life of the machine had been lost; but the engineer would say there was no loss, but a decided gain.

He was inclined to the opinion that too little thought was given by the works manager to the plant under his charge from a financial standpoint, and also facilities were not always at his command to find these things out for himself. If a more definite co-operation were arranged between the accountants' department and the works department it would be to their mutual advantage as well as to the advantage of the concern they were interested in.

Mr. P. D. Leake, F.C.A., wrote that the author advocated in his able and interesting Paper (page 803), that depreciation of plant and machinery should be written off "during the life in gradually decreasing increments by fixing a percentage to write off each year from the last year's value," but a simple calculation showed, that in order to write off the cost of machinery, with a life of ten years and having an estimated scrap value of 2 per cent., by means of a fixed percentage off the reducing balance, the percentage to be employed would be exceedingly heavy—at least 33 per cent.—which involved apportioning the cost to each of the ten years in round figures as shown in Table 3 (page 872).

If a rate of 5 per cent. instead of 33 per cent. were employed, it would take about seventy years to reduce the cost to scrap value, and again the greater part of the charge would be borne by the earlier years, and it would be found that the same objection applied to all rates and all periods, if a fixed percentage off the reducing balance were employed.

The distribution of depreciation charges should coincide as nearly as possible with the proportion of consideration or output which was obtained from the machinery during each year of its efficient economic life, and this would, he thought, be obtained by writing off

(Mr. P. D. Leake.)

TABLE 3.

—	Fixed Percentage.	On Last Year's Value.	Charge to Year. Per cent. on Original Cost.
		£	£
1st year . .	33	100	= 33
2nd year . .	33	66	= 22
3rd year . .	33	45	= 15
4th year . .	33	30	= 10
5th year . .	33	21	= 7
6th year . .	33	12	= 4
7th year . .	33	9	= 3
8th year . .	33	6	= 2
9th year . .	33	3	= 1
10th year . .	33	3	= 1
Scrap value . .	—	—	= 2
			£100

one-tenth of the original cost less scrap value against each year, in the case assumed above. If ninety-eight were taken to represent the total output of the machinery during the ten years, this output was more likely to be enjoyed by each year in the way shown in Table 4, than in the proportions involved by the author's method.

TABLE 4.

—	Output.
1st year	10
2nd year	11
3rd year	11
4th year	11
5th year	10
6th year	10
7th year	9
8th year	9
9th year	9
10th year	8
Total output during life	98

Machinery was of course expected to do its work well, and to give an output not seriously diverging from the highest of which it was capable in a state of complete efficiency.

Considerations of interest such as were involved in what was known as the annuity method of calculating depreciation, or of discount which arose under the sinking fund method, should, he thought, be discarded altogether as unsuitable for use in connection with the charge for depreciation of plant and machinery. He had dealt with the reasons for this in a Paper read before the Institute of Directors in March 1907, entitled "The Question of Depreciation and the Measurement of Expired Outlay on Productive Plant; a plea for the study and use of better methods." In case anyone cared to consult that Paper, he might state that it was published by the Institute of Directors, and was also reproduced in full in the "Accountant" and in several engineering journals about that time.

If one took as an example the case of a workshop which had just been fully equipped with plant and machinery, the cost of this would be recorded as usual in an ordinary financial ledger in the accountants' department, possibly under several accounts, or possibly under one account only. He suggested that in the first place the engineers should prepare and settle schedules of the various types of plant and machinery, each type being subdivided according to the estimated length of efficient economic life stated in years, based on the best information then obtainable, having due regard to wear and tear, and also to probabilities of obsolescence, or of supersession by improved inventions and appliances of a similar nature, and these schedules should be handed to the accountants. The accountants would then fill in the cost price to each of these schedules, and when complete the total costs shown on these schedules, if added up and summarized, would equal the sum charged to the plant and machinery account in the ordinary financial ledger mentioned above. The accountants would also be provided with a book of record (described below) subsidiary to the ledger, which might be called "Register of Plant," and in this they would forthwith make the necessary entries for each type or subtype of plant and machinery, obtaining the details from the completed schedules.

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A convenient form for a Register of Plant was a loose-leaf book of suitable size, having a page which could be supplemented by additional pages as required, allotted to each type or subtype of plant and machinery, each page ruled with twelve separate cash columns, one for each year, each page being headed with a description of the type or subtype, and the declared length of life in years, and having a space for the signatures of the engineers responsible for declaring that length of life. In making up the financial accounts at the end of each year, outlay on additional plant and machinery during the year, and also outlay on renewal of any of the old plant and machinery would be abstracted from the ordinary financial ledger, and distributed into the columns for that particular year in the Register of Plant. The Register of Plant was then ready for the process of computing the depreciation belonging to the year just ended, and the operation consisted of deducting one year's depreciation from each of the still active yearly columns, for in an old established undertaking the expenditure in the earlier columns might have expired and been completely extinguished by previous years' deductions. Only a half-year's depreciation should be deducted from the expenditure appearing in the columns for the year just ended, because the average period of employment of the plant and machinery purchased during that year would be nearer to a half than to a whole year. The deduction from each annual column would then be entered in total on a summary sheet for each class, and these totals would ultimately be extracted from each of the class summary sheets to a general summary for the year, this general summary showing the amount necessary to be charged to the profit and loss account for the year, as inexorably as operative wages or other obvious expenditure, before any profit could result.

The engineers should have free access to this Register, and as time went on, and they found in the light of subsequent knowledge that this or that class of plant would probably last a longer or a less time than was originally estimated, they would, in consultation with the management, alter the life-period appearing in the Register of Plant at the head of the page allotted to that particular class, and thus, when the accountants came at the end of the year to compute the depreciation, effect would automatically be given to the altered circumstances.

In writing of plant and machinery for depreciation purposes, he did not include those loose tools and utensils, the value of which was commonly ascertained annually by taking a count or inventory. All these would be excluded altogether from the proposed Register of Plant, and dealt with in the ordinary financial ledger.

Current repairs to factory plant and machinery generally averaged themselves fairly well year by year in a workshop of any size, and might, he thought, best be charged to the profit and loss account each year as incurred; but extensive renewals of parts of a machine necessary from time to time, the cost of which it might be thought better to spread over the efficient economic life-period of the machine to which the partial renewal was applied, should be scheduled and the cost estimated and recorded in red ink on the proper page of the Register of Plant in the column containing the original cost of the machine, because such extensive renewals added to the cost of the machine, and the whole cost should be apportioned equally over each year of the expected efficient economic life-period. The proposed Register of Plant was a very simple matter in practice, although it sounded rather complicated, and when once installed a junior clerk could write it up as a very small part of his duties, and he could also calculate the depreciation at the end of each year on the lines originally settled by the engineers, and afterwards varied by them if found necessary.

The whole subject of depreciation was most interesting and important, and it is one upon which it was very necessary that engineers and accountants should co-operate.

Mr. Thomas Parkin thought that the author's suggestion for Repair Sheets as shown in Appendix III (page 811) was in every way admirable for repairs of any magnitude; but there were numerous small repairs required daily in a large works for which it would be both unnecessary and impracticable to employ separate sheets and order numbers, and which, if adopted, would entail much unnecessary work on the Costing Department.

(Mr. Thomas Parkin.)

The writer had found the following system to answer very well for dealing with these smaller repairs, which, although they might only take from a few hours to less than an hour to set right, yet required the services of a skilled man from the repair shop or tool room (the two departments being often worked in conjunction) and an order number on which to book the time and material expended. Each shop was given a distinctive letter, or double letter where the number of shops exceeded the range of the alphabet, and the plant and machinery in each shop were divided into convenient sections, each section having a number, and also bearing the prefix of the general shop letters, the numbers commencing with unity in each shop.

Taking for example a general plating shop, the Repairs Order Number Sheet (a copy of which would be hung in the foreman's office) would be somewhat as follows:—

ORDER NUMBER SHEET FOR SMALL REPAIRS.

Plating Shop.—Prefix PL.	No.
Shafting and Fittings	1
Repairs and Renewals to Belts	2
Punching and Shearing Machines	3
Bending and Straightening Rolls	4
Drilling Machines, Cold Saws, and miscellaneous	5
Compressed-air Plant and Pneumatic Tools	6
Accumulator, Pumps, Presses, and General Hydraulic Plant	7
Furnaces	8
Travelling and Jib Cranes	9
Loose Tools	10

The Costing Department would then be able to obtain the total cost of each subdivision at the end of each financial year, without the trouble of going through numerous job cards, these only being used for the more important repairs, for which it was desirable to keep a separate cost.

The writer agreed with the author that in large works a special maintenance engineer should always be employed, as it was obviously impossible for the works manager to devote the necessary time to this work, and to perform his other multifarious duties in addition. The maintenance engineer would require to be a man of resource, with sound practical knowledge, and to be a competent designer and draughtsman, as he would often be required to get out sketches and drawings in connection with repairs, renewals and additions to plant and machinery. In addition to the cost cards previously referred to, he would keep a private reference book, in which he would enter any item in connection with maintenance likely to be of use, such as dates when certain alterations were made, causes of breakdowns to be avoided in future, full particulars of parts of machines found to be liable to periodical breakdown, and whether new parts were to be made at the works or obtained from the makers, pattern number, if any, and all other information conducive to a quick repair. It would also be his duty to anticipate repairs as far as possible, and to see that spare parts were kept in stock to replace those which he found by experience were liable to periodical failure, so that in case of breakdown the repair could be effected in the quickest possible time. The writer had known days and sometimes weeks to be wasted with valuable machinery standing idle, through neglect of this precaution. Such a man, by reason of his being in constant touch with the whole of the works plant and knowing its weak points, by observing and correcting wasteful methods, and by exercising his judgment and experience in other directions, should effect great economies in works maintenance, not the least being the reduction to a minimum of stoppages and consequent loss of time.

Mr. W. R. Pettit wrote that the author dealt with a subject, unfortunately neglected by a considerable number of engineering concerns, much to their discredit and financial loss, and it might reasonably be hoped that Papers such as the author's might stimulate

(Mr. W. R. Pettit.)
those lacking in such matters into action. The writer had experienced in some large works he had been connected with a most deplorable state of affairs; no depreciation had ever been taken into account and the machinery at the end of thirty years was only worth so much scrap, with no funds at hand to re-equip the works. The word depreciation was barely understood in connection with machinery, and their disability to compete with foreign markets was put down to anything else but their own want of proper commercial engineering management. Fortunately there were in this country many reputable firms who had excellent systems of depreciation accounts, and in some cases their commercial management had saved them from going under during times of bad depression, or changes from one class of work to that of an entirely different character, necessitating very considerable additions to their machine tool equipment, which was a very common occurrence nowadays, owing to the very rapid advance of engineering science.

Depreciation of machinery was at the present time far more rapid than heretofore, due to a great extent, in fact it may be said almost entirely, to the advent of high-speed steels, and the writer had known cases of drilling machines having been depreciated at the rate of 25 per cent. to 30 per cent. per annum, as they were unable to stand up to the capacity of high-speed twist drills.

The writer had adopted a machinery record card which he found more convenient than the Machinery Registers. This was filed in the usual cabinet, and at the back of each card a machine breakdown card of another colour was filed in order of date, and showed at a glance the number of stoppages of the machine and cause, from which might be gathered the suitability for the work it had to do, as well as bringing to the notice of the works manager every breakdown, and the points connected therewith. It was not considered necessary to issue a fresh order for the repair of every machine; the labour and material was charged against the machine number prefixed by the symbol P.M. (plant maintenance).

There was a point on page 806 where the author referred to additions to machines which increased their productive capacity, the cost of such additions being added to their stock value. He also went on to state that the machines should then be so depreciated that the additions were written off at the end of their respective lives. The writer presumed that the original estimated lives was meant; if this were so he disagreed with the author in this respect. For instance, taking the case of a planing machine which was out of date as regards speed, and had its belt drive converted to a reversible motor-drive coupled direct to the gear, increasing the speeds 50 per cent., or in a lesser degree a drilling machine having its cast-iron gears replaced by cut-steel gears and the feeds and speeds increased. Both these machines had been given a fresh lease of life and their value appreciated; therefore the depreciation should then be re-arranged, and the original date of the end of the life of each machine extended.

It was customary nowadays with many up-to-date concerns to reconsider the depreciation of machinery every year, and the writer considered this the proper course to adopt, as owing to the rapid improvements always being made in machine tools, a machine which might be today considered in the front rank would probably be obsolete in 5 years' time, due to some entirely new and better machine being brought out. The care and maintenance and depreciation of workshop plant and machinery was a wide subject and much might be said about it, especially with regard to loose plant, lifting and erecting tackle, the depreciation of which was very rapid. The writer also made use of a card which he had adopted for keeping track of this gear. He would have appreciated any remarks the author might have made on the maintenance and depreciation of tool-room plant. It was a point very much neglected and the losses due to want of attention were very considerable, and would come as a surprise to many engineers.

Mr. R. Price-Williams wrote, in continuation of his remarks at the meeting (page 812), that he greatly appreciated the consideration shown him by being called upon to open the discussion on Mr. Darbishire's Paper. He was, however, convinced that there was no ground whatever for the author's assertions that, in dealing with the question of the repairs and renewals of the plant and machinery of engineering

(Mr. R. Price-Williams.)
workshops, the conditions were different from those that applied to rolling stock, as to have done so would have occupied too much of the time of the meeting. The subject was, however, of such vital importance as affecting the interests of the owners of the many large engineering workshop undertakings whose business was not the manufacture, but, if he might coin a word, the "Mechanicufacture" of engineering products, that he was glad of the opportunity of explaining the reasons which justified the conclusion that the principles affecting the maintenance and renewal of the operative plant and machinery were precisely the same in all essential particulars as those which applied not only in the case of rolling stock, but in that of the permanent way and works of a railway which itself was subject to the destructive effects of it. He failed to see the relevancy of the reasons assigned by the author for this difference of the conditions as between ordinary engineering workshops and those appertaining to the much greater railway engineering undertakings which constituted an essential portion of them, and were subjected to the like effects of wear and tear and natural decay.

He would state at once that the subject of the destructive effects of the wear and tear of the railway traffic, both on the permanent way, rolling stock, and workshop plant, and the question of their depreciation, engaged the attention of, and received the greatest consideration from, the Royal Commission on Irish Railways in 1866, of which the late Sir John Fowler was the chairman, and the late Mr. Seymour Clarke, the then general manager of the Great Northern Railway, who at one time was Mr. Brunel's principal engineering assistant on the Great Western Railway, and the writer's own services were retained by the Commission. With a staff of assistants he was entrusted with the examination and valuation of each and all of these Irish railways, the result of which was such as to satisfy the Commission, that in great undertakings such as these, whose business was that of the mechanical conveyance of traffic on a railway, and had necessarily to be carried on without cessation for an unlimited period, which necessarily involved the constant removal of the worn-out portions of the operative plant and works and their replacement with new material, it was decided as an essential requirement that the rolling stock, permanent way and workshop machinery and plant subject to wear and tear must necessarily always be maintained in a fit and standard condition for carrying on the ceaseless work of the railway companies as common carriers of the great bulk of the nation's traffic. And consequently, so long as this standard and well-defined condition of efficiency was maintained, there was no justification whatever for any deduction being made for depreciation in the value of the works and plant of these revenue-producing undertakings, and that what alone had to be deducted as constituting depreciation was the amount requisite to make good any dilapidations of the operative portions needed to restore them to a standard condition for the continued efficient working; and further, that the capital or market value of these business undertakings was to be measured by the average annual net income, capitalized at a certain number of years' purchase with an additional number of years in respect of the unearned increment and for the prospective increase and goodwill of the business. This was the principle of the valuation adopted by the Irish Railway Commission.

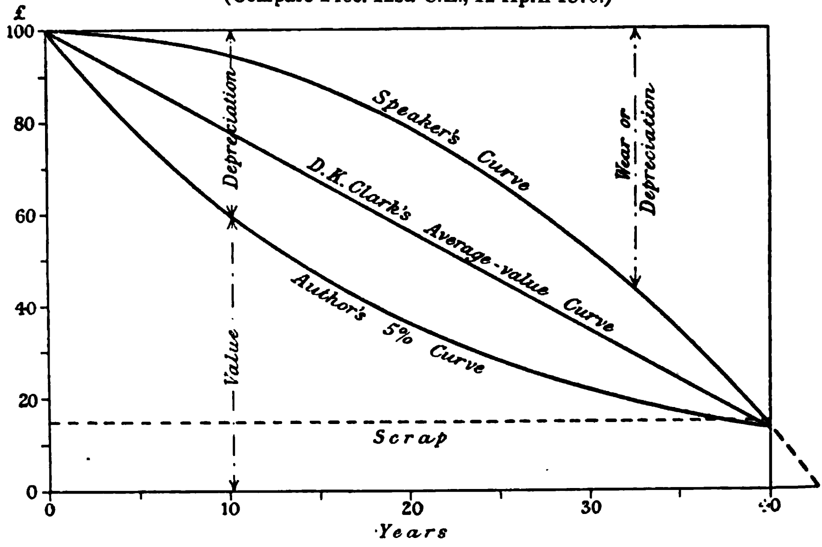
The later valuable data he had since obtained fully substantiated the soundness of the principles adopted by the Commission. He failed therefore to see why the same principles should be considered inapplicable in the case of the valuation of the machinery and other kinds of engineering workshop undertakings, subject in like but differing in degree to the effect of wear and tear, and requiring continual and continuous maintenance in a sound and standard condition of efficiency, to enable the engineering workshop business to continue to be administered in a thoroughly sound and profitable way. The various percentages allowed for depreciation in these engineering workshop undertakings, even if maintained in a standard condition of efficiency, was admittedly quite conjectural, and in fact amounted to an admission of the contention that it was justified, owing to the dilapidated state of the machines having reduced the revenue-earning capacity of the undertaking; this was a most unfair and unjustifiable contention.

(Mr. R. Price-Williams.)

Taking by way of illustration the percentages of depreciations alluded to in the Paper, and graphically shown in the diagrams and typified in the case of the 5 per cent. depreciation curve during the long period of 40 years, the outline of this curve of depreciation as shown on the diagrams should be reversed and concave to the abscissæ which indicated the period of time, the ordinates showing the depreciated values as shown on Fig. 8.

Fig. 8.—*Amount of Wear or Depreciation on the Machinery of an Engineering Working Plant treated as a whole.*

(Compare Proc. Inst. C.E., 12 April 1870.)



This curve, which showed the percentage value of £100 during each of the forty years, discounted at the rate of 5 per cent. during that period, was that of an ordinary parabola, the depreciation increasing as the square of the time; the curves of some of the higher percentages were those where the rate of depreciation increased as the cube of the time. That the rate of increase of the repairs and renewals of some machinery (that is to say, due to the removal of the worn-out portions of them and their replacement with new material) was quite possible, even in a well-administered undertaking, but that the capital invested in the entire undertaking had continued to depreciate in a well-administered business for a period of 40 years, at the rate even of 5 per cent. per annum, was an absurdity, and he challenged any proof of any actual instance of a 5 per cent. depreciation during that long period.

From a consideration of the fact that the nature of the author's 5 per cent. curve and that of the writer's was exactly similar, namely that of a parabola, it followed that as the mean ordinate was two-thirds of the original or prime cost of the workshop machinery in the aggregate, it was the equivalent of its average value during the 40 years, and that the average wear or depreciation was one-third in the case of the writer's curve and obviously the converse in that of the author's inverted curve, namely two-thirds average depreciation and one-third average value; while in the case of D. K. Clark's uniform rate of wear and depreciation the average would be half that of the original cost. No data whatever for the adoption of a 5 per cent. or in fact for any percentage of depreciation was afforded by the author, and was apparently perfectly arbitrary.

He thought that full and further consideration should be given by the Institution (in every way the most capable of dealing with it) to this most important question, and he could only say that he would be happy to place at its disposal the results of his recent investigations on this subject.

Mr. Darbishire wrote, in reply to the written Communications, that he felt that the discussion had extended to such a length that he must be as brief as possible in his remarks upon the points raised in communications from members and others. Many of these points had already been dealt with during the discussion and in his reply; for example, he had already given his reasons for adopting a curve of decreasing depreciation in preference to that favoured by Mr. Leake and Mr. Price-Williams, as well as by some of the speakers.

The methods of registering the plant and showing the yearly valuation and expenditure on repairs, etc., from time to time, advocated respectively by Mr. Leake and Mr. Edward, were generally in accordance with the author's views; it would be

(Mr. Darbishire.)
recognised that details must be left for individual settlement, as what would suit one works might not suit another. This applied to the form of the entries, and also to the "Small Repair" Sheet of Mr. Parkin (page 876), which would save a considerable amount of trouble in some works. Mr. Parkin's description of the duties of the maintenance engineer was in every way excellent.

The author did not think that a useful list of questions could be formulated, as suggested by Mr. Bott (page 867), as a guide in estimating probable life. That estimate must of necessity be the result of individual consideration; different questions would arise in each different workshop, though of course there were certain obvious points to consider in every case, such as the quality of workmanship in the machine, the probability of constant or of intermittent work being found for it during its life, and so on. It seemed likely that different "Probable Lives" would be assigned to the two machines instanced by Mr. Bott, but it would depend upon various circumstances besides those mentioned. Over-valuation of new machinery could always be checked by reference to actual cost. The cost of alterations and additions should only be added to the Plant Book value of a machine when its productive capacity was permanently increased. An alteration only useful for one job should be charged to the cost of that job.

The author had already stated his objection to the system approved by Mr. Chambers, of allowing machines to stand in the Plant Book at their original or undepreciated value. This would only be sound if machines never became obsolete, and its adoption invited financial disaster, unless a separate Depreciation Reserve Fund were provided, which did not appear to him to be contemplated by Mr. Chambers. The two cases suggested by Mr. Chambers would be dealt with according to the circumstances under which the machines were acquired; in the first case it was not improbable that the official responsible for the payment of the £30 would also be dealt with. Both cases were obviously outside what could be provided for by any rule, and would require special consideration of what the machines were, what the demand for their services was, if permanent or temporary, and many other points.

The case of the planing machine mentioned by Mr. Pettit (page 879) was met by lengthening the life of the machine on account of its "unexpected vitality" (*see* page 804), and then writing off the addition so that the whole would die together at the end of the revised life. The author thought that the rate of depreciation originally assigned to a machine should be adhered to unless cause was shown to alter it, and not varied by a reconsideration every year. Tool-Room (or Tool-Store) plant was purposely left out of consideration in the Paper, the author feeling that the subject of machinery was sufficient for one Paper, as indeed it has proved to be.

Mr. Price-Williams' communication (page 879) had been to a great extent answered in the author's reply that he would treat the machinery of a railway workshop exactly as he would that of any other workshop. There was one broad principle, of universal application, that whoever owned a machine of any kind which would eventally cease to exist and be replaced (if business was to continue) by another machine, must provide, during its life, out of his earnings (but not necessarily out of the earnings of that particular machine) the sum necessary to replace it, no matter how well he maintained it during its life. Manufacturing engineers, as a matter of prudence, ought to provide this sum by setting aside a certain amount year by year during the life of the machine, whether the amount was calculated by a concave or convex curve, or by a straight line; otherwise the whole charge would fall upon the year in which the replacement was effected, and a very little consideration would show how inapplicable such a change would be to manufacturing concerns depending on the profit of their output, whatever might be its effect on other concerns in which the workshop was only an adjunct, and the profit was made by another trade altogether.

In every case the author asserted that, seeing that effluxion of life took place, the provision of the renewal value of the machine which was gradually nearing its end should be spread over its whole life and not taken out of the revenue of the year in which it died. Hence it seemed to him a fallacy to say that there was no justification for any deduction for depreciation as long as efficiency was maintained. Effluxion of life must somehow be provided for.

(Mr. Darbishire.)

In conclusion the author expressed the hope that the discussion of this subject might be of benefit to the Mechanical Engineering Profession, and he cordially welcomed the suggestion that the Engineer and the Accountant should act together in maintaining a sound system of finance in the important matter of Depreciation.

The Institution of Mechanical Engineers.

PROCEEDINGS.

November 1908.

An Ordinary General Meeting was held at the Institution on Friday, 20th November 1908, at Eight o'clock p.m.; T. Hurry Riches, Esq., President, in the chair.

Before proceeding to business, the President said he had with great regret to announce the death of an esteemed colleague and Vice-President of the Institution, Mr. Henry Chapman. He was sure the members would agree with the Council, who had dealt with the matter that day, in expressing to the relatives of Mr. Chapman their deep sense of the loss which they had sustained, and at the same time informing them how very sorry the members were to lose the services and the kind co-operation of their old friend.

The Minutes of the previous Meeting were read and confirmed.

The President announced that, to fill the vacancy caused by the decease of Mr. Henry Chapman, the Council had appointed Mr. Henry Davey a Vice-President, and to fill the consequent vacancy among the Members of Council, they had appointed Mr. Walter Pitt, of Bath, a Member of Council.

Both these gentlemen would retire at the next Annual General Meeting, in accordance with Article 25, but would be eligible for election.

The PRESIDENT said he had the pleasing duty of presenting the Willans Premium Award to Mr. H. A. HUMPHREY, Member, for his Paper on "Power Gas and Large Gas Engines." * In addition to the Gold Medal, Mr. Humphrey had been awarded a framed plaque of the head of Willans and a book.

In making the presentation the PRESIDENT congratulated Mr. Humphrey very sincerely on the Paper he had been good enough to bring before the Institution, a Paper much appreciated by the members, and he hoped it would be only the first of many similar successes attained by Mr. Humphrey in future.

The PRESIDENT announced that the following three Transferences had been made by the Council:—

Associate Members to Members.

LARMUTH, WILLIAM OLIVER, ...	Manchester.
PATEY, ARTHUR PETTMAN, ...	London.
RAYNER, HARRY STAFFORD, ...	Manchester.

The following Papers were read and discussed:—

"The Resistance of Materials to Impact"; by Mr. T. E. STANTON, D.Sc., and Mr. L. BAIRSTOW, of the National Physical Laboratory, Teddington.

"Different Methods of Impact Testing on Notched Bars"; by Mr. F. W. HARBORD, Assoc. Royal School of Mines, F.I.C., of London.

The Meeting terminated at Ten o'clock. The attendance was 121 Members and 82 Visitors.

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* Proceedings 1901, page 41.

THE RESISTANCE OF MATERIALS TO IMPACT.

By Mr. T. E. STANTON, D.Sc., and Mr. L. BAIRSTOW,
of the National Physical Laboratory, Teddington.

During the years 1904–1905 the authors were engaged in a research on the resistance of certain kinds of iron and steel to reversals of direct stress.* In these experiments the change from tension to compression was gradual, and followed an approximately simple harmonic law, special care being taken to avoid the subjection of the specimens to sudden shock, the effect of which, it was considered, would complicate the problem, and might conveniently form the subject of another research.

Since in ordinary machine practice the stresses induced in the moving parts are, in general, due to a combination of shock and gradually applied load, as might happen in the case of the crank-pins and bearings of reciprocating engines, it appeared to the authors that the determination of the relative resistances to sudden shock of the same materials as used in the previous work on gradual reversals of stress would, combined with the previous results, be of considerable value to the designer. This determination appeared to be the more urgently required, since in the opinion of engineers of such wide

* Proceedings, The Institution of Civil Engineers 1905-6, vol. clxvi, page 78.

experience as Messrs. Seaton and Jude,* the proof resilience of a material, that is, the maximum work which can be stored up per unit volume without permanently deforming it—as calculated from statical experiments—is quite unreliable as an index of "useful toughness."

A research with this object in view was accordingly commenced, and some suitable testing machines for the work were designed and made in the workshop of the department.

As in the research on alternating stresses, the testing machines were designed for the purpose of carrying out endurance tests up to one million shocks or more. Since however these machines lent themselves equally well to the fracture of specimens under comparatively few blows, the authors were led to the comparison of the results of impact tests which consisted of a large number of small blows with these consisting of a small number of heavier blows or even of a single blow to destruction.

The results of this comparison, together with the interest taken at the present time by engineers in the respective merits of impact tests by the "single-blow" and the "many-blow" methods, induced the authors to enlarge somewhat the scope of the work so as to include a study of the development of the changes in the relative shock-resisting properties of materials as the number of blows for fracture is increased. In doing this the authors have no intention of making any comparison of the *relative merits* of the two methods of test, since in their opinion such a comparison cannot be made for the following reasons:—

An impact test on any given material may be made for one of two objects.

(1) To ascertain if the material is in an abnormal or dangerous state, that is, is brittle; or

(2) To determine the resistance to shock under working conditions of the material relative to the resistance of other well-known materials.

It is obvious that the first object will primarily concern the steel maker, who will be naturally anxious not to supply the

* "Impact Tests on the Wrought Steels of Commerce." Proceedings 1904, Part 4, page 1135.

constructor with dangerous material; and that the second will concern the engineer or designer of machinery, to whom a knowledge of the relative values of the true resilience of materials, which are otherwise constructionally satisfactory, is of considerable importance.

It is further almost obvious that the nature of any proposed impact test will depend upon which of the above objects is in view, since for the detection of brittleness, its chief characteristic, which is an absence of permanent strain on fracture under impact, will be best brought out by a test to destruction, which will involve the least amount of energy spent in elastic deformation, that is, a single-blow test. Again, for the determination of resistance to shock under approximate working conditions, the test should be one in which the energy absorbed in plastic deformation is a minimum, since such plastic deformation has little relation to its constructional value. The proper test in this case would therefore appear to be what may be called a "shock-fatigue" test, involving a large number of relatively small blows. It seems evident, therefore, that no comparison of the relative merits of two tests which reveal different properties of the material can be made, but these considerations do not seem to have been fully appreciated in previous discussions on the subject, in which there has been frequent evidence of the opinion that impact tests by the single-blow method afford all the information which the steel maker and engineer require for the selection of the material which is best suited for endurance of shock.

As the very considerable expenditure in time and trouble involved in making fatigue tests would be saved, if this assumption were true, the authors decided to make the investigation of its validity the chief feature of the present research, by selecting materials differing widely in their strength and elastic properties, and by subjecting them to a varied treatment under impact, so that a scale of "useful toughness" for the materials could be determined.

Methods of Test and Testing Machines used.—For the experiments on the bending of a notched specimen by the single-blow method, an Izod impact tester was kindly lent to the Laboratory by Messrs. Avery and Co., of Birmingham, at the request of Captain Sankey, who has shown great interest in the present work.

This machine, which has been fully described* and is well known to engineers, is shown diagrammatically in Fig. 1, in which is indicated the standard form of specimen and method of estimating the energy absorbed in fracture.

The other form of single-blow impact tester adopted was that which would produce fracture of a plain specimen by direct tension. The machine made in the workshop for this purpose is shown in

FIG. 1.
Impact Tester (Izod).

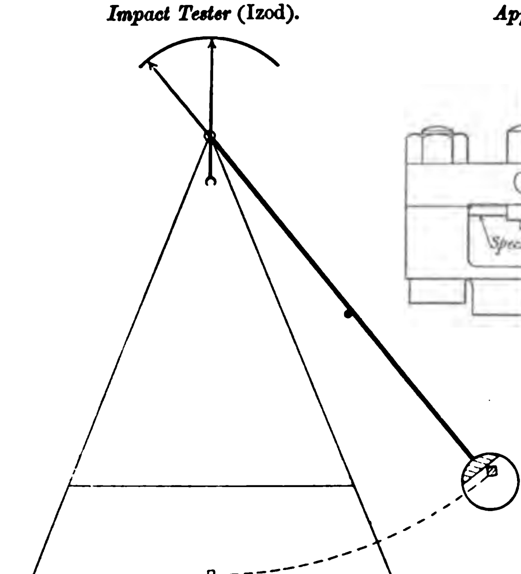


FIG. 2.
Apparatus for Static Tests.
(N. P. L. Method.)

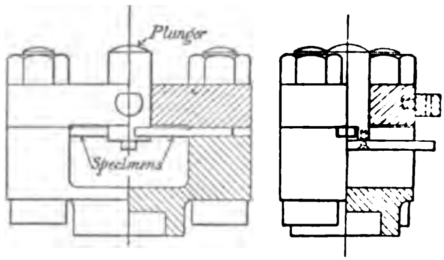


Fig. 3. The specimen is 0·25 inch diameter, 1 inch long, and has shanks at each end screwed with a half-inch Whitworth thread. In testing, the specimen is screwed into the base-plate BP, and at its other end is attached to the cross-head C. This cross-head is connected by two side-rods to a piston P, which is struck by the

* Proceedings 1904, Fig. 170, Plate 43; and "Engineering," 25 September, 1903.

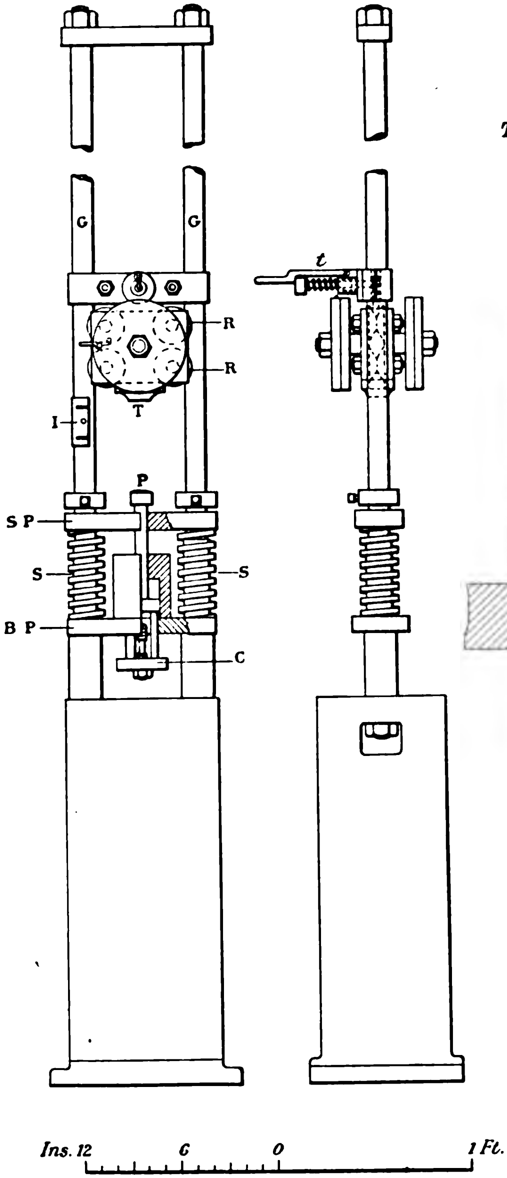
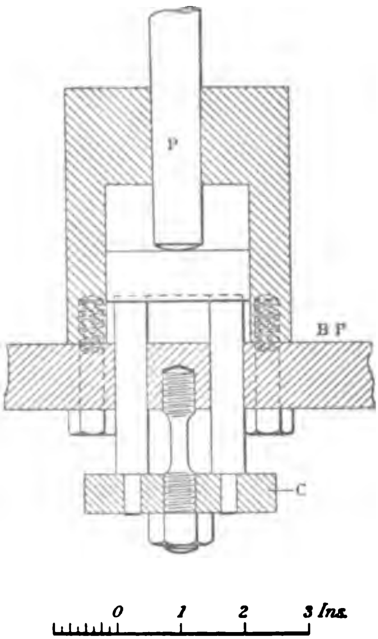


Fig. 3.

Single-blow Tensile Impact-Testing Machine.

(N. P. L.)



falling tup T. This piston is provided with a collar at its upper end, which, after the fracture of the specimen, engages with the striking plate SP, resting on the spiral springs SS, which absorb the residual energy in the tup. This energy appears in the rebound of the tup, and is measured on a calibrated scale I. The tup is supported before the test by a movable cross-head attached to the guides G, and the release is performed by the trigger *t*. The tup is provided with four conical rollers R to reduce the friction as much as possible.

For the comparison of the energy expended in the fracture of a specimen in this machine with the work done in a static test of a precisely similar specimen, the laboratory 10-ton machine was used with a special micrometer for taking the extension.

The corresponding static test on the notched specimens used on the Izod machine was more difficult, and the arrangement finally adopted for doing this is shown in Fig. 2 (page 892).

In this, two specimens are clamped in the cross-head, which is fixed to the shackles of a compression testing-machine, facing each other in such a way that the plunger bears upon both at points equal to the distance of the striking tup from the notch in the impact tester. In this way a steady downward pressure is all that is necessary to make the test, the deflections being taken by a micrometer.

Corresponding to the two machines on the single-blow method, two repeated-impact testing-machines were designed and made, one for bending-impact tests on notched specimens, and the other for direct-impact tests on plain specimens.

In the bending-impact tester, which has been fully described,* the turned specimen, 0·50 inch in diameter, with a V notch in the centre 0·40 inch in diameter at the bottom, is placed on knife-edges 4½ inches apart and receives blows over the notch from a falling tup which strikes it alternately at each end of a diameter. To do this the specimen is reversed between successive blows by a link motion, the details of which will be clear from Fig. 4. The fall of the striking tup can be regulated from 0 to 3½ inches

* "Engineering," 13th July 1906.

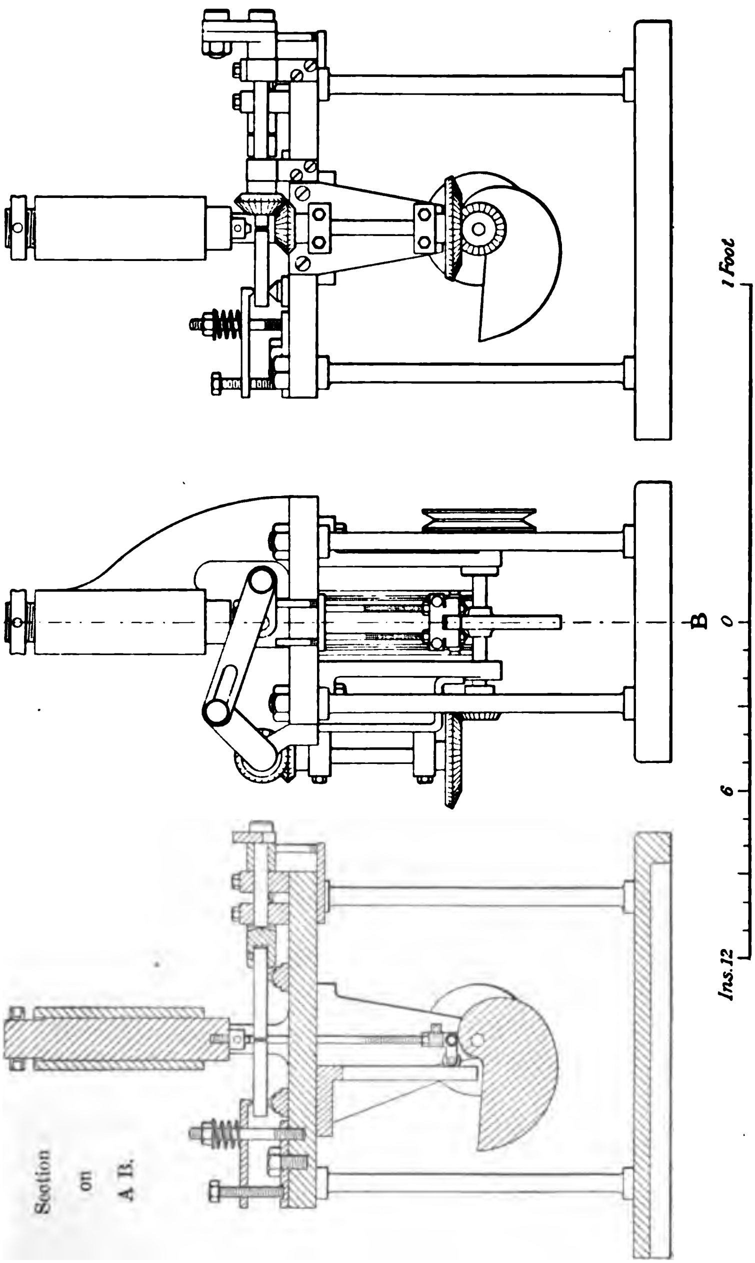


FIG. 4.—*Repeated-Impact Testing Machine* A *for Bending of Notched Specimens.* (N. P. L.)

and its weight is 4·7 lbs. On the fracture of the specimen the tup strikes a small bell-crank lever which breaks the circuit of the driving motor and thus stops the machine. A counter is attached to the machine, which registers the number of blows, so that the machine can be left without any attention except for occasional lubrication. The maximum speed attained in this form of tester was 100 blows per minute, which renders a fatigue test up to half a million blows a somewhat long process.

The manner of fracture of the specimens, whether of soft or hard material, is that a crack is developed on each side of the specimen at the bottom of the notch, the two cracks spreading inwards as the test proceeds. In the case of a light blow and many reversals these cracks will spread nearly to the centre before fracture occurs, as will be seen from the photograph in Fig. 20, Plate 29, which is from a specimen of mild steel (0·20 per cent. carbon) which broke after 50,000 blows.

Except for tests in which the number of blows is small, that is, less than 100, there is no appreciable permanent set in the specimen until within a few blows of the ultimate fracture.

Testing Machine for Alternating Direct Impact.—In this machine the specimen is held by two concentric hard steel sleeves S_i and S_o into which it is screwed and locked as shown on the right of Fig. 5. The blow of the striking tup is always delivered on the inner sleeve, the outer one being supported on a rigid steel ring R. The change from compression to tension is effected by a rotation of the sleeves about a horizontal axis between successive blows. For the compression blow the inner sleeve is struck at that end of it which holds the specimen, and for the tension blow, at the opposite end on the two projections PP, which pass through openings in the outer sleeve.

The outer sleeve is held by the cross-head C, which is carried on the bearings BB, at the extremities of the two side rods working in the side guides *gg*.

The rotation of the cross-head and sleeves is performed in two operations. First, the cross-head is raised vertically by the two side cams AA, (which engage with rollers on the side rods) to a distance

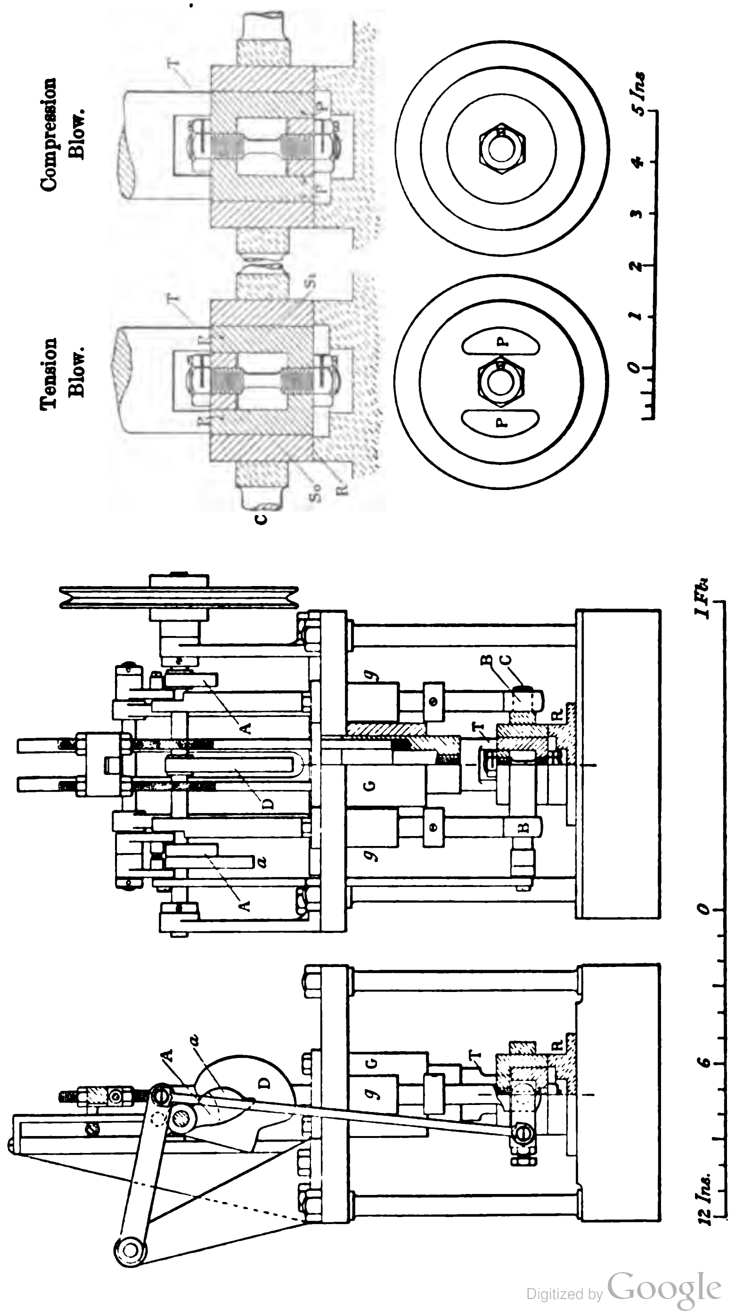


FIG. 5.—*Impact-Testing Machine, for Alternating-Tension and -Compression.* (N. P. L.)

sufficient to enable the cross-head in its rotation to clear the ring R. Secondly, by means of another cam *a* and the system of rocking levers shown in the figure, the cross-head is rotated into its new position and then lowered on to the ring R. The initial motion of the cross-head during rotation is made as rapid as possible, so that its inertia carries it over the "dead point."

The striking tup T moving on the guide G is actuated by the centre cam D, which engages with a hard steel roller on an adjustable cross-head attached to two tail-rods on the striking tup. By this means the fall of the tup can be varied from 1 inch to 3·3 inches. To reduce the friction of the tup in the guide as much as possible, the former is machined with a broad spiral fluting to reduce the surface of contact.

The machine is driven by a $\frac{1}{8}$-H.P. motor through a reduction gear, and is provided with an automatic cut-out worked by the tup on fracture of the specimen and a counter to register the number of blows.

Materials used in the Research.—As previously stated, one of the chief objects of the present research was to predict the limiting resistance, under impact, of the materials for which the resistance to alternating stresses had already been determined. Unfortunately the amount of this available was not large, and although Sir Robert A. Hadfield very kindly procured for the Laboratory another supply of Swedish Bessemer steel of carbon content varying from 0·16 to 0·6, the strength properties of these did not precisely agree with those used previously. It was therefore decided to use the remainder of the original stock for the experiments on limiting resistance and the new material for the comparison of the one and the many-blow methods. The description, analyses, and results of the tensile tests of the materials used are given in Tables 1 and 2, and for convenience these materials will be referred to in the Paper by the numbers attached to them in the Tables.

TABLE 1.—*Analysis of Materials used.*

Test No.	Description.	Carbon.	Manganese.	Silicon.	Sulphur.	Phosphorus.
1	Swedish Charcoal Iron.	0·039	trace	trace	0·000	0·018
2	Commercial Bessemer Steel.	0·160	0·640	0·007	0·056	0·069
3	Swedish Bessemer Steel.	0·165	0·310	0·017	0·019	0·022
4	Mild Steel Boiler Plate.	0·170	0·570	0·040	0·030	0·050
5	Best English Wrought Iron.	0·195*	0·005	0·086	0·011	0·054
6	Swedish Bessemer Steel.	0·206	0·290	0·009	0·016	0·020
6A	,, ,, ,,	0·170	0·100	0·021	0·012	0·013
7	,, ,, ,,	0·270	0·250	0·027	0·012	0·023
8	,, ,, ,,	0·414	0·320	0·036	0·012	0·017
8A	,, ,, ,,	0·446	0·370	0·058	0·012	0·028
9	,, ,, ,,	0·604	0·190	0·022	0·012	0·016
9A	,, ,, ,,	0·645	0·260	0·062	0·010	0·028
10	Boiler Plate supplied by Mr. Milton.	0·311	0·415	0·018	0·033	0·020

* *See* Dr. Stanton's further Note to the Discussion (page 1021).

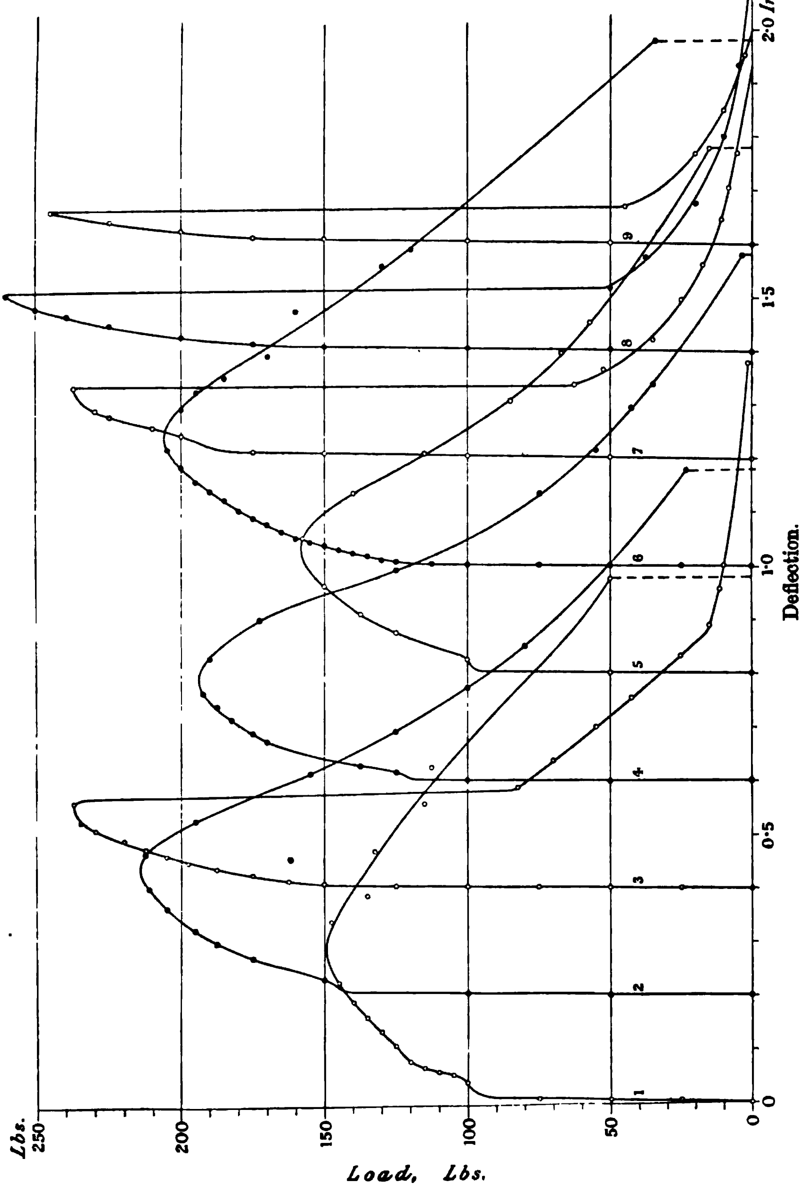
TABLE 2.

Tensile Tests of Materials Used.

Test No.	Tons per square inch.		Elongation on 2 inches.
	Yield-Point.	Maximum Load.	Per cent.
1	14·46	19·60	48·0
2	24·10	30·10	37·0
3	26·80	31·30	27·0
4	16·12	28·56	30·0
5	17·44	22·80	41·0
6	21·80	27·50	38·5
6A	23·78	28·53	32·0
7	30·55	37·00	28·0
8	31·90	41·10	24·5
8A	28·05	43·75	24·5
9	31·40	44·20	22·0
9A	29·10	47·60	20·5
10	16·35	31·00	34·0

Fig. 6.

Load-Deflection Diagrams, Static Tests on Notched Specimens.



Results of the Experiments.

Single-Blow Method.—Sets of specimens were prepared from the materials described above and tested in the Izod machine and the single-blow tensile impact tester. Exactly similar sets of specimens were then subjected to the static test in bending and direct tension, and the work done in fracture carefully estimated in each case, Fig. 6.

The results are stated in Table 3 (page 903), and for the purpose of comparison are also shown graphically in Figs. 7 and 8, in which the values of the energy are plotted on a carbon base.

Comparison of Impact and Static Tests. (Single-blow Method.)

Fig. 7.

Bending Notched Specimens.

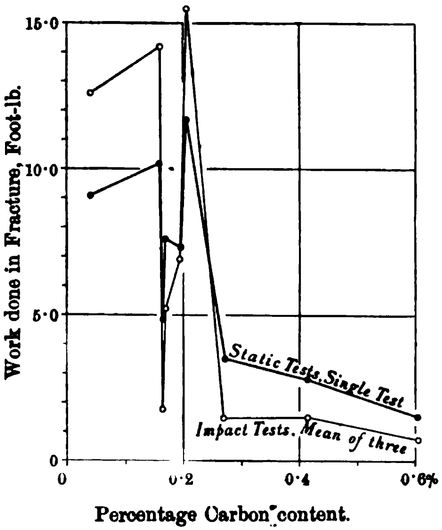
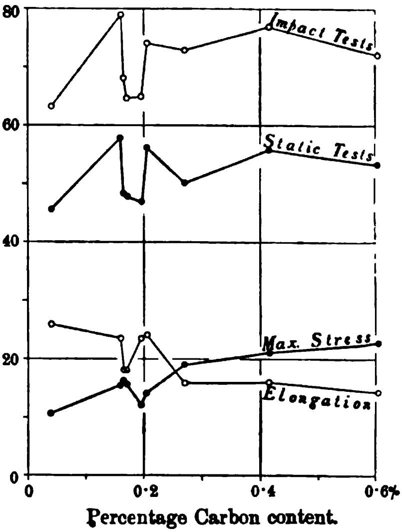


Fig. 8.

Tension Tests on Plain Specimens.



It will be noticed that, in the case of the tensile tests, the values of the energy absorbed in impact are well above the corresponding values of the work done in the static test. This is due to the loss of energy at the surfaces through which the force of the blow is transmitted and which was practically unavoidable, in order to secure the tensile effect of a blow. The most important feature of the curves is the remarkable similarity which is seen to exist between the impact test and the static test, both for the direct tensile tests on plain specimens and for the bending tests on notched specimens.

The static tests on the notched specimens presented so many difficulties that a marked agreement was hardly to be expected, especially in the cases of the low-resistance specimens; but the chief characteristics of the impact curves are reproduced so faithfully in the static-test curves, that there seems no reason to doubt that more refined methods of observation would yield results which would make the curves identical for the moderate velocities of impact here used.

The conclusion which the authors arrive at from these tests is that there is no source of weakness brought out by single-blow impact tests on plain or notched specimens which is not revealed by a careful static test.

This is in accordance with the results of the previous experiments of Professor Hatt,* of Purdue University and of Mons. Pierre Breuil,† of the Conservatoire des Arts et Métiers, Paris.

TABLE 3.

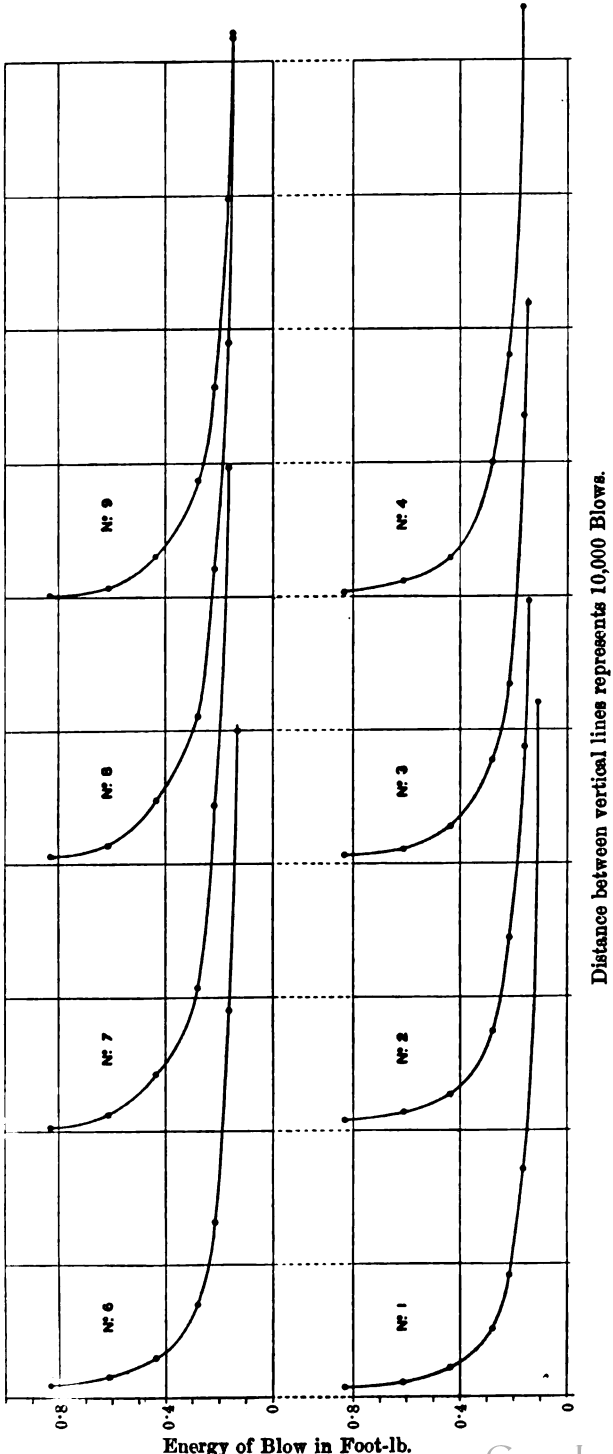
Single-Blow Method.				
Bending of Notched Specimens.			Tension of Plain Specimens.	
Material.	Energy absorbed in Impact. (Izod Test.)	Work done in Static Test.	Energy absorbed in Impact.	Work done in Static Test.
	Ft.-lb.	Ft.-lb.	Ft.-lb.	Ft.-lb.
1	12·6	9·1	63·2	45·6
2	14·2	10·2	79·0	57·9
3	1·8	4·8	68·1	48·3
4	5·2	7·6	64·7	47·8
5	6·9	7·3	64·9	46·9
6	15·5	11·7	74·1	56·2
7	1·4	3·5	72·9	50·2
8	1·5	2·8	76·9	55·8
9	0·8	1·5	72·1	53·4

* "Tensile Impact Tests of Metals." Proceedings, American Society for Testing Materials. Vol. 4. 1904.

† Journal, Iron and Steel Institute. Supplement to vol. LXV, 1904.

Fig. 9.

Bending-Impact Tests, Comparison of Results for varying Number of Blows.



Many-Blow Method.

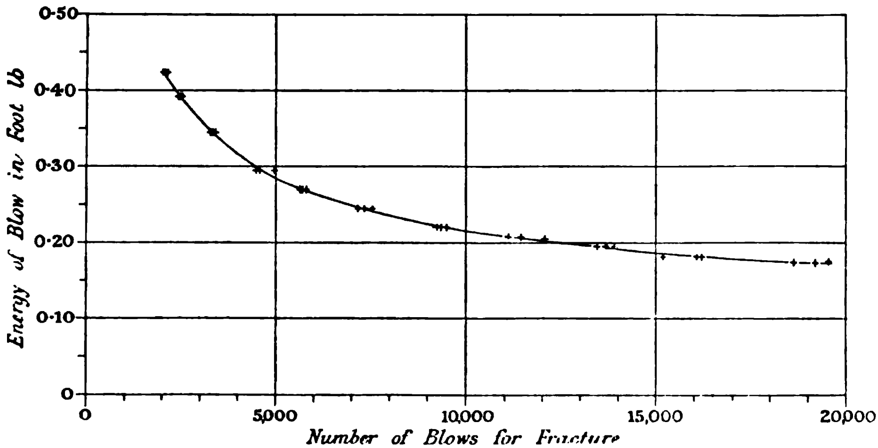
(1) *Bending-Impact Tests on notched specimens.*

(*a*) *Comparison of Results for varying Number of Blows.*—For this purpose sets of seven specimens were prepared from each of the materials, and were tested in the Repeated-Bending Impact Tester. The variation in the number of blows for fracture was made by varying the fall of the tup, whose weight was kept constant for this set of observations.

Fig. 10.

Bending-Impact Tests on Notched Specimens all prepared from one Bar of Mild Steel.

3 Tests at each setting of tup.



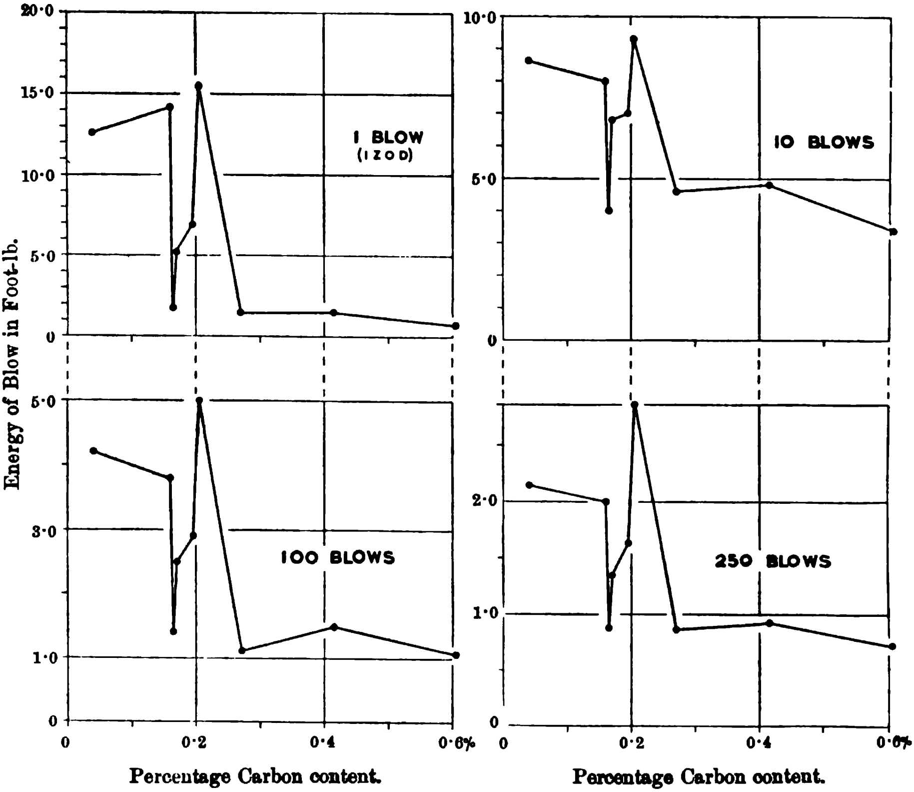
The results are plotted in Fig. 9, which shows the curves, co-ordinating height of fall of tup, and number of blows for fracture for each material. The remarkable uniformity of the results will be evident from the distribution of the dots about the curves of mean position, and throughout the work it was found that these tests could be repeated with only small deviations in the number of blows per fracture, which rarely exceeded 3 per cent. This is in marked contrast to results obtained in previous experiments in which the reversal was not performed mechanically. A further

3 Q 2

proof of the uniformity of the results obtained by this method is shown in Fig. 10 (page 905), in which are plotted the results of the tests on 30 specimens all cut from the same bar of ordinary mild steel. Three specimens were tested at each setting of the tup, and in only

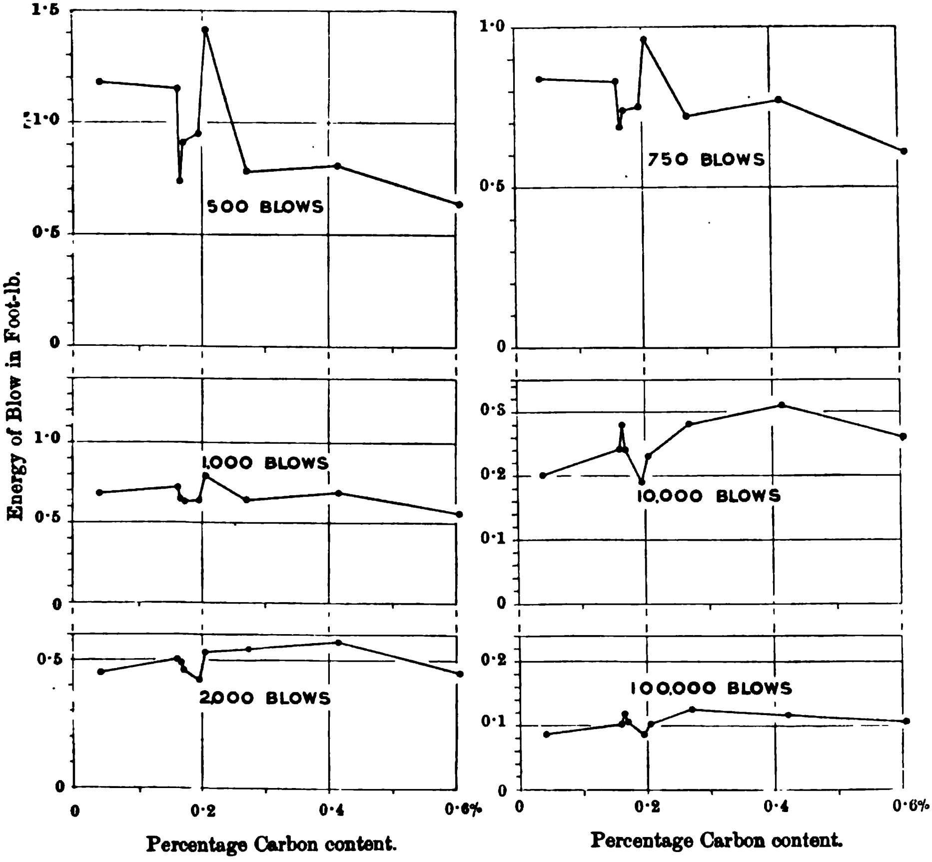
FIG. 11 (*continued on opposite page*).

Bending-Impact Tests on Notched Specimens.



one case did the number of blows for fracture differ from the mean of the three tests by more than 3 per cent. As the curves in Fig. 9 are not very suitable for comparison with each other, a graphic method has been adopted by means of which the relative energies of the blows required to fracture the materials after a given number of blows is clearly indicated. For this purpose the number of blows for fracture after 10, 100, 250, 500, 750, 1,000, 10,000 and 100,000 blows respectively has been scaled

Fig. 11 (*concluded from opposite page*).
Bending-Impact Tests on Notched Specimens.



off from the curves in Fig. 9, and for each of these cases a curve co-ordinating energy of blow and carbon content has been plotted.

These curves, together with the one showing the results obtained by the one-blow method in the Izod Tester, are given in Fig. 11.

On examination it will be seen that the characteristics of the curve for the one-blow method are practically the same as those obtained in the many-blow method when the number of blows for fracture is not considerable, as has been previously pointed out by Mr. Izod.* Thus the curves for 1, 10, 100, 250, 500 and 750 blows agree in giving a relatively high value of resistance for No. 6 material, and a relatively low value for No. 3 material. As, however, the number of blows for fracture increases, the elastic resistances, which was inappreciable in resisting a heavy blow, become more and more apparent, as is seen in the increased resistance of the higher carbon steels. This factor grows in importance, until at 10,000 blows the characteristics of the one-blow curve are practically reversed, a peak in one curve corresponding to a depression in the other.

(*b*) *The Limiting Resistances of the Materials.*—It was hoped that, by increasing the number of blows for fracture in this way, it would be possible to arrive at a limiting blow under which the material would not develop a crack, but it was found that even after a million blows this limiting resistance was not nearly reached. This experience seems to be in agreement with that of Wöhler in the similar case of the fatigue of bars under alternating bending stresses, and to be in contrast to the case of direct alternating stresses on which the limiting resistance is reached in about one million reversals. Another method of predicting the limiting resistance was therefore adopted. This consisted of subjecting the specimen to a fairly large number of blows—420,000—after which a section was made across the notch on the plane of bending, which was polished and etched and then examined to see if a crack had commenced. If so, its depth was measured and another specimen of the same material tested for 420,000 blows with a slightly less fall of tup, and was then cut up and examined microscopically. In this way, by making a sufficient number of tests, a curve co-ordinating depth of crack and fall of tup could be plotted, and as the least fall observed corresponded to a depth of crack of approximately four-thousandths of an inch in depth, only a slight

* Proceedings, 1904, Part 4, page 1213.

extension of the curve was necessary to predict the limiting fall for no crack. Owing to the length of time required for this part of the work, these limits were only attained for four materials, which were specially chosen because their limiting ranges of stress were known from the authors' previous experiments on alternating stresses, which enabled a calculation to be made of their respective proof resiliencies. The curves for these materials are shown in Fig. 12 (page 910), from which the limiting values of the energy may be scaled off. Now, the theoretical proof resilience or maximum work per unit volume which can be stored up in any material under direct or bending stresses within the elastic limit is proportional to

$$\frac{f^2}{E}$$

where f is the real elastic limit of the material;
E is Young's Modulus of Elasticity.

From the known values of f and E, derived from the authors' previous experiments, the values of the proof resiliences of the four materials chosen—which were a wrought-iron and steels of 0·2, 0·4 and 0·6 per cent. carbon content—are respectively as:—

1 : 0·92 : 2·5 : 2·7.

The limiting values of the energy of blow scaled off from the curves in Fig. 12 are as:—

1 : 0·92 : 1·3 : 1·5,

being 0·026, 0·024, 0·033, 0·038 foot-lb. respectively.

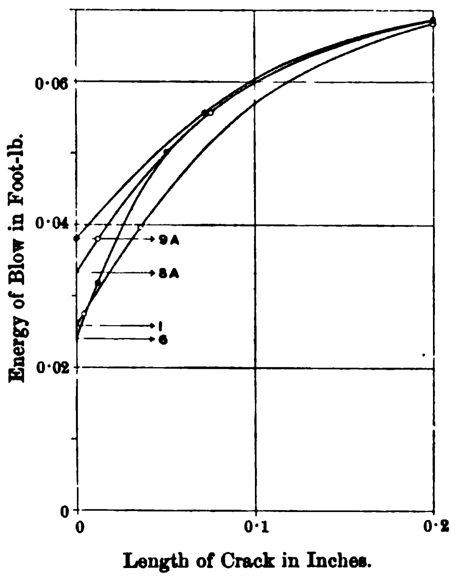
It will be noticed that, although the experimental resiliences increase in the same order as the theoretical ones, the ratio of the highest to the least of these quantities is considerably greater theoretically than that found by experiment. The authors think it possible that this discrepancy is due to the extreme difficulty in detecting a crack which has only extended two or three thousandths of an inch into the specimen, which was a difficulty in distinguishing between a crack and a boundary between crystalline grains.

2. *Direct Impact-Tests on plain turned specimens.*

(*a*) *Comparison of the Resistances.*—Owing to the relatively slow speed of the direct-impact tester, it was not found practicable to

FIG. 12.

Prediction of Limiting Resistance during Bending-Impact Tests.



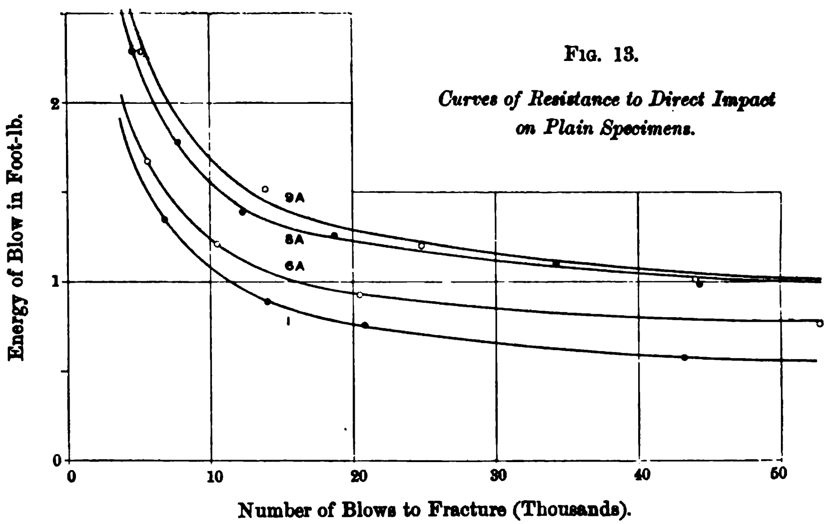


FIG. 13.

Curves of Resistance to Direct Impact on Plain Specimens.

carry out endurance tests with a greater number of blows than 50,000. Tests within this limit have been made on the same materials as those chosen for the prediction of the limiting resistance in the repeated-bending impact tester, that is, a wrought-iron and three Swedish Bessemer steels of 0·2, 0·4, and 0·6 carbon content.

The curves co-ordinating energy of fall of striking tup and number of reversals for fracture are shown in Fig. 13. The general features of these curves are similar to those obtained from the same materials under gradually applied alternating stresses, and the resistances increase in the same order. From a study of these curves there does not seem any reason for doubting that the limiting resistances are in agreement with those found from the bending impact tests on notched specimens.

(*b*) *The Changes in the Microstructure of Materials due to Impact.*—The changes which occur in the crystalline structure of strained materials have already been studied in various researches, since their original investigation by Ewing and Rosenhain. In the present work the observations made by the authors on materials subject to direct alternating stresses have been extended to the case of materials subject to repeated tension and compression due to impact. Although the microscopic study of lines of fracture due to impact has received considerable attention,* the development of slip lines due to repeated impact has not been previously investigated, so far as the authors are aware.

The specimens were of the same dimensions as the standard form for the direct impact tester, Fig. 5 (page 897), except that they were slightly tapered towards the centre in order to localize the strained region as much as possible. A narrow flat was then made on the surface parallel to the axis. This surface was polished and etched and subjected to alternate blows in tension and compression in the machine, being periodically removed for microscopical examination. The first material used was Swedish iron which had been heated to

* Proceedings, 1904, Part 4, page 1135.

1,000° C. (1,832° F.), and then cooled slowly. Figs. 14, 15, and 16, Plate 29, show three photographs of the surface of a specimen of this material, taken at intervals during the progress of a test. In Fig. 14 a set of slip lines running diagonally across the crystal have developed after 8,400 blows, half in tension and half in compression. In Fig. 15, which is a photograph taken after 12,000 blows, a second set of slip lines are seen to have developed approximately at right angles to the first, and in Fig. 16 is seen a still further development of these lines after 29,000 blows. The specimen eventually broke outside the field photographed. Fig. 17 shows a photograph of a specimen of 0·6 per cent. carbon steel which has been heated to 1,000° C. and slowly cooled, and tested as in the previous cases. It will be seen that the line of development of the crack unmistakably takes a path through the ferrite of the section, whereas in Fig. 18 the crack passes chiefly through the pearlite. As was pointed out in the Paper on alternating stresses, the surface does not definitely indicate which of the two constituents is chiefly concerned in the fracture of the material, although the greatest number of observations seem to point to the ferrite as the weak constituent.

In each of the preceding cases the repolishing and re-etching of the specimen would have removed all trace of the strain, as the lines had not developed into definite cracks. When, however, a specimen was broken by a sharp blow, a series of lines, or rather narrow bands, appeared which had quite different characteristics. Fig. 19 shows a photograph of these bands in a sample of Swedish iron. The specimen was notched and then fractured by a hammer blow. One piece was then polished and etched with the result shown. The main series of bands runs across the photograph from left to right in parallel lines. Traces of two other sets are also visible, one approximately at right angles to the first and the other inclined at about 30° from left to right. Many of these will be seen to consist of double lines, and under high magnification show as narrow bands. The bands are not visible before etching, and are not eliminated by repolishing and re-etching, this distinguishing them from "slip lines."

These bands have been described by Messrs. Osmond, Frémont and Cartaud,* under the name of "Neumann" lines, and are evidently intimately connected with the crystalline structure, and are probably due to molecular changes along cleavage planes throughout the whole crystal. These lines do not seem to have been found except when the specimen has been fractured under impact, with rupture in a very small number of blows.

On the other hand, when failure occurred under fatigue, the cracks resulted from the development of the "slip lines," and the process was the same under impact as under gradually applied alternating stress.

The Effect of the Dimensions of the Specimen.—In the discussion on Messrs. Seaton and Jude's Paper, the great desirability of discovering an impact test, the results of which should be independent of the dimensions of the specimen, was pointed out by several speakers.

As the results on the standard form of specimen in the bending-impact machine could be repeated with considerable accuracy, the authors made a series of experiments to determine to what extent these results could be repeated on specimens of different sizes.

From some preliminary experiments it was found that the number of blows for fracture with a given fall of tup—

(1) was practically independent of the sharpness of the V notch, when the number of repetitions of the blow for fracture was large;

(2) depended on the ratio of the diameter at the bottom of the notch to that of the body of the specimen;

(3) depended on the distance between the knife-edges.

The effect of the notch was observed by testing two similar specimens of the same material, one having a very sharp notch and the other a rounded one, when it was found that the number of blows for fracture was practically the same for each when the total number of blows was about 10,000.

For the second and most important determination three forms of specimen were used, each having the same span and diameter

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* Revue de Métallurgie, January 1904.

at the bottom (0·40 inch) of the notch, the body diameters being:—

0·706 inch, 0·50 inch, and 0·40 inch.

From observations made on these it was found that the respective energies of the blows to break them after 10,000 blows were:—

0·175, 0·275, and 0·55 foot-pound;

so that, per cubic inch of the material, and for the above number of blows, the specimen reduced in diameter to the value at the bottom of the notch is nine times stronger than the one with the largest diameter.

Further, as was to be expected, the resistance of the specimens diminished as the distance between the knife-edges increased.

These observations appeared to indicate that, to obtain the same results from specimens of varying size, they should be geometrically similar in form.

To test this conclusion, a series of experiments have been made on sets of specimens in which the ratio of the linear dimensions to those of the standard form was

$$1 : \sqrt{2}$$

and in order to make the conditions as dynamically similar as possible, the weight of the tup was reduced to the ratio

$$1 : 2\sqrt{2}$$

so that with the same height of fall, or velocity of striking, the energy of the tup per cubic inch of the specimen was the same as in the tests on the standard form. The results in tests of over 3,000 blows show that the resistance of the smaller specimens is somewhat higher than that of the standard form, but it is probable that, with the more refined experiments now in progress, the agreement will be found to be very close.

The Many-Blow Method applied to Brittle or Faulty Materials.—Although the investigation of the failure of faulty or brittle material under impact forms no part of the present work, this question is of such fundamental importance in impact testing that the authors have considered that the results of the methods here described on one or two typical cases of abnormal material would be of interest. For this purpose a sample of presumably faulty material has been kindly given to the Laboratory by Mr. J. T. Milton. This was a piece of boiler-plate 1 inch thick cut from a single-ended boiler 11 feet 6 inches diameter, 13 feet long, which, on being prepared for a test of 300 lbs. per square inch to meet the rules of Lloyd's Register, gave out by rupturing nearly from end to end at a pressure of 270 lbs. per square inch.* For the tests on a brittle material the authors produced some specimens by hammering some ordinary mild steel bar at a low red heat initially until nearly cold, in the manner described by Mr. Ridsdale in his Paper on the production of brittleness in soft steel.† This hammered steel had somewhat remarkable qualities, as the mechanical work put on it raised its maximum stress from 27·3 tons per square inch to 46·0 tons per square inch, and its elastic limit in tension from 18·0 to 26·0 tons per square inch. Its resistance to impact by the single-blow method when notched was exceedingly low, showing a crystalline fracture throughout, but it could be bent cold and doubled over on itself without showing the least signs of fracture.

Tests on notched specimens of these materials were made in the bending-impact tester, and the results are shown in the curves of Fig. 21 (page 916), together with the curves given by samples cut from an ordinary piece of boiler-plate for comparison.

It will be seen that the brittle specimens, although having a very low endurance for comparatively heavy blows, have remarkable endurance for lighter blows, being considerably tougher under this action than the untreated material from which they were prepared.

This characteristic is not evident in the tests of the faulty boiler plate, as the curve for it lies everywhere well below that of ordinary plate. The difference is also well marked in tests made on the two plates in the Izod tester, in which the work absorbed by the faulty plate specimens varied from 2 to 3 foot-pounds, whereas that absorbed by the ordinary plate was from 5 to 6 foot-pounds.

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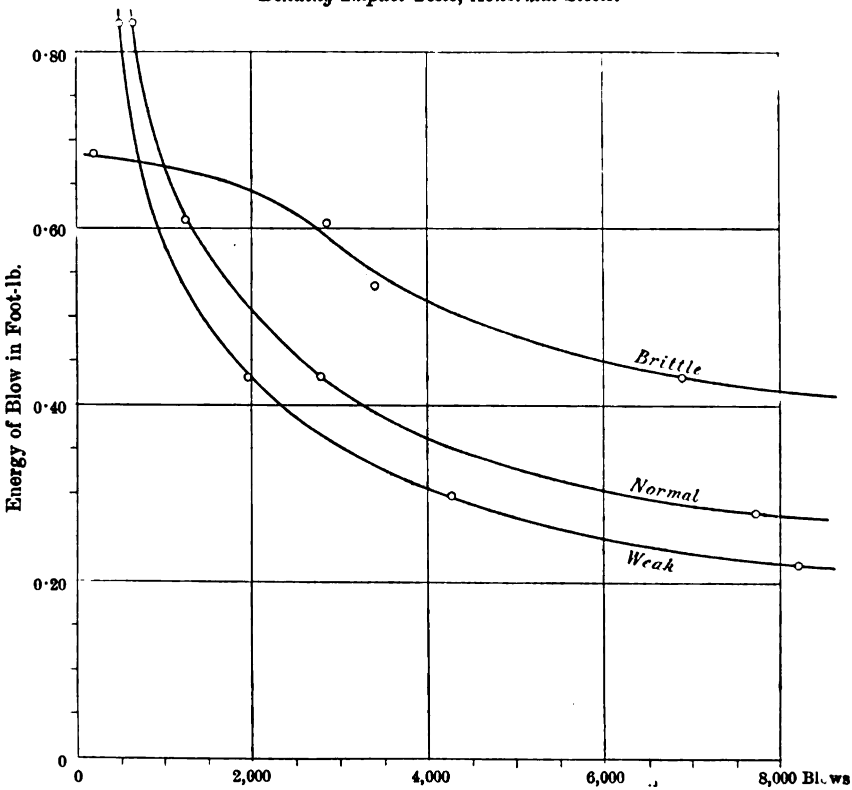
* Full details of this plate are given in a Paper by Mr. Milton at The Institution of Naval Architects. 1905, vol. XLVII, Part 2, page 358.

† Journal, Iron and Steel Institute, 1898, vol. I, page 220.

The marked feature of this piece of boiler-plate seems to be the very low value of the elastic limit when taken by a very sensitive extensometer. Using a Marten's Mirror Extensometer, the elastic limit of the faulty plate was found to be 8·8 tons per square inch.

FIG. 21.

Bending-Impact Tests, Abnormal Steels.



General Conclusions.—The general results of the experiments described in this Paper prove, in the opinion of the authors, that for the detection of two important faults in materials, that is, brittleness and low elastic resistance, two distinct tests are necessary, according as a weakness in plastic resistance or in elastic resistance is to be revealed. The distinction between the tests to be applied will be appreciated from the consideration that for the former case an expenditure of energy is necessary, which is approximately three hundred times greater than that required for the latter.

The authors are of opinion that conclusive evidence has been shown that materials which are strong under alternating stresses are in general strong under those shocks which are likely to be put upon them in ordinary machine practice, and not weaker as seems to be commonly supposed.*

As regards the general methods of impact testing, the bending test on a notched bar seems to be the most searching and the easiest to be made. As the detection of brittleness in steel is of supreme importance, the one-blow method would be naturally the one most used, but for the study of the constructional value of a material its resistance to impact should be investigated, not at one point of the curve, but throughout a considerable range. To do this some form of impact tester should be used in which the energy of the blow can be varied, and the specimen rotated mechanically. By a series of tests under varying strengths of blow, valuable information can be obtained and the results correlated to those given by other methods.

As an example of this, the case of two copper-aluminium alloys which formed part of a series in Messrs. Carpenter and Edwards' Report to this Institution in January 1907, may be taken. The two chosen are those containing 9·9 per cent. and 7·4 per cent. of aluminium respectively.

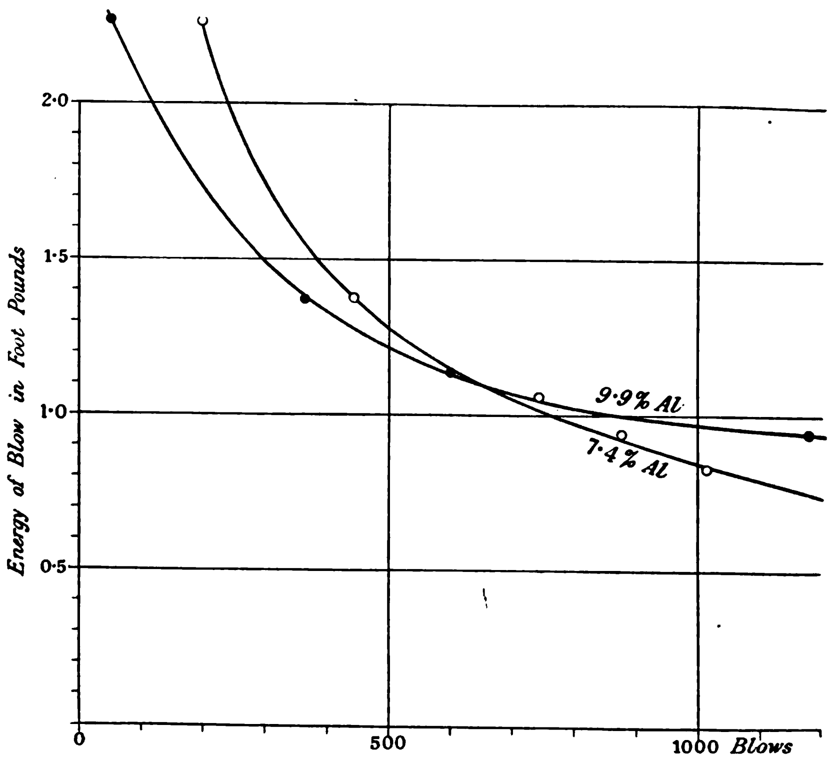
Specimens of these were tested in the bending-impact tester, and the results are given in the curves of Fig. 22 (page 918). On examination, it will be seen that these curves give practically all the information on the relative resistances to shock and alternating stress of those two materials which were given in the Paper. Thus the upper limits of the curves tend to the relative values given by the Izod test, the lower limits to those given by the alternating direct-stress

* Proceedings, 1904, Part 4, page 1135.

testing machine, and further the relative values of the number of shocks for fracture with a blow of 2·0 foot-pounds agree with those determined by Professor Arnold in his alternating-bending machine. Again, it was found that the limiting resistance of the 9·9 per cent. aluminium alloy, as determined in the bending-impact tester, was

Fig. 22.

Bending-Impact Tests, Copper-Aluminium Alloys.



approximately 2½ times greater than that of a similar specimen of 0·4 per cent. carbon steel. Now the limiting values of the stress in alternating tension and compression for these two materials have been found to be approximately the same, so that the difference in impact resistance must be sought for in the respective values of the modulus of elasticity. These were found to be :—

0·4 per cent. carbon steel	. .	30,000,000 lbs. per square inch.
9·9 „ „ aluminium alloy	. .	13,500,000 „ „ „ „

The ratio of which is 2·2, so that the ratio of the impact resistances is approximately that of the respective values of

$$\frac{f^2}{E}$$

where f is the limiting stress and E the values of the modulus of elasticity.

This agreement between relative values of impact resistance and relative values of the proof resilience, as given by

$$\frac{1}{2}\frac{f^2}{E} \text{ per unit volume,}$$

has been so marked in all these experiments that the authors cannot agree with Messrs. Seaton and Jude's conclusion that the "common interpretation of resilience has failed in its practical application," but, on the contrary, believe it to be the best guide for the designer in the use of normal materials, of which the real elastic limits are known.

The experiments further showed that steel was a much more homogeneous material than it had been recently suspected to be, because, if this had not been the case, it would have been impossible to repeat so accurately the bending-impact tests on a notched bar which were admittedly the most crucial mechanical tests of want of homogeneity.

In conclusion, the authors beg to thank the Director of the Laboratory for the facilities he has afforded for carrying out the work, and the interest he has shown in the progress of the research.

The Paper is illustrated by Plate 29, 15 Figs. in the letterpress, and Tables 1 to 3.

[*The Discussion on this Paper was combined with that on Mr. Harbord's Paper, and commences on page* 974.]

DIFFERENT METHODS OF IMPACT TESTING ON NOTCHED BARS.

By Mr. F. W. HARBORD,
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So many methods of testing steel by impact have been suggested by engineers during the last few years, that it has become a matter of importance to investigate the value of these tests as compared with the ordinary tensile tests which in the past it has been customary to rely upon largely, and also to compare the better-known methods of impact testing with each other to see which gives the most concordant results.

The experiments recorded in this Paper were undertaken (1) to compare the results obtained by different methods of impact testing: (2) to see whether such tests detected any irregularity in steel not revealed by the ordinary tensile tests, and to what extent they were in agreement with the latter.

With this object in view three very high-class Sheffield steels were originally selected, and are referred to as "Standard steels," but as the work proceeded it was considered desirable to include a series of steels made by the Acid Bessemer, Acid Open-Hearth, Basic Bessemer and Basic Open-Hearth processes, so that all steels used by engineers for structural and railway work should be represented. Tensile tests of all the steels and hardness tests by the Brinell method are also included. In all the tensile tests automatic diagrams were taken, and three are reproduced on Fig. 26 (page 936). Analyses of all the steels are also given in Appendix I, Table 17 (pages 966–967).

The methods of impact testing were too numerous to allow of all of them being experimented with, but broadly the methods may be divided into four or five classes, each having its supporters and all being more or less used by different engineers and metallurgists. The methods of testing in common use may be divided as follows:—

(1) One notch in the centre of the bar: TWO supports: fracture effected by a SERIES of blows of a falling weight. (*Seaton and Jude.*)

(2) One notch in the centre of the bar: TWO supports: fracture effected by ONE blow of a falling weight. (*Frémont.*)

(3) One notch not necessarily in the centre: ONE support: fracture effected by ONE blow on overhung portion from a falling pendulum or weight. (*Izod.*)

(4) Two opposite notches not necessarily in the centre: ONE support: fracture effected by a series of blows of a falling weight on overhung portion. (*Brinell.*)

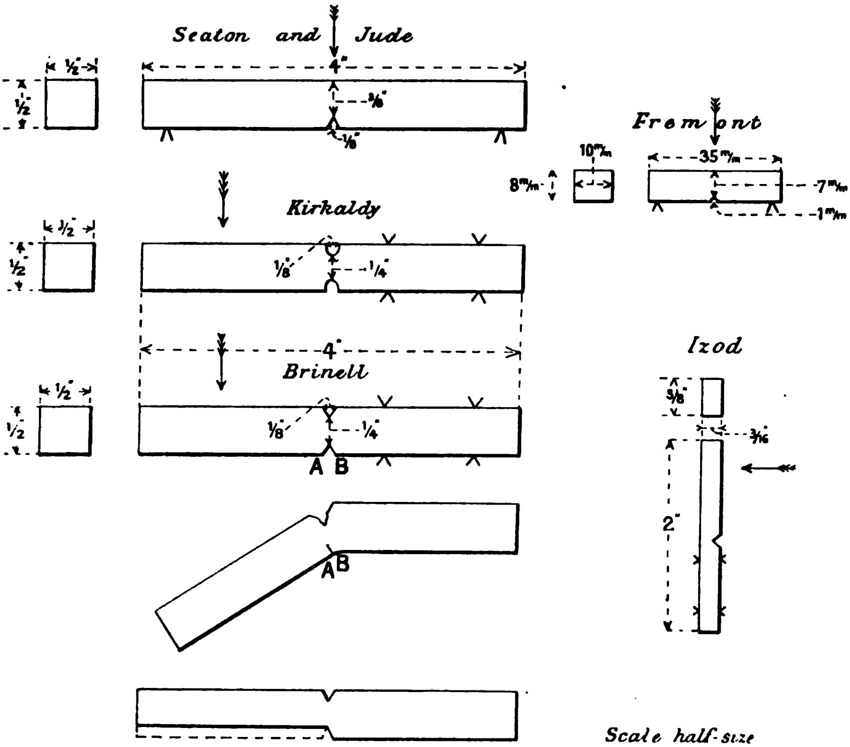
(5) Same as (4), but with an arrangement for reversing the bar after every blow. (*Kirkaldy.*)

In the case of the "Standard steel," six duplicate tests were made on each steel by each method, except in a few cases, and in the case of these each was tested at least in duplicate, and in most cases four tests were made. It was intended to make six duplicate tests of each, but, owing to some sets of bars which had been prepared for Brinell tests having to be discarded, there was not sufficient steel left for more than two tests in a few cases.

In all over forty different steels were experimented with by the five different methods. Over 800 bars were prepared and tested, and the detailed results for each are given in Tables 12 to 16 in Appendix I (pages 952–965).

It will readily be realized that the author could not afford to purchase a machine of each type to carry out the different experimental tests, so he sought the co-operation of the various gentlemen who had designed the different machines, and in every case they most kindly consented to test the samples if he would have them machined to the correct dimensions. This arrangement had the great advantage that in every case the tests were made by men with special experience of

FIG. 23.—*Test-bars.*



the particular method of testing, and the results from each machine were obtained under the best possible conditions, and are far more trustworthy than if, after a few days' experimenting with each impact machine, the author had carried out the tests himself. In the case of the Kirkaldy tests, though they were done under the supervision of Mr. Kirkaldy, the author or one of his senior assistants was always present.

It will be seen from the sketches of the test-bars, Fig. 23, that they not only varied in size but also in the form of the notch, and the results would no doubt have been more comparable if it had been possible to carry out the experiments on bars of identical cross-sectional area at the point of fracture, and notched in a similar manner; each machine unfortunately has been designed to take bars of a special size. No doubt very different results might have been obtained had it been possible to use identical test-bars for all methods, but the object of these experiments was, if possible, to obtain some definite results as to the best *method* of testing, apart from such details as the variation in the shape and size of the test-piece or the form of the notch, and to compare the different methods in actual use. The importance of having a standard test-bar is fully realized, but this can only be effectively discussed after the method of testing has been decided upon.

The Standard steels were all originally $\frac{5}{8}$-inch square rolled bars, and before preparing the test-pieces the rolled bars were all heated for 30 minutes to a temperature of 620° C. (1,148° F.) and allowed to cool in air to remove any stress due to cold rolling. The test-bars from the other steels were all machined from bars of approximately the same section, rolled as far as possible from ingots of about the same size, so that the amount of work on each should be the same. These bars were also heated to 620° C. for half-an-hour, and allowed to cool in air to remove any stresses due to cold rolling and render them as nearly comparable with each other as possible. The bars were all slotted from adjacent portions so that any irregularity due to segregation should be eliminated as far as possible.

It is well known that, above 0·5 per cent. carbon, the hardness of the steel prevents any reliable results being obtained with impact tests, and although a number of tests on higher carbon steels were made they have not been recorded in the Paper, as they are of no special interest.

Description of the Methods of Testing.—Before proceeding to give details of the experiments, a brief description of the various methods of impact testing investigated is necessary.

(1) Frémont.—In this method the test-piece is machined to the size and form shown in Fig. 23 (page 923). It has a groove in the centre and is supported on a bearing at *each end* with the groove downward, and is broken by *one* blow from a falling weight striking it in the centre. The residual energy in the weight not expended in fracturing the specimen is measured by allowing the weight and broken test-piece to fall on a steel plate placed directly below the test-bar and supported on two strong springs. The compression of these springs so produced is measured and recorded by a lever, the short arm of which is attached to the steel plate while the long arm is provided with a pointer or pencil which travels over a graduated scale. The energy required to fracture the bar is the difference between the original impact energy of the weight, deduced from its mass and height of drop, and the residual energy as recorded on the scale. The error in reading amounts to about 0·3 kilogramme with a 10-kilogramme weight, or about $\frac{1}{75}$ of the energy required for a fairly tough sample.

(2) Izod.—By this method a sample of the shape and dimensions shown in Fig. 23, with a V notch, supported at *one end* in a clip or vice and held vertically, is fractured by *one* blow from a swinging pendulum striking the overhung portion, the residual energy in the pendulum being measured by the arc through which it swings after fracturing the sample. This residual energy is recorded by a special attachment.

In this method, as in the Frémont method, an exact measure of the energy expended in fracturing the sample within a very slight error is obtained.

(3) Seaton and Jude.—In this method the sample of shape and dimensions shown in Fig. 23, with a V notch, is supported on a bearing at *each end*, and broken by a *series* of blows from a falling weight striking it in the centre. The weight and height of drop can be varied at pleasure according to the class of steel under test. The energy absorbed in breaking the samples is calculated into foot-pounds. In the case of ductile steels requiring a number of blows,

say seventy or more, the actual energy absorbed can be obtained to within one blow, that is, $\frac{1}{70}$ or so of the total energy, but in the case of brittle steels requiring only one to three blows, the error is still one blow, equal at the least to one-third of the total, or even if one half the last blow be taken as the breaking weight the error would still be one-sixth of the total.

(4) Brinell.—In this method the sample of form and dimensions shown in Fig. 23, with V notches, is supported at *one end* in a suitable block and fractured by a *series* of blows on the overhung portion. The tests may be made in two ways, namely, with the notch either horizontal or vertical. In this method, as in that of Seaton and Jude, the force required to fracture the bar is calculated into foot-pounds, and the degree of accuracy largely depends upon the number of blows which the steel stands before fracture. In ductile steels the error would be small, but in hard steels comparatively large. A very serious objection, however, to this method of testing in the case of ductile steels is that when the notches are horizontal after a few blows, but before fracture, the bar bends so much that the point A binds on point B, and the test cannot be continued. To prevent this the dotted portion shown in Fig. 23 was slotted away, but in the case of the ductile standard steels the overhung portion bent over so considerably that the falling weight striking the inclined surface had little if any striking force after the first few blows, and it was seen that any results obtained by this method would be most unreliable and misleading, and the tests were discontinued. This applied, though not to the same extent, to the tests with the notches disposed vertically, and it was decided not to proceed with the tests. This was unfortunate, as all the samples had been prepared for these tests for all steels and consequently were useless, and in some cases there was not sufficient steel left to prepare more than two or three duplicates, instead of four, for testing by the method used by Mr. Kirkaldy.

(5) Kirkaldy.—In this case the sample is of the same dimensions as that used by Brinell, but instead of V notches it has two opposite

circular grooves, as shown in sketch, Fig. 23 (page 923). The test-bar is supported in a suitable block or vice at *one* end, and fractured by a *series* of blows from a falling weight on the overhung portion, but after every blow the entire block is turned over by a cam attachment, so that blows are delivered alternately on each side of the test-bar. In this method, as in the Seaton and Jude, the force required to fracture the bar is calculated into foot-pounds, and the degree of accuracy largely depends upon the number of blows which are required to produce fracture; owing, however, to the reversal after each blow, the number of blows required to produce fracture, even in very brittle steels, is comparatively large, and consequently the error is not very considerable, and in moderately ductile steels is inappreciable.

Variation on Duplicate Tests.—In considering any method of impact testing the first thing to determine is whether the method can be relied upon to give concordant results when testing the same material, and what is the maximum variation that is likely to occur. Other things being equal, the method which shows the least variation may be taken as the most reliable.

The next point is to compare the results obtained with other methods of testing, for, assuming a method gave perfectly regular results, but that these results were quite at variance with those obtained by tensile tests under a static load or other accepted method of testing, the results would, to say the least, be open to the greatest suspicion, and certainly could not be accepted as correct, however regular they might be, withont a most complete investigation.

These were the first two points which, in the author's opinion, called for investigation, and with this object the three Standard steels, all having been duly heated to 620° C. (1,148° F.) for half-an-hour to remove any stresses due to cold rolling, were tested by each method of testing referred to. With the exception of the Kirkaldy method, six tests of each steel were made by each method, and the detailed results are given in Table 12 in Appendix I (pages 952–953) under the heading of Untreated Steels. In a separate column are given the percentage variations in each method, and this has been arrived at by taking the average of all the results in each case, and expressing the difference between the highest and the lowest of the results as a percentage of this average. In Fig. 24 (column *a*) these results are expressed diagrammatically, and the following Table 4 gives a summary.

TABLE 4.

Standard Steels.

Percentage of Variation shown by each method.

UNTREATED STEELS.

Method.	Percentage Variation for			Maximum Variation on any.
	0·26 per cent. C.	0·32 per cent. C.	0·41 per cent. C.	
Seaton and Jude . .	15	35	48	48
Frémont	25	20	38	38
Izod	7	49	64	64
Kirkaldy (Horizontal) .	30	13	8	30
,, (Vertical) .	2	14	5	14

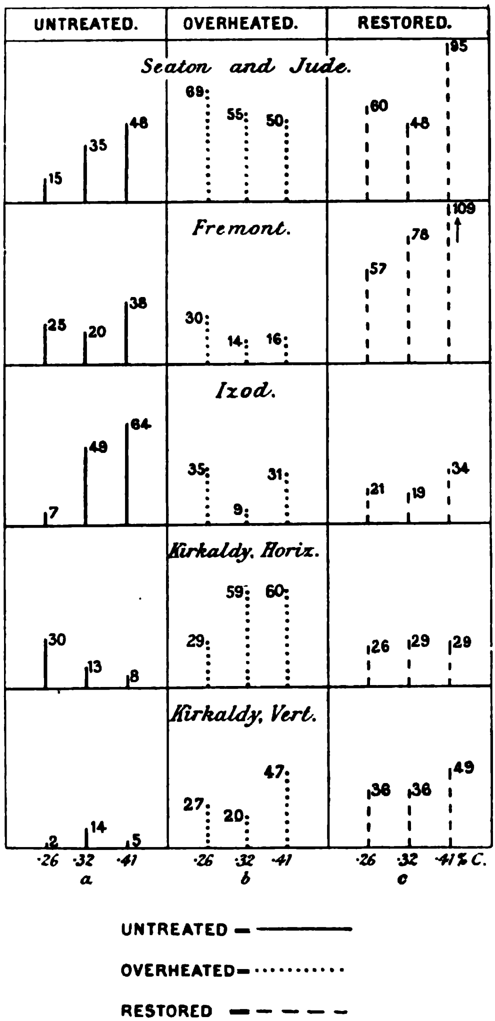
From these it will be seen that for the *softest* steel the Kirkaldy horizontal showed the greatest variation, the Frémont showed the next greatest variation, and the Kirkaldy vertical the least. With the *second hardest* steel, Izod showed much the greatest variation, and both the Kirkaldy methods much the least. With the *highest carbon* of this series Seaton and Jude, Frémont, and Izod all give most irregular results, the Kirkaldy, both horizontal and vertical, being the only methods giving any approach to regularity.

It was considered that before drawing any deductions from the above results further tests were desirable, and if possible steels of inferior quality, but at the same time uniform in themselves, should be used, and it was decided that the best way to attain this object

FIG. 24.

Diagram showing Extent of Variation for each grade of Standard Steel, Untreated, Overheated, and Restored, by five methods.

Vertical lines and numbers represent percentages of variation.

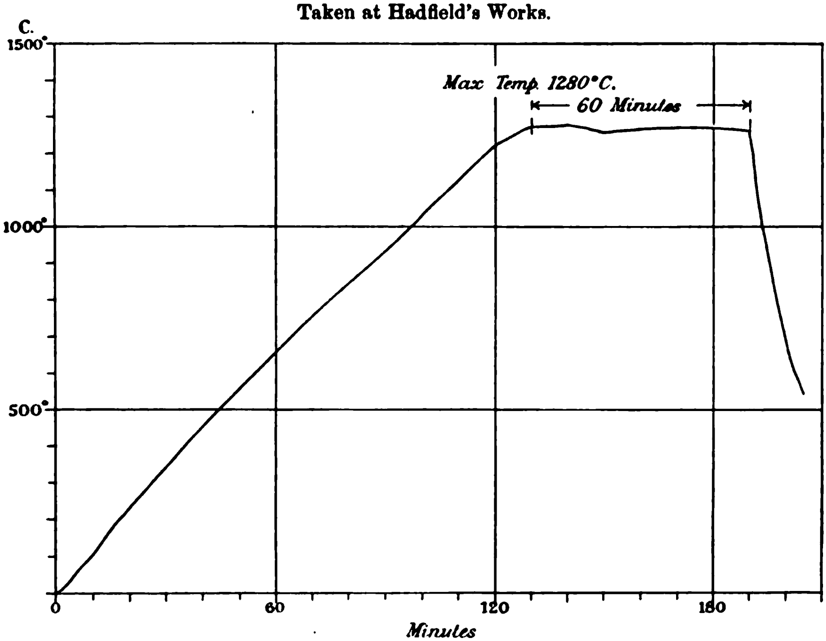


was to take two sets of six pieces of each of the three Standard steels, and by heating them to a temperature of 1,230–1,250° C. (2,246°–2,282° F.) to destroy their ductility partially, and then take half of these bars and reheat them at a lower temperature to restore in part the original properties of the steels. There is generally no great difficulty in spoiling steel by overheating, but its restoration to its original condition by reheating is by no means so easily achieved, and it was realized that the results might not be all that was anticipated; but there could be no question that the properties of the steel would be distinctly affected by the drastic treatment proposed, and each set of duplicate bars being subjected to identical conditions, they should all be affected in a similar way, and when tested by the same methods should give fairly concordant results.

Two complete sets of bars, each set sufficient to give six duplicate tests by all methods, were therefore prepared, packed in two wrought-iron boxes, the lids carefully luted on and screwed down to exclude air as much as possible, and both annealing boxes were heated slowly to 1,230° C. (2,246° F.) for one hour. At the end of this time one box was removed from the furnace, and the bars were cooled as rapidly as possible in air. The box containing the other set of bars was allowed to cool down slowly to below 600° C. (1,112° F.), and then heated up gradually to a temperature of 870° C. (1,598° F.), and held there for ¾ hour, when it was allowed to cool slowly, the object of this reheating being to restore the bars partially to their original condition, and thus produce a set of bars intermediate as regards toughness between the untreated bars and those heated to 1,230° C. and rapidly cooled.

It may be of interest to some of the members to know that these heatings were done in a small electric furnace erected by The Electrical Co., at the works of the Westinghouse Brake Co. This furnace is of the resistance type, and a fused bath of a mixture of barium and calcium chloride was employed, which was gradually heated by the passage of the current: the annealing boxes containing the samples were completely immersed in the molten bath, and the temperature of the furnace was controlled with the greatest ease to within 10°, even at such high temperatures as over 1,230° C. In this particular case two pyrometers were kept in the bath, one being taken down by the author to act as a check upon the works instrument and avoid the possibility of any mistake. The author is greatly indebted to the Westinghouse Co. for their kindness in allowing him the use of their furnace, which is an exceptionally useful type for heating small iron or steel articles where an exact

FIG. 25.—*Curve showing Temperature and Time of Overheating Test-bars.* Taken at Hadfield's Works.



temperature is required; and when it is desired to prevent oxidation, as immersion in the fluid bath completely protects the iron or steel bars from the action of the air.

Before proceeding with the tests, a few trial bars from the *overheated* set were tested by impact, and apparently little if any deterioration had taken place; it was thought that possibly the complete exclusion of all oxidizing conditions might have prevented the usual deterioration taking place, so it was decided to subject these bars to another heating in the annealing box in an ordinary gas-fired furnace; and Sir Robert Hadfield very kindly did this for the author at his Sheffield works. In Fig. 25 is given the temperature curve, showing that the bars were heated for one hour at 1,280° C. (2,336° F.) and then quickly cooled. The overheated bars and the restored bars were then tested by all the methods, and the detailed results are given in Table 12 (pages 954–957); the variations per cent. of each set are diagrammatically shown in columns *b* and *c*, Fig. 24 (page 929).

Table 5 is a summary of the percentage variations for overheated and restored steels:—

TABLE 5.

Standard Steels.

Percentage of Variation shown by each method.

OVERHEATED AND RESTORED STEELS.

	Percentage Variation.						Maximum percentage Variation in six sets of Steels.
	Overheated.			Restored.			
Carbon per cent.	0·26	0·32	0·41	0·26	0·32	0·41	
Seaton and Jude	69	55	50	60	48	95	85
Frémont	30	14	16	22	78	109	109
Izod	35	9	31	21	19	34	35
Kirkaldy (Horizontal)	29	59	60	26	29	29	60
„ (Vertical)	27	20	47	36	36	49	49

These results are by no means in agreement with the untreated bars, the variations are much greater, and this is especially so in the restored bars. It might at first be assumed that these irregularities were due in a measure to the heat treatment, but it is hardly conceivable that under the conditions of heating this can be the case, as, whatever the effect of heating on the physical condition might be the effect of the treatment should be the same for all bars of the same steel. To make sure, however, that this was so, duplicate tensile and alternating tests were made. Professor Arnold very kindly did the alternating tests at Sheffield and Mr. Kirkaldy did the tensile tests. The results are given in Table 6 (page 934), and show that the steel is uniform and free from any marked irregularity.

It will be seen by comparison with Table 7 (page 936) that twice heating (once to 1,230° C. (2,246° F.) for one hour and once to 1,280° C. (2,336° F.) for one hour) with rapid cooling, has actually improved both the elongation and contraction in area, which are higher than in the original bars and also higher than in the restored bars reheated to 870° C. (1,598° F.) and slowly cooled.

This is a most extraordinary result, which is certainly entirely at variance with accepted opinions, and suggests that heating under non-oxidizing conditions may not have such deleterious results on steels as is generally assumed; the author hopes to be able to investigate this interesting point further.

The variation in duplicate tests by the same method is so important that it is desirable to consider these somewhat in detail. In the case of the 0·26 per cent. low carbon *untreated* steel we find that the Kirkaldy vertical gives the most uniform results, showing a variation of only 2 per cent., while the Kirkaldy horizontal gives the maximum variation on duplicate tests of 30 per cent., the maximum variation shown by the other methods being 25 per cent., and the minimum 7 per cent.; and these if they stood alone might be considered satisfactory as approximating to the variation in duplicate alternating and tensile tests. If, however, we consider the *overheated* steels, we find the Seaton and Jude method showing a mean percentage variation of 69 per cent., Izod 35 per cent., and Kirkaldy methods 29 per cent. and 27 per cent. Turning to the *restored* steels, we find the same methods again giving totally different results, and instead of the Kirkaldy Vertical and Izod methods showing the best results with variations of 2 per cent. and 7 per cent., we get variations of 36 per cent., and 21 per cent., while the Seaton and Jude shows 60 per cent. against 15 per cent. for the *untreated* steel.

An examination of the 0·32 per cent. and 0·41 per cent. carbon steels by Seaton and Jude methods gives a variation of 55 per cent. and 50 per cent. respectively for the overheated and 48 per cent. and 95 per cent. for the restored, by the Frémont method 14 to 16 per cent.

TABLE 6.

Tensile Tests, Standard Steels.

Number.	Elastic Stress. Tons per sq. in.	Ultimate Stress.	Elastic Ratio.	Yield-Point.	Contraction of area per cent.	Extension in 2 ins. per cent.	Composition. C.	Si.	S.	P.	Mn.
Overheated.											
20	13·3 14·8	28·4 28·4	0·468 0·521	15·8 15·8	65·6 67·2	34·0 32·5	0·262	0·046	0·044	0·019	0·807
30	16·1 15·9	30·9 30·9	0·519 0·516	16·9 17·6	64·1 64·1	29·0 28·5	0·325	0·077	0·032	0·019	0·797
40	15·9 15·8	31·5 32·1	0·565 0·491	18·9 18·4	57·8 57·8	30·5 27·0	0·409	0·085	0·030	0·015	0·487
Restored.											
20	17·7 17·0	29·8 30·1	0·595 0·564	18·6 18·0	65·6 64·1	31·5 33·5	0·262	0·046	0·044	0·019	0·807
30	17·3 17·9	33·1 32·7	0·522 0·548	18·7 18·6	59·4 59·4	30·0 30·5	0·325	0·077	0·032	0·019	0·797
40	19·2 21·3	33·9 33·8	0·568 0·630	21·2 21·3	51·6 51·6	28·0 27·0	0·409	0·085	0·030	0·015	0·487

Alternating Tests made by Professor Arnold.

Overheated.			Restored.		
No.	No. of alternations.	Mean.	No.	No. of alternations.	Mean.
20	194 208	201	20	140 150	145
30	204 192	198	30	160 162	161
40	226 224	225	40	160 198	179

for the overheated, and 78 per cent. to 109 per cent. for the restored, and the Kirkaldy horizontal 59 and 60 per cent. for overheated and 29 per cent. for the restored, and the Kirkaldy vertical 36 and 49 per cent. If we examine each steel it will be seen that some methods show the greatest variation on the overheated bar, others on the restored bars, so that there is nothing in the results to suggest that variations are due to lack of uniformity in the steels.

To appreciate fully the variable results obtained on duplicate tests by the same method, it will be necessary to consult the Tables giving detailed results, as the percentage variations already referred to are frequently the means of such widely varying figures, that they are liable to be misleading unless the detailed figures are carefully examined. It was intended in calculating this percentage variation to have eliminated the highest and lowest in each case before calculating the mean average, but the great irregularity made it impossible to do so, and it was thought better to include all with the exception of a few special cases which were obviously abnormal, and these are marked in the Tables with an asterisk (*).

From a consideration of the above it seems reasonable to assume that the irregularity disclosed by the different methods of impact testing is not due to lack of uniformity in the material, but largely at all events results from the defects of the method of testing, and it is a serious question how far methods showing such variations should be relied upon by engineers to differentiate between the physical properties of different materials.

Relation between Carbon Content and Impact Tests.—Leaving the question of the variations on duplicate tests, we now have to consider how the properties of the three different steels, as revealed by the impact tests, compare with those shown by the tensile and alternating tests.

An examination of the tensile tests in the untreated steels, given in Table 7 (page 936), shows that they were of very good quality, the ultimate stress increasing with the increase of carbon with a corresponding slight decrease in the extension and contraction; between the lowest carbon 0·26 per cent. and the highest carbon

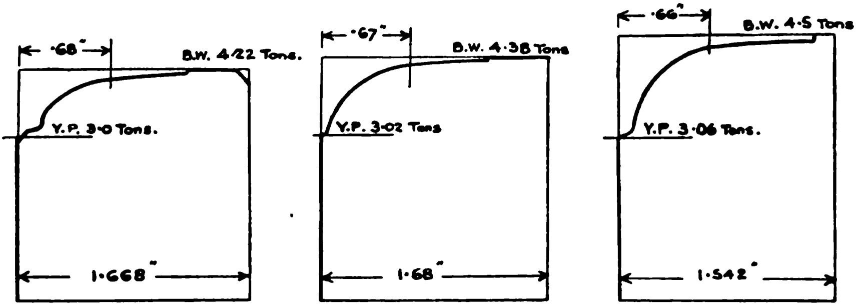
TABLE 7.—*Tensile Tests on Standard Steels.*

UNTREATED.

No.	Ultimate Stress.	Yield-Point.	Contraction of Area per cent.	Extension in 2 inches per cent.	Composition.				
					C.	Si.	S.	P.	Mn.
20	33·44	23·88	63·38	27·80	0·262	0·046	0·044	0·019	0·807
	33·91	26·35	62·47	28·40					
30	34·87	24·04	60·28	28·00	0·325	0·077	0·032	0·019	0·797
40	38·22	24·36	51·23	25·70	0·409	0·085	0·030	0·015	0·487
	37·10	25·47	63·25	25·60					

FIG. 26.—*Tensile Curves of Standard Steels. Untreated.*

No. 20. 0·26 per cent. C. No. 30. 0·32 per cent. C. No. 40. 0·41 per cent. C.



steel 0·41 per cent. there is a difference of about 5 tons in the ultimate stress, equal to about 12 to 13 per cent., and we should expect that this would approximately represent the difference in resistance to impact. If the automatic diagrams of these steels are examined, Fig. 26, it will be seen that at the point where local contraction commences there is no sudden break in the curve, showing that the steels were ductile in all cases and that there was no tendency to brittleness.

The impact and tensile results are tabulated in Table 8 (page 940), the percentage difference between each steel compared with the lowest carbon being shown; diagrammatically these results are shown in Figs. 27 and 28 (pages 938–939).

From these it will be seen that both the Seaton and Jude and Frémont methods show a fall in resistance to impact between the 0·26 and 0·41 carbon steels of about 80 per cent., the Izod about 27 per cent., the Kirkaldy horizontal 24 per cent. and the Kirkaldy vertical only 6 per cent. It is clear from the tensile tests that a difference of anything approaching 80 per cent. is very far from the truth, and the Izod and Kirkaldy horizontal, with about 25 per cent. difference, is certainly the very maximum, and in all probability the real difference is considerably less than this.

Turning now to the overheated and restored steels we find both from tensile and alternating tests, Table 6, the overheated steels are shown to be the most ductile, and both are distinctly better than the original untreated steels; comparing the differences between the highest and lowest carbon in each case in the overheated bars, we find a maximum increase in ultimate stress of rather less than 4 tons, with a maximum decrease in extension of 7 per cent. The restored bars, although giving somewhat higher tensile results than the overheated and slightly less extension and contraction, show approximately the same differences between the lowest and highest carbons as the overheated, and we might reasonably conclude that the maximum difference in ductility between highest and lowest carbon steel in each set of overheated or restored bars would not exceed about 15 to 20 per cent.

The Arnold alternating tests show very little variation between the duplicate tests, as will be seen from the Table of results, although like the tensile tests they show that the overheated bars are more ductile than the restored.*

The difference in alternations between the highest and lowest carbon steels in the overheated shows 12 per cent. and in the restored 23 per cent., and assuming this is a measure of the ductility, we arrive at a figure in the case of the overheated bars approximately

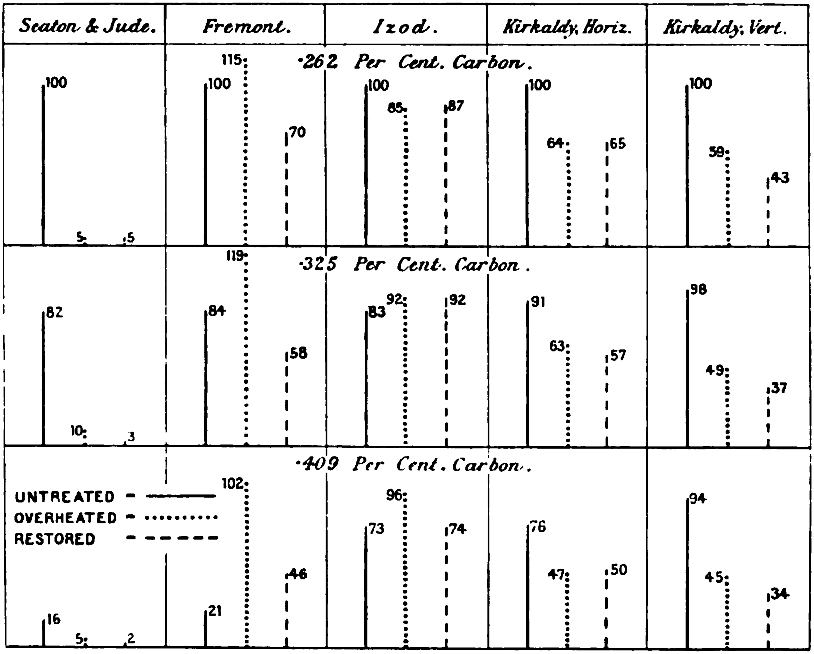
* *See* Appendix II (page 968).

in agreement with that deduced from the tensile results, and in the case of the restored bars a somewhat higher result. Table 9 (page 941) shows the results obtained from the impact tests for the overheated steels, and they are shown diagrammatically in Fig. 27.

FIG. 27.—*Diagram showing Relative Resistance to Impact of Standard Steels, Untreated, Overheated, and Restored, according to different methods.*

In each method the value for impact resistance of the 0·26 per cent. Carbon untreated steel has been taken as 100 and the other results plotted on the same scale.

Vertical lines and numbers represent percentages of variation.

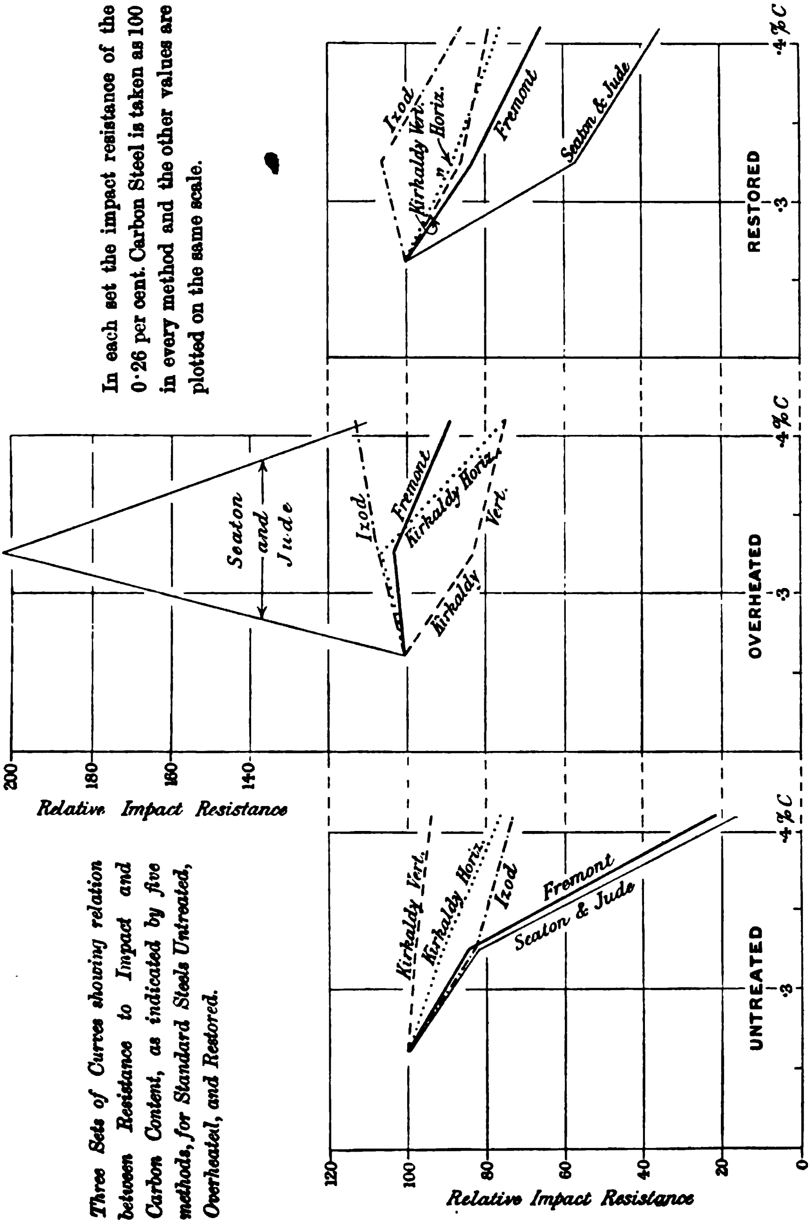


From these the following results are obtained :—

Overheated Steels.—Seaton and Jude results show that the 0·32 carbon steel gave an average resistance of 77 foot-lb. against 38 foot-lb. for the 0·26 carbon steel, or an *increase* of 103 per cent. in ductility, and that the 0·41 carbon steel gave an average resistance

(*Continued on page* 944.)

Fig. 28.



Three Sets of Curves showing relation between Resistance to Impact and Carbon Content, as indicated by five methods, for Standard Steels Untreated, Overheated, and Restored.

In each set the impact resistance of the 0·26 per cent. Carbon Steel is taken as 100 in every method and the other values are plotted on the same scale.

TABLE 8.—*Untreated Standard Steels.*

Average of Six Duplicate Tests.

Carbon per cent.	Seaton and Jude. Foot-lb.	Seaton and Jude. Per cent. difference from 0·26 Carbon result.	Frémont. Foot-lb.	Frémont. Per cent. difference from 0·26 Carbon result.	Izod. Foot-lb.	Izod. Per cent. difference from 0·26 Carbon result.	Kirkaldy (Horizontal). Foot-lb.	Kirkaldy (Horizontal). Per cent. difference from 0·26 Carbon result.	Kirkaldy (Vertical). Foot-lb.	Kirkaldy (Vertical). Per cent. difference from 0·26 Carbon result.	Tensile Tests. Ultimate Stress.	Tensile Tests. Per cent. difference from 0·26 Carbon Steel.	Tensile Tests. Per cent. extension on 2 inches.	Tensile Tests. Per cent. difference in Extension from 0·26 Carbon Steel.
0·26	808	—	174	—	16·4	—	528	—	3032	—	33·67	—	28·10	—
0·32	661	−18	146	−16	14·4	−17	480	− 9	2984	−2	34·87	+ 3·5	28·00	−0·4
0·41	131	−84	36	−79	12·0	−27	404	−24	2248	−6	37·66	+12·0	25 65	−9·0

TABLE 9.—*Standard Steels.*

Average of Six Duplicate Tests.

OVERHEATED.

Carbon per cent.	Seaton and Jude.		Frémont.		Izod.		Kirkaldy (Horizontal).		Kirkaldy (Vertical).		Tensile Tests.			
	Foot-lb.	Per cent. difference from 0·26 Carbon result.	Foot-lb.	Per cent. difference from 0·26 Carbon result.	Foot-lb.	Per cent. difference from 0·26 Carbon result.	Foot-lb.	Per cent. difference from 0·26 Carbon result.	Foot-lb.	Per cent. difference from 0·26 Carbon result.	Ultimate Stress.	Per cent. difference from 0·26 Carbon result.	Per cent. extension on 2 inches.	Per cent. difference from 0·26 Carbon result.
0·26	38	—	200	—	14·0	—	335	—	1796	—	28·4	—	33·25	—
0·32	77	+103	207	+ 3	15·0	+ 7	357	+ 6	1492	−17	30·9	+8·7	28·75	−13·5
0·41	42	+ 11	178	−11	15·8	+13	251	−25	1352	−25	31·8	+12	28·75	−13·5

TABLE 10.—*Standard Steels.*

Average of Six Duplicate Tests.

RESTORED.

Carbon per cent.	Seaton and Jude. Foot-lb.	Seaton and Jude. Per cent. difference from 0·26 Carbon result.	Frémont. Foot-lb.	Frémont. Per cent. difference from 0·26 Carbon result.	Izod. Foot-lb.	Izod. Per cent. difference from 0·26 Carbon result.	Kirkaldy (Horizontal). Foot-lb.	Kirkaldy (Horizontal). Per cent. difference from 0·26 Carbon result.	Kirkaldy (Vertical). Foot-lb.	Kirkaldy (Vertical). Per cent. difference from 0·26 Carbon result.	Tensile Tests. Ultimate Stress.	Tensile Tests. Per cent. difference from 0·26 Carbon result.	Tensile Tests. Per cent. extension on 2 inches.	Tensile Tests. Per cent. difference from 0·26 Carbon result.
0·26	37	—	122	—	14·2	—	344	—	1304	—	29·95	—	32·5	—
0·32	21	−43	101	−17	15·1	+6	304	−12	1124	−14	32·9	+10	30·25	−7
0·41	13	−65	80	−34	12·2	−14	363	−24	1028	−21	33·85	+13	27·5	−15

TABLE 11.

	Method.	Impact Resistance (taking value for 0·26 per cent. C. as 100).			Percentage Variation between duplicate results.			Maximum Variation in any grade.
		0·26 per cent. C.	0·32 per cent. C.	0·41 per cent. C.	0·26 C.	0·32 C.	0·41 C.	
Untreated.	Seaton and Jude	100	82	16	15	35	50	50
	Frémont . .	100	84	21	25	20	38	38
	Izod . .	100	83	73	7	47	64	64
	Kirkaldy (H.) .	100	91	76	30	13	8	30
	Kirkaldy (V.) .	100	98	94	2	14	5	14
Overheated.	Seaton and Jude	100	203	111	69	55	50	69
	Frémont . .	100	103	89	30	14	16	30
	Izod . . .	100	107	113	35	9	31	35
	Kirkaldy (H.) .	100	106	75	29	59	60	60
	Kirkaldy (V.) .	100	83	75	27	20	47	47
Restored.	Seaton and Jude	100	57	35	57	50	85	85
	Frémont. . .	100	83	66	60	78	109	109
	Izod . .	100	106	86	21	19	34	34
	Kirkaldy (H.) .	100	88	76	26	29	29	29
	Kirkaldy (V.) .	100	86	79	36	36	49	49

of 42 foot-lb. against 38 foot-lb. for 0·26 carbon, or an *increase* of 11 per cent. in ductility; while the two Kirkaldy methods each show a maximum reduction in ductility of 25 per cent. between the 0·26 and 0·41 carbon steels. The other methods in some cases show a slight increase of ductility with the increase of carbon percentage, and in others a marked decrease, while the tensile results are quite normal, giving a higher tensile as the carbon increases.

These results cannot be regarded as anything but most unsatisfactory, as there can be no question that as the percentage of carbon increases the ductility decreases.

Restored Steels.—In these steels the results are more satisfactory, as in all cases the ductility, as shown by the impact tests, Table 10 (page 942), decreases as the percentage of carbon increases; but in the case of Seaton and Jude the decrease between the 0·26 per cent. carbon and the 0·41 per cent. carbon is 65 per cent. and in the Frémont 34 per cent., both far more than would be expected. The other methods give results more in accordance with the tensile tests.

Summary of Results of Standard Steels.—Table 11 (page 943) summarises the results on Standard steels, showing the relative resistance to impact of each steel compared with the 0·26 per cent. carbon steel taken as 100, and also the variations on duplicate tests.

If we compare the 0·41 carbon steel in the untreated, overheated, and restored conditions with the 0·26 carbon taken as 100, we get for Seaton and Jude method values 16, 111, and 35 respectively; for the Frémont method 21, 89, and 66; for the Izod 73, 113, and 86; the Kirkaldy methods being the only ones which show little variation.

Taking the results as a whole the Kirkaldy methods and Izod method give results more in accordance with the tensile tests, and also show less variations generally in the duplicate tests, but some of the results obtained by these methods vary so much that their value seems very doubtful.

Commercial Steels.

In Appendix I, Tables 12 to 17 (pages 952–967) give the results of a large number of duplicate tests on ordinary commercial steels made by Acid and Basic Bessemer and Acid and Basic Open-Hearth processes, and these results are shown diagrammatically in Figs. 29 to 34 (pages 947–950), and for comparison tensile tests are also given in Table 17 (pages 966–967).

These steels were all heated to the same temperature and slowly cooled to ensure uniformity as much as possible, but, as will be seen from the Tables and also diagram, Fig. 34 (page 950), the variation between duplicate results is so considerable by all methods that little value can be attached to the results. Some of the variation shown is undoubtedly due to the irregularity of the steel, and Basic and Acid Bessemer steels show the greatest variations in duplicate tests as might be expected, but there can be little doubt that the impact methods of testing greatly exaggerate these variations in the material. Time does not permit the discussion of these results in detail, but it will be seen from the Tables and curves that the brittleness as shown by all methods, with one or two exceptions, increases with the percentage of carbon. The Kirkaldy method shows the least increase of brittleness for a given increase in carbon; the Seaton and Jude indicates very much greater differences, although curiously these differences are less in these steels than in the Standard steels for the same increase of carbon. With the exception of the steels below 0·2 per cent. of carbon, all these commercial steels would be condemned by the Frémont method, as they all break below 100 foot-lb., which is considerably below what Mons. Frémont considers a fair test of good quality. Not only were the tensile tests of these steels satisfactory, but they were good average samples of commercial steels such as are made every day by first-class firms. If we have to accept these impact tests as a true indication of the quality of the material, we not only have to accept results in entire disagreement with the tensile tests, but entirely at variance with general experience.

The claim of the supporters of impact testing is that it indicates certain latent defects not shown under a static test, and therefore it is unfair to condemn impact results when they do not agree with the tensile tests; to some extent this is true, and if experiments had shown that duplicate tests might be relied upon to agree with each other within reasonable limits and the results were in general agreement with experience, this contention would carry much weight; when, however, we find tensile tests on two steels show a difference of only about 4 tons with approximately the same elongation, and these results are confirmed by the analysis, and then impact tests of two such steels show by two methods the relative brittleness to be as 100 is to 16 and 100 to 21, while other methods give totally different results, one has very seriously to consider the value of these tests.

When the author commenced the investigation, the results of which are given in the Paper, he had but one object in view, to demonstrate which method of impact testing gave the most concordant results, and he had not the least intention of attacking impact methods of testing, and it is a matter of sincere regret to him that all the methods have shown such considerable variations in duplicate tests. In view, however, of the importance with which impact testing is regarded by some engineers he felt it was desirable that these results should be placed before engineers so that they might be fully discussed.

In conclusion the author has particularly to express his thanks to Mons. Frémont and Messrs. Izod, Jude, and Kirkaldy, without whose co-operation and assistance it would have been impossible to carry out the tests; also to Mr. James Hopps, late Superintendent of the Coopers Hill Engineering Laboratory, who kindly made the tensile tests for all the commercial steels.

The Paper is illustrated by 6 Figs. in the letterpress, Tables 4 to 11, and is accompanied by 2 Appendices of 7 Figs. and Tables 12 to 18.

[*The Discussion on this Paper was combined with that on Dr. Stanton and Mr. Bairstow's Paper, and commences on page* 974.]

APPENDIX I.

Tables 12 to 17 (pages 952–967) give the results of a large number of duplicate tests on ordinary commercial steels made by Acid and Basic Bessemer and Acid and Basic Open-Hearth processes, and these results are shown diagrammatically in Figs. 29 to 34 (pages 947–950); for comparison tensile tests are also given in Table 17 (pages 966–967).

Fig. 29.—*Showing decreased Resistance to Impact with increase of Carbon.*
Seaton and Jude.

(*See* Tables 12 to 16.)

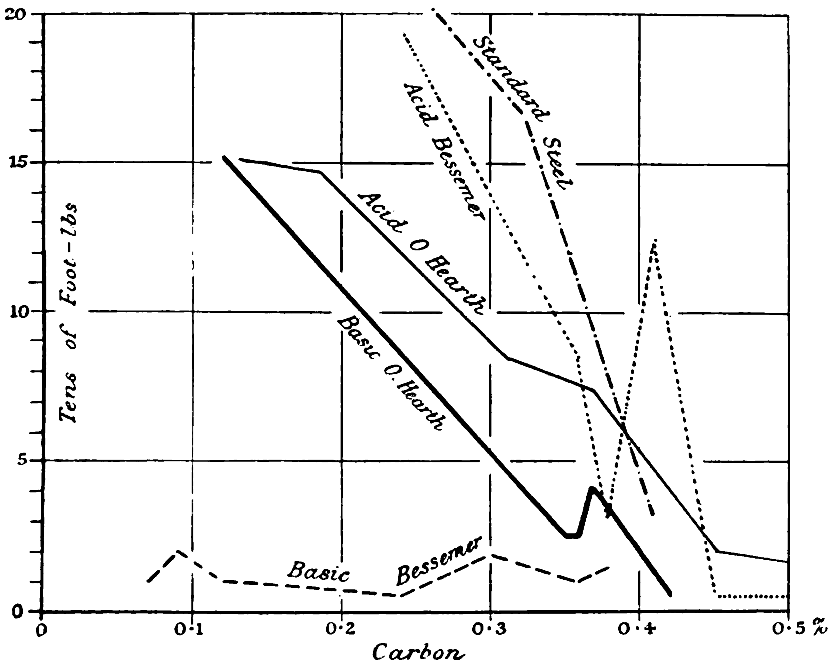


Fig. 30.—*Showing decreased Resistance to Impact with increase of Carbon.* Frémont. (*See* Tables 12 to 16.)

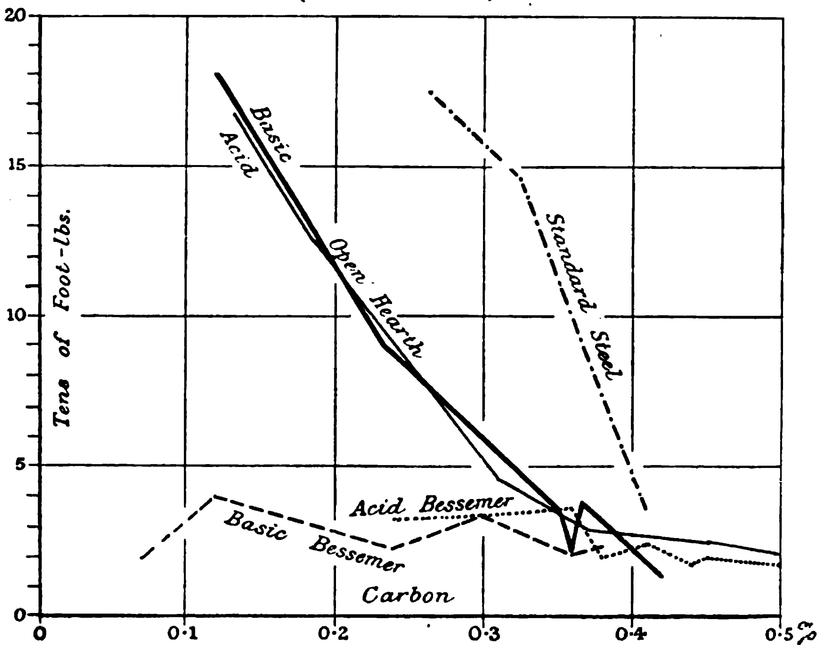


Fig. 31.—*Showing decreased Resistance to Impact with increase of Carbon.* Izod. (*See* Tables 12 to 16.)

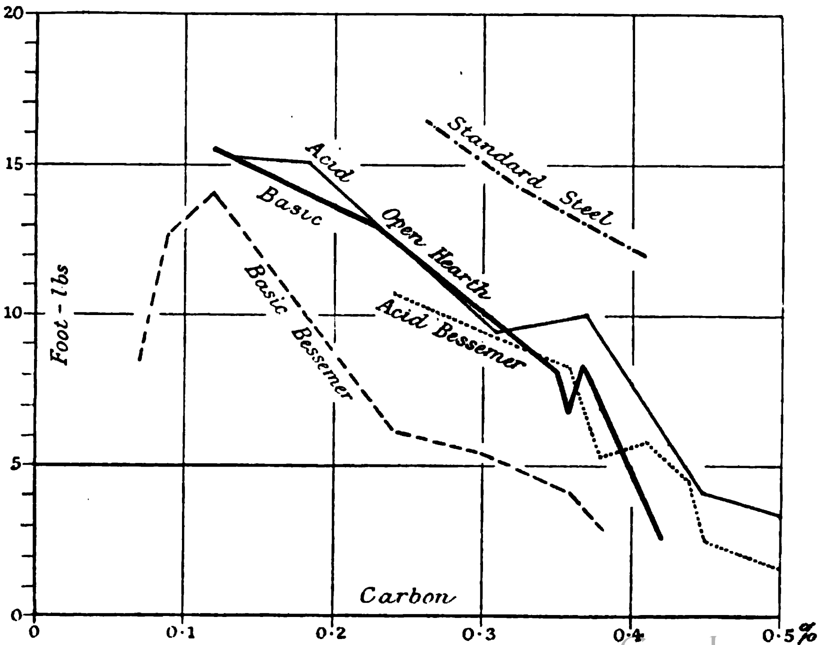


FIG. 32.—*Showing decreased Resistance to Impact with increase of Carbon.* Kirkaldy, Horizontal. (*See* Tables 12 to 16.)

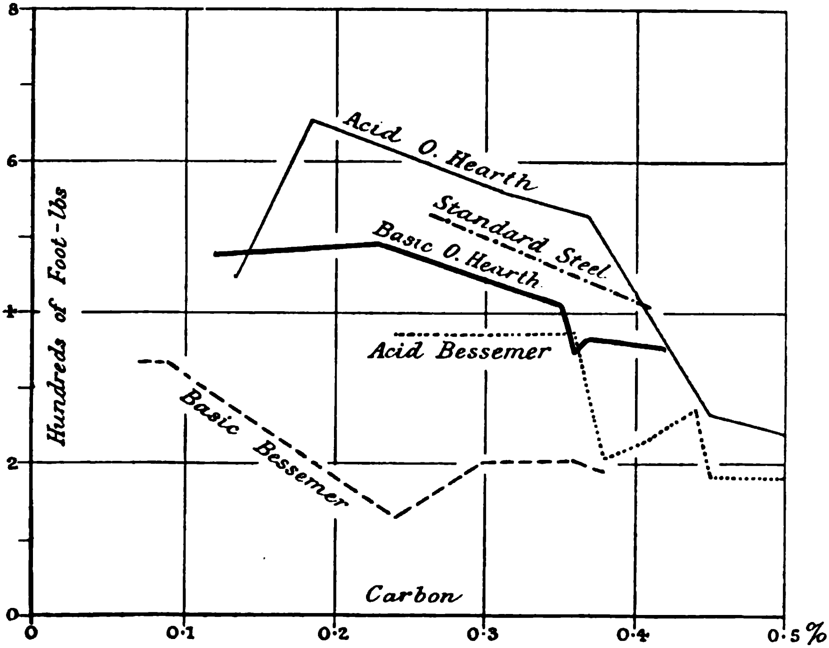


FIG. 33.—*Showing decreased Resistance to Impact with increase of Carbon.* Kirkaldy, Vertical. (*See* Tables 12 to 16.)

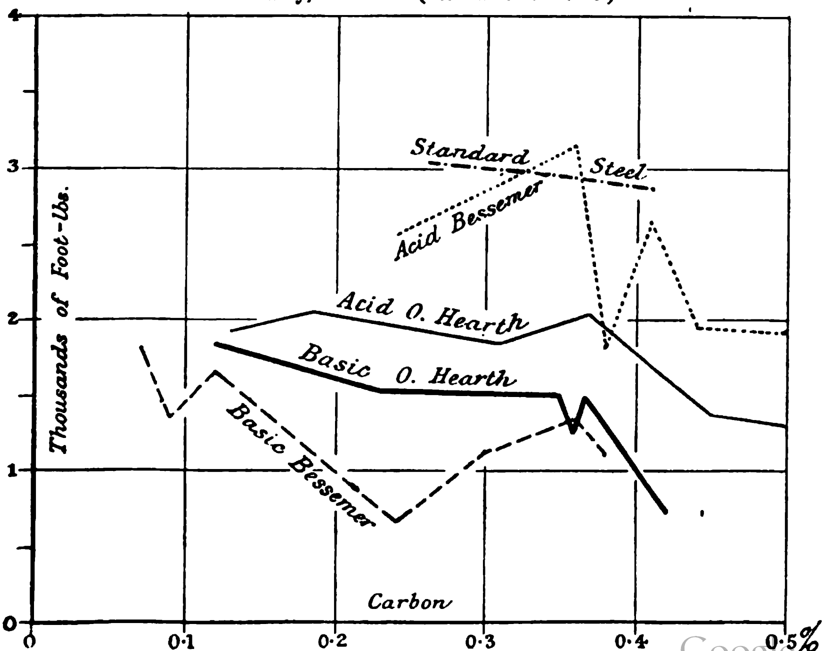
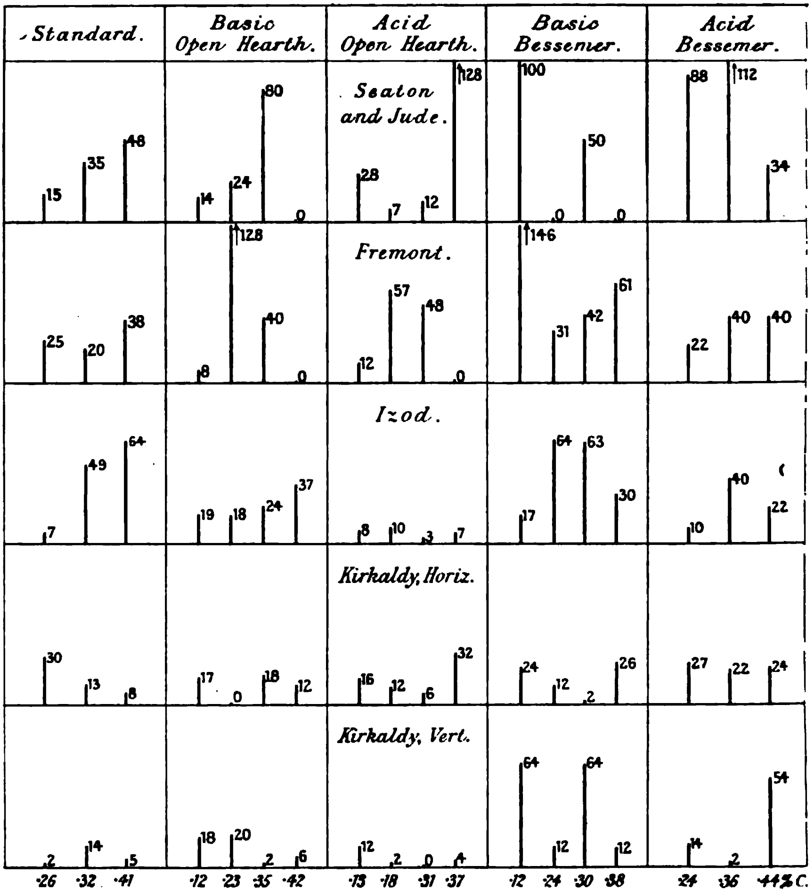


FIG. 34.—*Diagram showing the Extent of Variation for various grades of Steel up to about 0·4 per cent. Carbon and for each method.*

(*See* Tables 12 to 16.)

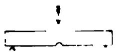
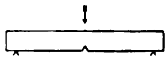
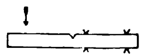
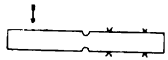
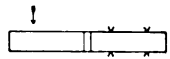
Vertical lines and numbers represent percentages of Variation among the duplicate (two or six) specimens.



TABLES 12 TO 17.

3 T

TABLE 12.—*Standard Steel. Untreated.*

Marks.	Carbon per cent.	Seaton and Jude. No.	Seaton and Jude. No. of Blows. Weight 5¼ lb., drop 24 ins.	Seaton and Jude. Foot-lb.	Seaton and Jude. Mean.	Seaton and Jude. Variation per cent.	Frémont. No.	Frémont. K.G.M.	Frémont. Foot-lb.	Frémont. Mean.	Frémont. Variation per cent.	Izod. No.	Izod. Foot-lb.	Izod. Mean.	Izod. Variation per cent.	Kirkaldy (Horizontal). No.	Kirkaldy (Horizontal). No. of Blows. Weight 4 lb., drop 12 ins.	Kirkaldy (Horizontal). Foot-lb.	Kirkaldy (Horizontal). Mean.	Kirkaldy (Horizontal). Variation per cent.	Kirkaldy (Vertical). No.	Kirkaldy (Vertical). No. of Blows. Weight 4 lb., drop 12 ins.	Kirkaldy (Vertical). Tens of Foot-lb.	Kirkaldy (Vertical). Mean.	Kirkaldy (Vertical). Variation per cent.
																									
20	0·262	1	77	808	808	15	1	27	195	174	25	1	16·0	16·4	7	1	152	608	528	30	1	752	301	303	2
		2	85	892			2	25	181			2	16·3			2	112	448			2	762	305		
		3	73	766			3	25	181			3	16·7								3	761	304		
		4	79	829			4	23	166			4	16·3												
		5	73	766			5	23	166			5	15·9												
		6	75	787			6	21	152			6	17·0												

30	0·325	1	61	640	661	35	1	22	159	146	20	1	15·9	14·4	49	1	128	512	482	13	1	730	292	298	14
		2	71	745			2	21	152			2	17·1			2	113	452			2	805	322		
		3	75	787			3	20	145			3	10·0								3	745	298		
		4	63	661			4	22	159			4	16·1								4	705	282		
		5	57	598			5	18	130			5	16·8												
		6	53	556			6	18	130			6	10·4												
40	0·409	1	7	73	87	48	1	5	36	36	38	1	16·8	12·0	64	1	97	388	404	8	1	731	292	285	5
		2	25	262*			2	5	36			2	9·5			2	105	420			2	702	281		
		3	7	73			3	5	36			3	15·7								3	703	281		
		4	11	115			4	7	50			4	10·0												
		5	3	31*			5	5	36			5	9·1												
		6	33	346*			6	5	36			6	11·1												

* Abnormal cases, eliminated in calculating averages (*see* page 935).

TABLE 12 (*continued*).—*Standard Steel. Overheated,* i.e. *heated to* 1,280° *C.* (2,336° *F.*) *for one hour and rapidly cooled.*

Marks.	Carbon per cent.	Seaton and Jude. No.	Seaton and Jude. No. of Blows. Weight 5¼ lb., drop 12 ins.	Seaton and Jude. Foot-lb.	Seaton and Jude. Mean.	Seaton and Jude. Variation per cent.	Frémont. No.	Frémont. K.G.M.	Frémont. Foot-lb.	Frémont. Mean.	Frémont. Variation per cent.	Izod. No.	Izod. Foot-lb.	Izod. Mean.	Izod. Variation per cent.	Kirkaldy (Horizontal). No.	Kirkaldy (Horizontal). No. of Blows. Weight 4 lb., drop 12 ins.	Kirkaldy (Horizontal). Foot-lb.	Kirkaldy (Horizontal). Mean.	Kirkaldy (Horizontal). Variation per cent.	Kirkaldy (Vertical). No.	Kirkaldy (Vertical). No. of Blows. Weight 4 lb., drop 12 ins.	Kirkaldy (Vertical). Tens of Foot-lb.	Kirkaldy (Vertical). Mean.	Kirkaldy (Vertical). Variation per cent.
20	0·262	1	5	26	38	69	1	26	188	200	30	1	15·1	14·0	35	1	71	284	335	29	1	403	161	180	27
		2	7	37			2	24	173			2	16·1			2	91	364			2	395	158		
		3	10	52			3	25	181			3	11·2			3	94	376			3	405	162		
		4	29	152*			4	32	232			4	14·1			4	84	336			4	475	190		
		5	5	26			5	30	217			5	14·0			5	83	332			5	485	194		
		6	9	47			6	29	210			6	13·6			6	79	316			6	516	206		

30	0·325	1	11	58	77	55	1	28	203	209	14	1	14·2	15·0	9	1	72	288	357	59	1	384	154	149	20
		2	19	100			2	26	188			2	15·3			2	61	244			2	396	158		
		3	41	215*			3	30	217			3	14·9			3	113	452			3	395	158		
		4	13	68			4	30	217			4	15·6			4	98	392			4	340	136		
		5	13	68			5	30	217			5	15·0			5	106	424			5	401	160		
		6	17	89			6	28	203			6	—			6	85	340			6	324	130		
40	0·409	1	11	58	42	50	1	25	181	178	16	1	19·3	15·8	31	1	88	352	251	60	1	422	169	135	47
		2	7	37			2	25	181			2	14·4			2	61	244			2	339	136		
		3	7	37			3	23	166			3	14·9			3	69	276			3	298	119		
		4	7	37			4	27	195			4	16·1			4	56	224			4	264	106		
		5	9	47			5	23	166			5	15·2			5	53	212			5	344	138		
		6	7	37			6	10	72*			6	14·8			6	50	200			6	362	145		

* Abnormal cases, eliminated in calculating averages (*see* page 935).

TABLE 12 (*concluded*).—*Standard Steel. Restored*, i.e. *heated to* 1,230° *C.* (2,246° *F.*) *for one hour, rapidly cooled, reheated to* 870° *C.* (1,598° *F.*) *for* 45 *minutes and slowly cooled.*

Marks.	Carbon per cent.	Seaton and Jude.					Frémont.					Izod.				Kirkaldy (Horizontal).					Kirkaldy (Vertical).				
		No.	No. of Blows. Weight $5\frac{1}{4}$ lb., drop 12 ins.	Foot-lb.	Mean.	Variation per cent.	No.	K.G.M.	Foot-lb.	Mean.	Variation per cent.	No.	Foot-lb.	Mean.	Variation per cent.	No.	No. of Blows. Weight 4 lb., drop 12 ins.	Foot-lb.	Mean.	Variation per cent.	No.	No. of Blows. Weight 4 lb., drop 12 ins.	Tens of Foot-lb.	Mean.	Variation per cent.
20	0·262	1	7	37	35	60	1	16	116	131	22	1	12·4	14·2	21	1	89	356	344	26	1	296	118	130	36
		2	5	26			2	20	145			2	14·9			2	80	320			2	280	112		
		3	13	68*			3	18	130			3	13·3			3	76	304			3	289	116		
		4	7	37			4	19	137			4	15·3			4	97	388			4	356	142		
		5	5	26			5	10	72*			5	14·0			5	96	384			5	338	135		
		6	9	47			6	18	130			6	15·5			6	78	312			6	399	160		

30	0·325	1	5	26	21	48	1	18	130	101	78	1	13·4	15·1	19	1	82	328	304	29	1	281	112	112	36
		2	3	16			2	11	79			2	14·8			2	69	276			2	334	134		
		3	5	26			3	8	58			3	15·6			3	64	256			3	232	93		
		4	3	16			4	18	130			4	15·9			4	81	324			4	293	117		
		5	3	16			5	10	72			5	16·3			5	74	296			5	265	106		
		6	5	26			6	19	137			6	14·6			6	86	344			6	—	—		
40	0·409	1	3	16	12	95	1	9	65	80	109	1	9·9	12·3	34	1	65	260	263	29	1	240	96	103	49
		2	3	16			2	7	51			2	14·0			2	73	292			2	238	95		
		3	1	5			3	6	43			3	13·2			3	58	232			3	270	108		
		4	1	5			4	9	65			4	13·6			4	77	308			4	214	86		
		5	5	26*			5	18	130			5	12·9			5	60	240			5	241	96		
			3	16			6	17	123			6	10·0			6	62	248			6	340	136		

* Abnormal cases, eliminated in calculating averages (*see* page 935).

TABLE 13.—*Acid Bessemer Steel.*

Marks.	Carbon per cent.	Seaton and Jude. No.	Seaton and Jude. No. of Blows. Weight 5¼ lb., drop 12 ins.	Seaton and Jude. Foot-lb.	Seaton and Jude. Mean.	Seaton and Jude. Variation per cent.	Frémont. No.	Frémont. K.G.M.	Frémont. Foot-lb.	Frémont. Mean.	Frémont. Variation per cent.	Izod. No.	Izod. Foot-lb.	Izod. Mean.	Izod. Variation per cent.	Kirkaldy (Horizontal). No.	Kirkaldy (Horizontal). No. of Blows. Weight 4 lb., drop 12 ins.	Kirkaldy (Horizontal). Foot-lb.	Kirkaldy (Horizontal). Mean.	Kirkaldy (Horizontal). Variation per cent.	Kirkaldy (Vertical). No.	Kirkaldy (Vertical). No. of Blows. Weight 4 lb., drop 12 ins.	Kirkaldy (Vertical). Tens of Foot-lb.	Kirkaldy (Vertical). Mean.	Kirkaldy (Vertical). Variation per cent.
25	0·240	1	21	110	194	88	1	4	29	32	22	1	12·0	10·9	10	1	106	424	369	27	1	600	240	258	14
		2	53	278			2	4	29			2	11·1			2	90	360			2	691	276		
							3	5	36			3	10·1			3	81	324							
							4	5	36			4	10·3												
30	0·365	1	7	37	84	112	1	4	29	36	40	1	10·1	8·3	40	1	105	420	371	22	1	794	318	313	2
		2	25	131			2	4	29			2	6·8			2	85	340			2	772	309		
							3	6	43			3	8·4			3	88	352							
							4	6	43			4	8·2												

35	0·406	1	1	5	126	192	1	3	22	25	28	1	5·5	5·9	14	1	86	344	237	68	1	710	284	266	14
		2	47	247			2	3	22			2	5·7			2	46	184			2	618	247		
							3	4	29			3	6·0			3	46	184							
							4	4	29			4	6·3												
40	0·380	1	7	37	31	34	1	2	14	20	36	1	5·4	5·3	22	1	39	156	203	56	1	564	226	180	50
		2	5	26			2	3	22			2	5·6			2	68	272			2	338	135		
							3	3	22			3	5·7			3	63	252							
							4	3	22			4	4·5												
45	0·443	1	7	37	31	34	1	2	14	18	40	1	4·7	4·5	22	1	76	304	271	24	1	631	252	198	54
		2	5	26			2	2	14			2	4·7			2	60	240			2	359	144		
							3	3	22			3	3·9			3	67	268							
							4	3	22			4	4·6												

TABLE 14.

Acid Open-Hearth Steel.

Marks.	Carbon per cent.	Seaton and Jude. No.	Seaton and Jude. No. of Blows. Weight 5¼ lb., drop 12 ins.	Seaton and Jude. Foot-lb.	Seaton and Jude. Mean.	Seaton and Jude. Variation per cent.	Frémont. No.	Frémont. K.G.M.	Frémont. Foot-lb.	Frémont. Mean.	Frémont. Variation per cent.	Izod. No.	Izod. Foot-lb.	Izod. Mean.	Izod. Variation per cent.	Kirkaldy (Horizontal). No.	Kirkaldy (Horizontal). No. of Blows. Weight 4 lb., drop 12 ins.	Kirkaldy (Horizontal). Foot-lb.	Kirkaldy (Horizontal). Mean.	Kirkaldy (Horizontal). Variation per cent.	Kirkaldy (Vertical). No.	Kirkaldy (Vertical). No. of Blows. Weight 4 lb., drop 12 ins.	Kirkaldy (Vertical). Tens of Foot-lb.	Kirkaldy (Vertical). Mean.	Kirkaldy (Vertical). Variation per cent.
14	0·132	1	25	131	152	28	1	22	159	168	12	1	15·5	15·3	8	1	103	412	450	16	1	508	203	192	12
		2	33	173			2	23	166			2	16·0			2	122	488			2	453	181		
							3	23	166			3	14·8												
							4	25	181			4	15·1												

							1	12	87			1	14·2												
20	0·183	1	27	142	147	7	2	16	116	127	57	2	15·8	15·1	10	1	173	692	652	12	1	517	207	206	2
		2	29	152			3	20	145			3	15·5			2	153	612			2	511	204		
							4	22	159			4	15·0												
							1	5	36			1	9·2												
31	0·311	1	15	79	84	12	2	6	43	45	48	2	9·5	9·3	3	1	136	544	562	6	1	462	185	185	
		2	17	89			3	6	43			3	9·5			2	145	580			2	462	185		
							4	8	58			4	9·3												
							1	4	29			1	9·8												
37	0·370	1	23	121	73	128	2	4	29	29		2	9·8	10·0	7	1	111	444	526	32	1	498	199	203	4
		2	5	26			3	4	29			3	10·0			2	152	608			2	518	207		
							4	4	29			4	10·5												

TABLE 15.—*Basic Bessemer Steel.*

Marks.	Carbon per cent.	Seaton and Jude. No.	Seaton and Jude. No. of Blows. Wt. 5¼ lb., drop 12 ins.	Seaton and Jude. Foot-lb.	Seaton and Jude. Mean.	Seaton and Jude. Variation per cent.	Frémont. No.	Frémont. K.G.M.	Frémont. Foot-lb.	Frémont. Mean.	Frémont. Variation per cent.	Izod. No.	Izod. Foot-lb.	Izod. Mean.	Izod. Variation per cent.	Kirkaldy (Horizontal). No.	Kirkaldy (Horizontal). No. of Blows. Wt. 4 lb., drop 12 ins.	Kirkaldy (Horizontal). Foot-lb.	Kirkaldy (Horizontal). Mean	Kirkaldy (Horizontal). Variation per cent.	Kirkaldy (Vertical). No.	Kirkaldy (Vertical). No. of Blows. Wt. 4 lb., drop 12 ins.	Kirkaldy (Vertical). Tens of Foot-lb.	Kirkaldy (Vertical). Mean.	Kirkaldy (Vertical). Variation per cent.
1	0·07	1	3	16	11	100	1	2	14	20	72	1	8·1	8·4	44	1	83	332	332		1	337	135	180	50
		2	1	5			2	2	14			2	8·4								2	565	226		
							3	3	22			3	6·8												
							4	4	29			4	10·5												
2	0·09	1	5	26	21	50	1	2	14	29	150	1	15·8	12·8	52	1	81	324	332	4	1	325	180	136	8
		2	3	16			2	2	14			2	9·2			2	85	340			2	353	141		
							3	8	58			3	15·2												
							4	20	145			4	11·0												
3	0·12	1	3	16	11	100	1	2	14	40	146	1	15·3	14·1	17	1	82	328	292	24	1	284	114	166	64
		2	1	5			2	4	29			2	12·8			2	64	256			2	547	219		
							3	6	43			3	14·3												
							4	10	72			4	14·2												

4	0·24	1	1	5	5		1	3	22	23	31	1	4·1	6·1	64	1	34	136	128	12	1	156	62	66	12
		2	1	5			2	3	22			2	8·0			2	80	120			2	174	70		
							3	3	22			3	6·3												
							4	4	29			4	5·9												
5	0·30	1	5	26	21	50	1	4	29	34	42	1	4·8	5·4	63	1	51	204	202	2	1	195	78	114	64
		2	3	16			2	4	29			2	3·9			2	50	200			2	373	169		
							3	5	36			3	7·3												
							4	6	43			4	5·6												
6	0·36	1	1	5	11	100	1	2	14	22	100	1	5·4	4·1	59	1	35	140	204	62	1	373	149	134	24
		2	3	16			2	2	14			2				2	67	268			2	296	118		
							3	3	22			3	4·1												
							4	5	36			4	3·0												
7	0·38	1	3	16	16		1	2	14	23	61	1	3·1	2·9	30	1	41	164	188	26	1	259	104	110	12
		2	3	16			2	3	22			2	2·4			2	53	212			2	293	117		
							3	4	29			3	2·9												
							4	4	29			4	3·3												

TABLE 15.—*Basic Bessemer Steel.*

Marks.	Carbon per cent.	Seaton and Jude. No.	Seaton and Jude. No. of Blows. Wt. 5¼ lb., drop 12 ins.	Seaton and Jude. Foot-lb.	Seaton and Jude. Mean.	Seaton and Jude. Variation per cent.	Frémont. No.	Frémont. K.G.M.	Frémont. Foot-lb.	Frémont. Mean.	Frémont. Variation per cent.	Izod. No.	Izod. Foot-lb.	Izod. Mean.	Izod. Variation per cent.	Kirkaldy (Horizontal). No.	Kirkaldy (Horizontal). No. of Blows. Wt. 4 lb., drop 12 ins.	Kirkaldy (Horizontal). Foot-lb.	Kirkaldy (Horizontal). Mean	Kirkaldy (Horizontal). Variation per cent.	Kirkaldy (Vertical). No.	Kirkaldy (Vertical). No. of Blows. Wt. 4 lb., drop 12 ins.	Kirkaldy (Vertical). Tens of Foot-lb.	Kirkaldy (Vertical). Mean.	Kirkaldy (Vertical). Variation per cent.
1	0·07	1	3	16	11	100	1	2	14	20	72	1	8·1	8·4	44	1	83	332	332		1	337	135	180	50
		2	1	5			2	2	14			2	8·4								2	565	226		
							3	3	22			3	6·8												
							4	4	29			4	10·5												
2	0·09	1	5	26	21	50	1	2	14	29	150	1	15·8	12·8	52	1	81	324	332	4	1	325	130	136	8
		2	3	16			2	2	14			2	9·2			2	85	340			2	353	141		
							3	8	58			3	15·2												
							4	20	145			4	11·0												
3	0·12	1	3	16	11	100	1	2	14	40	146	1	15·3	14·1	17	1	82	328	292	24	1	284	114	166	64
		2	1	5			2	4	29			2	12·8			2	64	256			2	547	219		
							3	6	43			3	14·3												
							4	10	72			4	14·2												

4	0·24	1	1	5	5		1	3	22	23	31	1	4·1	6·1	64	1	34	136	128	12	1	156	62	66	12
		2	1	5			2	3	22			2	8·0			2	80	120			2	174	70		
							3	3	22			3	6·3												
							4	4	29			4	5·9												
5	0·30	1	5	26	21	50	1	4	29	34	42	1	4·8	5·4	63	1	51	204	202	2	1	195	78	114	64
		2	3	16			2	4	29			2	3·9			2	50	200			2	373	169		
							3	5	36			3	7·3												
							4	6	43			4	5·6												
6	0·36	1	1	5	11	100	1	2	14	22	100	1	5·4	4·1	59	1	35	140	204	62	1	373	149	134	24
		2	3	16			2	2	14			2				2	67	268			2	296	118		
							3	3	22			3	4·1												
							4	5	36			4	3·0												
7	0·38	1	3	16	16		1	2	14	23	61	1	3·1	2·9	30	1	41	164	188	26	1	259	104	110	12
		2	3	16			2	3	22			2	2·4			2	53	212			2	293	117		
							3	4	29			3	2·9												
							4	4	29			4	3·3												

TABLE 16.—*Basic Open-Hearth Steel.*

Marks.	Carbon per cent.	Seaton and Jude. No.	Seaton and Jude. No. of Blows. Weight 5¼ lb., drop 12 ins.	Seaton and Jude. Foot-lb.	Seaton and Jude. Mean.	Seaton and Jude. Variation per cent.	Frémont. No.	Frémont. K.G.M.	Frémont. Foot-lb.	Frémont. Mean.	Frémont. Variation per cent.	Izod. No.	Izod. Foot-lb.	Izod. Mean.	Izod. Variation per cent.	Kirkaldy (Horizontal). No.	Kirkaldy (Horizontal). No. of Blows. Weight 4 lb., drop 12 ins.	Kirkaldy (Horizontal). Foot-lb.	Kirkaldy (Horizontal). Mean.	Kirkaldy (Horizontal). Variation per cent.	Kirkaldy (Vertical). No.	Kirkaldy (Vertical). No. of Blows. Weight 4 lb., drop 12 ins.	Kirkaldy (Vertical). Tens of Foot-lb.	Kirkaldy (Vertical). Mean.	Kirkaldy (Vertical). Variation per cent.
10	0·12	1	27	142	152	14	1	24	174	179	8	1	16·0	15·5	19	1	109	436	478	17	1	415	166	183	18
		2	31	163			2	24	174			2	13·1			2	130	520			2	499	200		
							3	25	181			3	15·8												
							4	26	188			4	15·2												
20	0·23	1	15	79	89	24	1	6	43	90	128	1	13·6	12·8	18	1	123	492	492		1	421	168	153	20
		2	19	100			2	10	72			2	11·3			2	123	492			2	345	138		
							3	12	87			3	13·6												
							4	22	159			4	12·6												

							1	4	29			1	8·6												
30	0 35	1	7	37	26	80	2	5	36	36	40	2	7·0	8·15	24	1	94	376	412	18	1	381	152	150	2
		2	3	16			3	5	36			3	8·0			2	112	448			2	371	148		
							4	6	43			4	9·0												
							1	4	29			1	8·0												
40	0·368	1	7	37	42	24	2	5	36	38	38	2	8·7	8·3	17	1	81	324	366	23	1	374	150	150	
		2	9	47			3	6	43			3	7·6			2	102	408			2	375	150		
							4	6	43			4	9·0												
							1	3	22			1	6·8												
50	0·36	1	3	16	26	80	2	3	22	23	31	2	6·9	6·8	22	1	93	372	342	18	1	340	134	127	13
		2	7	37			3	3	22			3	7·5			2	78	312			2	298	119		
							4	4	29			4	6·0												
							1	2	14			1	3·0												
60	0·42	1	1	5	5		2	2	14	14		2	3·0	2·7	37	1	83	332	352	12	1	175	70	72	6
		2	1	5			3	2	14			3	2·8			2	93	372			2	185	74		
							4	2	14			4	2·0												

TABLE 17.

Acid Bessemer.

No.	Elastic Limit. Tons per square inch.		Elastic ratio.		Ultimate Stress. Tons per sq. in.		Elongation on 6 ins. per cent.		Reduction of area per cent.		Brinell Hardness number.		Composition.				
	As rolled.	Heated to 610° C.	As rolled.	Heated to 610° C.	As rolled.	Heated to 610° C.	As rolled.	Heated to 610° C.	As rolled.	Heated to 610° C.	As rolled.	Heated to 610° C. (1,130° F.)	C.	Si.	S.	P.	Mn.
25	19·66	19·79	0·5682	0·5783	34·60	34·22	23·40	23·81	44·27	56·51	111·1	111·1	0·240	0·032	0·068	0·053	0·895
30	24·68	21·43	0·6130	0·5352	40·26	40·03	21·00	20·66	50·03	51·65	125·0	125·0	0·365	0·030	0·060	0·056	0·980
35	27·59	21·75	0·6247	0·5046	44·16	43·10	16·86	18·33	37·87	45·28	135·0	135·0	0·406	0·046	0·059	0·054	0·850
40	24·55	22·47	0·5915	0·5484	41·50	40·97	19·60	16·86	34·91	28·06	131·0	128·2	0·380	0·036	0·065	0·059	0·870
45	25·32	20·78	0·6101	0·5083	41·50	40·87	17·06	12·00	36·52	45·69	139·0	135·0	0·443	0·028	0·054	0·049	0·875

Basic Bessemer.

1	13·25	14·28	0·5678	0·6107	23·51	23·38	30·26	27·86	64·04	67·27	75·75	80·6	0·070	0·007	0·061	0·044	0·345
2	15·38	15·90	0·5602	0·5742	27·45	27·69	27·73	34·26	61·05	57·41	90·91	100·0	0·090	0·003	0·113	0·082	0·475
3	14·73	15·97	0·5109	0·5548	28·83	28·78	27·10	28·66	60·89	59·08	96·15	96·15	0·120	trace	0·086	0·076	0·665
4	18·96	20·52	0·5584	0·6056	33·95	33·88	23·06	23·63	49·82	52·04	111·1	106·4	0·240	0·018	0·082	0·099	0·520
5	18·49	18·36	0·5131	0·5419	36·02	33·88	22·20	19·40	50·63	53·12	108·7	111·1	0·300	0·010	0·055	0·076	0·740
6	19·14	16·88	0·4945	0·4647	38·70	36·32	20·53	17·03	40·73	45·93	113·6	119·0	0·360	0·011	0·096	0·070	0·825
7	20·91	22·07	0·5037	0·5363	41·51	41·15	19·48	15·96	43·15	49·23	122·0	119·0	0·380	0·019	0·057	0·065	0·955

Acid Open-Hearth.

14	13·64	12·33	0·5359	0·4863	25·45	25·35	29·23	30·60	62·30	62·65	82·0	78·1	0·132	0·026	0·031	0·055	0·400
20	13·17	15·58	0·4340	0·5158	30·34	30·20	27·20	27·70	57·41	60·70	98·0	96·1	0·183	0·037	0·024	0·052	0·710
31	14·29	13·96	0·4284	0·4218	33·35	33·09	23·26	24·10	52·04	55·32	106·4	102·0	0·311	0·040	0·021	0·052	0·575
37	16·55	17·53	0·4472	0·4920	37·00	35·63	21·76	22·03	45·51	52·80	119·0	111·0	0·370	0·062	0·021	0·029	0·800

Basic Open-Hearth.

10	12·34	13·50	0·5036	0·5578	24·50	24·20	23·03	29·66	63·00	68·35	78·1	78·1	0·120	0·035	0·027	0·057	0·400
20	12·99	13·63	0·4850	0·5355	26·78	25·45	25·56	24·66	43·59	60·16	86·2	80·6	0·230	0·009	0·047	0·054	0·450
30	21·17	20·13	0·5597	0·5551	37·82	36·26	20·66	20·10	40·11	44·00	121·9	116·3	0·350	0·012	0·049	0·077	0·853
40	18·83	18·18	0·5187	0·5164	36·30	35·19	21·86	22·40	47·59	49·64	111·0	106·4	0·368	0·039	0·044	0·010	0·625
50	17·72	16·54	0·5161	0·5157	31·37	32·07	22·13	18·10	44·63	51·64	106·1	104·1	0·360	0·010	0·028	0·018	0·900
60	17·40	17·79	0·4436	0·5011	36·97	35·50	18·76	19·23	43·80	47·59	111·0	104·1	0·420	0·037	0·037	0·041	0·575

APPENDIX II.

(Subsequently supplied by Captain H. Riall Sankey.)

Bending Tests made with the "Standard" Steels "overheated" and "restored" by means of Captain Sankey's Hand-Bending Testing-Machine.

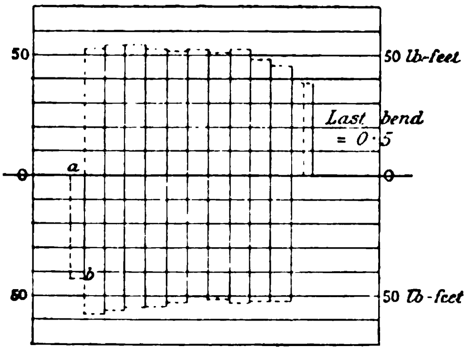
The principle on which this hand-bending machine is based was described in the Proceedings, 1907, Part I (page 281). The

Fig. 35.

Autographic Diagram. Hand-Bending Test (Sankey).

Test-piece "Standard Steel, 40" Restored."

Half Size.



Initial Bending Effort (a b) = 43 lb.-ft.

Maximum Bending Effect = 56 lb.-ft.

No. of Bends, 21.

Energy to Fracture, 2,200 ft.-lb.

Note.—The scale of the original diagram was such that one square inch represented 540 ft.-lb. energy.

arrangement of the machine used, however, differs from that described there, so that the autographic diagram obtained is of a different shape, as will be seen by comparing Fig. 35 with Figs. 180, 181, and 182 of Proceedings, 1907.

TABLE 18.—*Results of Hand-Bending Tests* (Sankey's method), *and comparison with Tensile Tests* (*Table* 6, *page* 934).

1	2	3	4	5	6	7	8	9	10
Number.	Bending effort. Initial (1st bend).	Bending effort. Maximum.	Yield-point (mean, from Table 6, page 934). Tons per sq. inch.	Column 2 (mean) divided by column 4.	Number of bends.	Elongation × contraction of area ÷ 100 (mean, from Table 6, page 934).	Column 6 divided by column 7 (mean).	Energy for fracture. Foot-lb.	Percentage difference in observations (column 9).
				Overheated.					
20	39	52	*15·8*	**2·14**	28·1	*22·2*	**1·20**	2510	6·0
	37	59			25·3			2660	
30	38	53	*17·25*	**2·17**	27·4	*18·5*	**1·47**	2900	1·8
	37	55			27·1			2850	
40	40	60	*18·65*	**2·09**	22·2	*16·6*	**1·37**	2310	1·7
	38	54			23·4			2350	
				Restored.					
20	36	51	*18·3*	**1·94**	28·2	*21·2*	**1·33**	2610	—
	35	53			14·0 (broke in grips)			—	
30	41	54	*18·65*	**2·12**	20·0	*18·0*	**1·09**	2020	2·0
	38	60			19·3			1980	
40	43	56	*21·25*	**2·1**	21·0	*14·2*	**1·51**	2200	6·8
	46	57			21·9			2350	

In all cases the fractures were *fine granular*.

Two duplicate specimens of each type of the "Standard" steels were tested, and the autographic diagram obtained, a reduced reproduction of one of which is given in Fig. 35 (page 968). The specimen is first bent to the left and a line *ab* is marked on the diagram; the length of this line, measured on the scale of foot-lb., gives the initial bending-effort. "One" bend is defined as bending the test-piece from the extreme position on the left to the extreme position on the right or vice versa. The total angle of bend is 114°, chosen because the arc corresponding to 1 foot radius is 2 feet in length, hence the energy or work expended for one bend is twice the bending effort, and is expressed in foot-lb. The machine is so arranged that each time the bend is made from left to right the drum carrying the paper is rotated one tooth of a ratchet wheel. In the diagram the vertical lines below the zero line represent bends from right to left, and those above the zero line bends from left to right. The rectangle to the left of each of these lines represents by its area the energy expended for this bend. The initial bend *ab* must, however, only be reckoned as half a bend, since the test-piece starts from the middle position, hence only half the energy must be taken, as shown by the dotted line to the left of *ab*. The last bend is seldom a complete one, and a note is taken of the portion of the bend described when the fracture actually occurs. In the case under consideration, 0·5 of a bend was so described, and the energy corresponding to this portion of the bend is represented by the dotted rectangle to the left of the last bend. The number of bends is obtained by counting the number of vertical lines, and making allowance for the one half-bend at the beginning, and for the portion of the bend at the end. The energy expended for fracture can be obtained by measuring the area included within the dotted lines.

The results of these tests are given in Table 18 (page 969), together with some data obtained from Table 6 (page 934) for the purpose of comparison. It will be noticed that:

(1) The initial bending-effort is in all cases considerably smaller than the maximum bending-effort. This shows that the test-pieces had been well annealed. When artificial stiffness has been imparted

to steel the initial bending-effort is equal to the maximum, and in extreme cases is actually the greatest bending-effort.

(2) The ratio of the initial bending-effort to the yield stress is approximately constant (*see* Column 5). The yield stress can therefore be inferred from the initial bending-effort. Trials with many other steels have given practically the same ratio, namely, 2·1 with a $\frac{3}{8}$ in. diameter test-piece.

(3) The number of bends is an approximate measure of the ductility of the steel, as will be seen from Column 8, which is the ratio of the number of bends to the elongation multiplied by the contraction of area as obtained from the tensile tests.

(4) The energy for fracture does not greatly vary for any of the specimens, and the variation in the measurements for duplicate test-pieces is small, except in two cases.

(5) There is no great difference in the results for corresponding overheated and restored test-pieces, the advantage being with the overheated test-pieces, which is in agreement with the somewhat unusual tensile results referred to by the author in the second paragraph on page 938. (*See* remarks by Mr. Harbord.)

Dr. Stanton said the President had kindly given him permission to lay before the meeting the result of some experiments recently made at the National Physical Laboratory, experiments which formed a typical example of the value of impact tests. The specimens on which the tests were made were cut from a fractured crank-shaft. The firm of engineers who supplied the specimens, and who had kindly given permission for the tests to be quoted, subjected some of them to a restoring treatment; he was not quite sure what it was, but thought it was annealing. Tests were made on the restored specimens and also on specimens which were not treated in any way. The results would be found in Table 19 overleaf.

(Dr. Stanton.)

TABLE 19.—*Tests on Specimens cut from Crank-Shaft.*

	Without further Treatment.	Annealed before Machining.	
Elastic Limit . .	13·25	17·90	Tons per square inch.
Yield Load . .	17·12	23·87	,, ,, ,,
Maximum Load .	34·42	36·92	,, ,, ,,
Extension . .	30·0	34·5	Per cent. on 2 inches.
Number of blows for fracture in Bending Impact Machine	1414	3600	
Energy absorbed in Izod Test . .	3·8	8·1	Foot-Pounds.

He thought they formed a valuable set of tests, and would afford material for a considerable amount of study. Referring first of all to the tensile test of the untreated specimen, it was not at all a bad one; he hardly thought that a material could have been rejected which gave those results, as they came fairly well up to specification. When the results of the impact tests came to be looked at, he was almost sure that the material would have been rejected, because a good crank-shaft steel should stand over 3,000 blows under the conditions stated, whereas this one only stood 1,400 blows; and in the Izod test, also, the resistance was very low. Not only that, but although there was nothing abnormal about the tensile fracture of the untreated specimen, the fracture under the impact test was decidedly suspicious, as would be seen on Fig. 37, Plate 31. In this photograph the fracture of the restored material was characteristic of very good material, and showed how the cracks spread inwards until they nearly reached the centre, when the specimen broke. On the other hand, the photograph of the untreated material showed that the cracks due to the repeated blows had only penetrated a comparatively short distance when the final fracture occurred.

He thought these two comparisons were valuable, because they indicated a real difficulty in the interpretation of tensile tests as regards resistance to shock. In the case quoted the low shock resistance of the untreated material was definitely revealed, for taking the values of the elastic limits given in Table 19, the ratio of the squares of these numbers was approximately that of the proof resiliences of the materials, since the value of the modulus of elasticity would be approximately the same in each. On calculation, the value of this ratio would be found not to differ greatly from that of the observed quantities in the impact tests. He believed that the results of these tests pointed to the conclusion of the whole matter, which was that low resistance to shock could be detected in the tensile test but the interpretation was very difficult, whereas the interpretation of the impact test was easy and unmistakable.

Mr. F. W. Harbord, at the conclusion of the reading of his Paper, said that since it was written Captain Sankey had also made a series of tests by his method of alternating-bend tests (*see* Appendix II, page 968). One of the duplicate bars broke off from the grips, and for some mysterious reason, failed, but with that exception in no case was there a greater difference than 7 per cent. in the energy absorbed before fracture between two duplicate bars. They were all in perfect agreement, showing that the material as far as its regularity was concerned had not been affected by the heat treatment.

He wished to refer to the Tables at the end of the Paper, because whatever value there was in the Paper was contained in them, and the question of the variations could be only really grasped by examining the actual detailed figures. In Table 12 (page 953) it would be seen that some of the variations were very great, and when they had been exceptionally great they had been eliminated in calculating the percentage variations. There was a case in point in connection with the Seaton and Jude tests, where the figures obtained were 73, 262, 73, 115, 31 and 346, and it would be seen that the *average* of such results as these really did not give any indication of what the actual variation was, and it was only by consulting the Tables in detail that one could arrive at it.

The PRESIDENT said it had been decided to have a joint discussion on the two Papers, but before it was opened, he would ask the members to pass a hearty vote of thanks to Dr. Stanton and Mr. Bairstow and to Mr. Harbord for their Papers and for the most painstaking and careful way in which they had placed the facts before the meeting. The Papers would afford a sound basis for a thorough and searching discussion.

The vote of thanks was unanimously accorded.

Discussion.

Sir ROBERT HADFIELD, Member of Council, was sure the Institution was greatly indebted to all three authors for the excellent Papers they had put forward that evening. He could not help looking back and thinking how many must have been the troubles of early workers in metallurgical development, such as Sir Henry Bessemer and Sir William Siemens, and how great the difficulties they had to encounter in their early struggles when trying to improve the quality of steel, also how much their labour would have been reduced had they only been in possession of some of the facts given by the authors that evening. When first perfecting their methods of making steel, there was very little to guide them on the question of the mechanical properties of steel. As an instance he might quote one of the best books published at that time, in the "sixties" of last century, Kohn's Metallurgy of Iron and Steel, largely due, it might be mentioned, to their friend Mr. Maw. In this book of some 400 pages only two pages were devoted to the mechanical testing of iron and steel. There was then but little to describe; Kirkaldy was practically the only investigator of note. That gave a very good idea of how little was known on the subject and how little attention had been paid to mechanical testing. It was not, therefore, surprising that occasionally material got into service from which failures resulted, these often then being well described as mysterious. But by means of mechanical testing, including impact tests such as brought under their notice that evening, it could be easily understood how those failures were gradually becoming no longer mysterious. Engineers were beginning to see the why and wherefore of such results.

Before making a few comments on the Papers he would like to refer to an interesting example of sudden impact testing, namely, the impact of a steel cap attached to a projectile when fired against a hard-faced armour-plate. He exhibited a cap similar to that which was placed on the shot before firing, and the one recovered after being fired at the proof butt at his (the speaker's) works in Sheffield. The piece of steel forming the cap in question was suddenly converted into the curious ring shown. The cap weighed, within a few grammes, the same as before firing, so that no portion of it was missing. Under such conditions it was seen that steel was quite a plastic material, and this was what our scientists had always taught. The cap shown was an excellent illustration of the fact that steel, ordinarily thought to be so rigid, was under certain conditions as plastic as lead, that is, when submitted to such an extraordinarily quick impact test as that of a cap attached to a projectile when coming into collision with a plate. The shell in question was fired at a velocity of 1,800 feet per second and struck a hard-faced plate having a thickness equal to the diameter of the shell (10½ cm.). The impact energy was about 500 or 600 foot-tons, and the shell perforated the hard-faced plate unbroken. He had also a piece of cap which was attached to a 12-inch projectile, which struck with an impact energy of no less than 23,000 foot-tons, so that it was easy to imagine the enormous amount of impact energy to which the cap had been subjected.

He was sure the members would congratulate Dr. Stanton and Mr. Bairstow on the valuable Paper they had put forward. They were bound to admire the perseverance of the authors in carrying out and watching tests which involved millions of blows, as mentioned on page 896, mechanical though part of this might be. Very careful investigation was necessary in such research work. He had had the pleasure of visiting the National Physical Laboratory

(Sir Robert Hadfield.)
not long ago, and was quite certain that no one carried out his work with more care than Dr. Stanton, who, he was glad to see, used the term "useful toughness" (page 890) which was an excellent phrase for defining satisfactory material. There might in certain cases be material having toughness, and yet not of a useful kind. Sometimes toughness was obtained under slow bending or less sudden impact, but, although the material appeared tough, it was wanting in the necessary qualities to resist sudden shock. This was now being conclusively proved by impact tests. It might be useful to mention that the derivation of the word "toughness" was from an Anglo-Saxon word "toh," which meant stiff, viscous, firm, tenacious.

Dr. Stanton made a strong statement (page 891) which very few would have cared to make three or four years ago, namely, that in his opinion impact tests by the single-blow method afforded all the indication which the steel maker and engineer required for the selection of material which was best suited for endurance of shock. He quite agreed with that conclusion, and thought if impact tests were properly carried out the necessity for tensile tests was largely reduced. Tensile tests required, comparatively speaking, a considerable amount of material, were expensive, and not easy to make. Although he did not for a moment say they should be abandoned, yet he thought they were relied upon too implicitly. For example, supposing a large quantity of the same kind of steel were required for structural purposes, he did not think it was necessary to take tensile tests as now. It would be far better to watch the shock-resisting qualities of such material.

Dr. Stanton stated that there was no appreciable permanent set in the specimen until within a few blows of the ultimate fracture (page 896). He did not remember that having been observed by any one before, and he thought they were greatly indebted to Dr. Stanton for pointing out that remarkable fact. Until reading this, he himself would rather have expected some change being noticed at a lower stage. Dr. Stanton spoke of the shock following the crystallisation or structure of the material (page 912), in other words, the shock apparently loosened the crystalline structure and "shook" it, so to speak, or tore it apart. For the same reason he thought he could agree with Dr. Stanton that it was necessary for the steel maker to try and improve his ferrite, which, after all, was the matrix, if it might be so termed, of all steel. The authors gave an excellent description (page 913) of how cleavage took place, and on the same page referred to the great desirability of discovering a satisfactory method of impact testing. This has been done by the well-known Frenchman, Mons. Frémont, whose name had often been referred to that evening, and who had brought into use a method which in every way could be thoroughly relied upon.

The authors referred to low elastic limit (page 916), and he quite agreed that the figures given for the low elastic limit were certainly bad. Puzzling inconsistencies were often met with in different types of steel. Of course such figures as given by the authors applied only to the particular kind of steel dealt with. In the case of manganese steel, which he had studied very closely for the last twenty years, it was somewhat extraordinary to find that notwithstanding its extraordinarily high tenacity, namely 60 tons per square inch, the elastic limit was extremely low. It was possible to get a slight set at low stresses, that is, a few tons per square inch, which Mr. Aspinall perhaps might remember, as he once rolled a tyre of this steel for the speaker many years ago. Taking a test-bar of such material, whilst the elastic limit was low, the material had extraordinary toughness and high tenacity. This seemed rather inconsistent, but the fact remained, and he could not offer any explanation. On the same page Dr. Stanton referred to his experiments on boiler-plate steel. He would ask him what he considered would be a suitable elastic limit, the lowest point he would recommend, for good boiler-plate steel. Dealing with the curves on page 910, he was not quite sure whether he understood them; also, was the sample referred to obtained from Mr. Milton?

Dr. Stanton said it was No. 10.

Sir Robert Hadfield said it was interesting to know, inasmuch as he had had a sample of the same steel given to him by Mr. Milton.

(Sir Robert Hadfield.)

With regard to the second Paper, Mr. Harbord had been very modest in taking up so little of the time of the meeting, and perhaps might have asked for a little longer to explain some of the points he had referred to. The Paper was an important one, and they were very much indebted for it. He was glad to see that he (Mr. Harbord) recognised the work done by Mons. Frémont. It must not be imagined that everything was done so well on the Continent that no difficulties were experienced in introducing new methods, as many people seemed so apt to believe. Mons. Frémont had an extremely uphill fight to establish his system, but its utility was now generally admitted. It was found valuable for large numbers of tests, including those on cheaper kinds of steel, boiler-plate steel, and so on, and he thought Mons. Frémont had helped to solve a number of difficulties which could not have been overcome in any other manner. He did not mean to say that other methods of impact testing were not also useful, but he thought Mons. Frémont had established a system which was now universally used on the Continent. It was a pity Great Britain could not in some way follow suit, because then the results of all such tests would be, so to speak, interchangeable. That was why he somewhat disagreed with Mr. Harbord in his expression of "foot-lb." He did not desire to be thought unpatriotic, but he did wish Mr. Harbord had used "kilogrammètres" instead. The expression "foot-lb." had to be converted into "kgm.," which was rather a troublesome piece of work when many tests were involved. It was a great pity there was not an international standard. There was no reason why there should not be, as in this instance, at any rate, it was not a case involving measurements, and the figures would have been more readily comparable with all Continental results. In America he thought they were adopting the kilogrammètre system of expressing such tests.

With regard to the use of nick and notch tests, it seemed to him their utility consisted in the following points. The function of a nick in the case of low-quality steel was to give an opportunity for the cleavage already existing, owing to its bad crystallisation, to commence its disruptive work or enable this to be developed to the point of complete fracture. Dr. Stanton had referred (page 913) to that matter, where he spoke of certain appearances known as Neumann lines as being intimately connected with crystalline fracture and probably due to molecular changes along cleavage planes throughout the whole crystal. That was a valuable explanation, enabling one to see the cause of the defective condition met with; this was also shown in the photo-micrographs, Plate 29. In his "James Forrest" Lecture * the speaker referred to the matter very fully, and pointed out that information could be obtained from tests of that kind which could not be obtained from ordinary tensile tests. He felt quite convinced on that point, and the sooner it was recognised the better for the improvement of material that had to withstand shock tests. He thought the method of heating specimens described by Mr. Harbord (page 930) was important, and he would like to ask for particulars as to the cost of such a furnace as was spoken of, as the heating method would be valuable for research purposes. Steel at high temperatures had not been sufficiently studied. At the present moment he was engaged in carrying out a number of tests which he hoped would eventually lead in a practical direction. Many reports of tests did not seem to lead anywhere, but he thought there was room for a very full investigation with regard to the effect of high temperatures upon steel. That work had not been done in the past, because high temperatures had been difficult to obtain, or more difficult to determine when such temperatures were reached, but now, thanks to improvements in pyrometers, these could be easily determined. In conclusion, he had to congratulate the authors on their excellent Papers, in which he personally had been most interested, and he was sure that all those who worked with iron and steel would be exceedingly indebted to them for the trouble they had taken in communicating these Papers.

Mr. Alexander Jude, who spoke on behalf of Mr. A. E. Seaton and himself, was sure the Institution was very much indebted to the

* Proceedings, The Institution of Civil Engineers, 1906, Part 4, vol. clxvi page 190.

(Mr. Alexander Jude.)
authors for their most useful and valuable Papers. At the same time he did not think they enabled one to arrive at a perfect understanding of the impact tests, although by the authors' help a great advance had been made. He hardly thought that Mr. Harbord's object as stated on page 946 was the thing to be aimed at. Engineers did not want to know what test—impact or other—would produce the most uniform results; they wanted to know the test that possessed a maximum sensitiveness to the structural properties of steel. Otherwise all mechanical tests might just as well be abolished right away and steel simply be judged by its colour, a test which he thought would be at least uniform enough for the most fastidious. He was sure Mr. Harbord would not misunderstand him when he said that he felt the atmosphere of the commercial testing room was rather tainted with the desire to have a charitable test. He (Mr. Jude) therefore thought it was only his duty as a steel user to keep on protesting against it.

He was inclined to disagree with Mr. Harbord that the variable results produced in all the methods of testing with duplicate specimens were due to the defects in the methods themselves; and he thought that Messrs. Stanton and Bairstow's uniformity of result was also evidence against Mr. Harbord's opinion on this point. The variable results appeared to him to indicate that the specimens were not structural duplicates in spite of identical treatment. He thought they also indicated that some of the methods of testing were on the whole more or less sensitive—that is, they had a different scale of magnification—than others to the structural peculiarities. If Messrs. Stanton and Bairstow's view as to the uniformity in single bars were accepted, Mr. Harbord seemed to have been less fortunate with his steels.

In the Tables in Mr. Harbord's Paper were the results of the tests which he personally had had the honour to make, and there were many high figures side by side with low figures in duplicate specimens. He had a clear recollection of those tests and remembered the astonishing shortness of many as compared with what he expected from a mild steel of the grade; and he had wondered when indeed some of the other specimens were going to break through. Now when two pieces of steel were tested, one going off at the first touch and the other withstanding blow after blow and no impression being made, he thought there was no doubt that the steel was the variable item and not the method of testing. Nevertheless he had from the beginning, in the Paper read in 1904, admitted the imperfection of the third method of testing (Mr. Harbord's numeration) when the blows were only a very few; although very few blows for any of the structural steels that were then under consideration indicated very bad brittleness.

During the last two or three years he had spent much time in investigating the ranges of variability of steels, both mechanically and microscopically, with to him rather astonishing results. From what he had seen he would suggest that the big differences, at least in Mr. Harbord's results, could be broadly identified with the peculiarities in the structure. Fig. 36, Plate 30, would indicate roughly what he meant.

The three vertical groups illustrated the three main varieties of structure produced in forgings of the same class and to the same specification, namely, 35–38 tons tensile with not less than 25 per cent. elongation in 2 inches. It did not, of course, follow that the analysis of the members of a group was the same, because, speaking generally, the process of fining the grain tended to raise the coarse-grained steel into a slightly harder group.

The term "tenside" was adopted to express the roughness of the outside surface of the specimen, caused by tension. Those familiar with tensile tests knew that there was a vast difference in the appearance of the drawn-down bars, some specimens having a fine velvety side, with a good cup-end, and others having a grossly gnarled side with a many-peaked end. These were the extremes, and yet the appearances might accompany practically the same ultimate strength, elongation, and reduction of area.

He had classified the intermediate stages into nine grades, No. 0 being the finest and No. 8 the coarsest. The tenside appeared to be a fairly reliable index of the coarseness of the structure—rather more so than the single impact test. But he noted, on the whole, a decided concurrence of the "tenside," the impact results,

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and the size of the grain, whereas ordinary commercial tensile test figures (ultimate tensile strength, elongation and reduction of area only) failed to give a tangible indication of the quality, except sometimes in extreme cases. These facts and deductions were based on the result of several hundred tests he had carried out, the particular series here referred to being a collection of one hundred. The Izod test was adopted in these series, because of the generally hard grade of the steel. He suggested that the "tenside," impact test, and standard sized micrograph might provisionally be substituted for the other—provisionally because no claim for finality was conveyed in the accompanying illustrations.

On the question of variability he was very sorry that he could not agree with Messrs. Stanton and Bairstow's statement that "steel was a much more homogeneous material than it had been recently suspected to be." It was true that their bars had individually shown an excellent homogeneity, but his own experience was more like Mr. Harbord's—and that referred not only to the impact tests, but to the whole of the other tests. On Messrs. Stanton and Bairstow's own showing, different steels of practically the same grade gave enormously different results, as would be seen in the various diagrams. He ventured to consider that the authors' generalised statement was an exceedingly dangerous one, and, if forced on the engineer by the steel maker, would certainly lead to disaster.

He would be very glad to see that an approximate identity had been established between the proof resilience and the elastic impact strength, as it then disposed of one end of the problem, but he really failed to recognise any such identity. Examples were given in the Paper which made it hard to see the identity. The impact figures given on page 909 showed impact strengths nearly in proportion to the root of the proof resiliences as given on the same page. He asked the authors for some explanation of those figures, for on turning up the old data for that particular iron and steel, he found that the primitive elastic limits were respectively 12·93, 21·42, 25, and 27·66 tons per square inch. But if E was about 30,000,000, for each, then the ratio of the proof resiliences appeared to him to be 1, 2·62, 3·73, 4·57. If, however, the figures on page 909 were correct, then the relative values of E appeared to be 10 millions, 30 millions, 15 millions, and 17 millions. These were rather remarkable figures. He would therefore be glad if Dr. Stanton would clear that matter up, and he thought it would also be desirable if he would give the complete data relating to those particular steels, the same remark applying to the other examples—the copper-aluminium and the 0·4 per cent. carbon steel. He also observed that yield-points were given in the Paper, and these had little to do with the various points at issue. There seemed to him something very queer about the 0·4 per cent. carbon steel—the 0·35 per cent. he thought it should be—of Professor Carpenter's series. That steel had 38 tons ultimate stress and 15·2 yield-point, and presumably the elastic limit would be about 13 tons, which was a most extraordinarily low result for a carbon steel of the grade; and it had a 30,000,000 modulus. Referring again to Figs. 11 and 12 (pages 907 and 910), it seemed that after all—although he must express his admiration for Messrs. Stanton and Bairstow's splendid micrographic work—the radical deductions as to the proof resilience were based on almost ultra-microscopical evidence. The authors themselves admitted the extreme difficulty of their problem. Figs. 11 and 12 conveyed to him the very strong idea that the deficiencies of the tests had made the apparent ultimate impact strengths diverge from one another and not converge. It appeared to him from the curves that the limit tended to the same for all steels, both good and bad, and that constant seemed to be a remarkably low one. The last curve of Fig. 11 was far more horizontal than the curve of limiting alternating-stress previously given by Dr. Stanton, or for the curve of the elastic limit. On the whole, therefore, he ventured to think that the identity which Messrs. Stanton and Bairstow would have engineers accept was hardly established, and that we must await the result of their further experiments before any definite conclusion could be come to on this point.

Referring to the limit which only just exceeded 0·02 foot-lb., he thought a 0·02 foot-lb. blow was a very small amount for a ½-inch bolt, which was practically the equivalent of the authors' test specimen, and he much feared that the apparent limit thus given

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was very often exceeded in practice, temporarily if not permanently. He therefore still felt unable to agree with them in the second paragraph of page 917. Quite apart from the question of identity the authors presented a very patent fact, that if the magnitudes of such temporary shocks produced, say, by a motor-car going over a brick or a steam-engine having its bearings a little slack, were rather more than was bargained for, the tables were completely turned; and the high-carbon steel instead of being only just a trifle better than the low-carbon steel became several hundred times worse—as represented by the Izod tests for example. His experience had shown him as a fact that in practice a fine-grained mild steel did hold out where the coarse-grained came to grief; it was also a fact in practice that the tough, leathery, oil-quenched mild steel (not exceeding 0·25 per cent. carbon, commercial steel) stood where the untreated bar constantly failed. It was further a fact that high-grade steels for threaded and more or less notched parts that had to stand a lot of racket had not come up to expectations; it was likewise a fact that low-carbon steel, to say nothing of iron, had been a veritable haven of refuge; and, finally, it was a fact that reducing the shanks of bolts to much below the bottom of the thread never saved a bolt from breaking through the thread, if it was going to break at all. He would like to ask Dr. Stanton whether any of his direct impact test-bars broke through the thread.

Dr. Stanton replied that not a single one had broken through the thread.

Mr. Jude said Dr. Stanton had not given the dimensions of the specimen bar, but he now understood it was ½ inch thread reduced to ¼ inch in the middle. This reduction was rather more than he (the speaker) had met with in any fractured part in practice, and apparently the authors were successful in getting outside the limit of risk of breaking through the thread.

Dr. Stanton had given two limits, one the ultimate impact elastic strength and the other what Dr. Stanton called the plastic strength, and of those two limits he (Mr. Jude) was much more disposed to favour the one-blow limit than the multi-blow limit. After what Dr. Stanton had said, the latter limit probably told them very little about the steel, because there was little indeed between extreme cases, whereas the former magnified the peculiarities of the steel to an appreciable extent—an extent that could be seen. But so long as there seemed to be some uncertainty as to the true limit, so he thought the happy medium of having an impact test consisting of a comparatively few number of blows was the sort of thing engineers required. He thought that Dr. Stanton's very elegant little machines were a great step nearer to the testing apparatus for which they had been looking for the past few years. Although some of his remarks had been adverse to Dr. Stanton's conclusions, nevertheless, taking his particular figures in their absolute sense, they would be of extreme value to the designer, especially if he bore in mind the ultimate elastic impact strength that he might be allowed to put on the parts that were subject to shock.

If then he understood the Paper rightly with particular reference to Figs. 7 and 8 (page 902), and the paragraphs relating to the proof resilience, it seemed to him that at last they had a comprehensive statement that the tensile test of the usual engineering specification was quite useless. For there was obviously no tangible association between the maximum stress and elongation curves and the curves of work, and the deduction as to quality had to rest on some assumption—such as an assumed ratio of elastic to maximum stress —or rest on something that was not specified to be recorded (*e.g.* "tenside." Refer photo-micrographs, Plate 30).

He supposed that one of the real reasons why elastic limit did not figure in specifications was because the average commercial testing machine did not possess the elaboration of an extensometer; and that a still more potent reason was that there was only a very small difference between bad and good results. He would refer to the last column of Table 3 (page 903), which is not confined simply to one grade, but covered a large range.

Dr. Stanton made the case for the ordinary tensile test worse by stating, in his interim reply, that the elastic limit of the tensile test was not the proper factor of the proof resilience, but was that derived from alternating-stress tests, so that we came to the old contention, that we should have to quibble over odd per cents., as in fact Dr.

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Stanton had shown in his supplementary example, in which, by the way, the *tensile* elastic limits were quoted.

Mr. Bertram Blount said that evening he was a spokesman for engineers who were more competent than himself in connection with the subject. Some time ago he felt an interest in the methods of testing by shock, and not pretending to much engineering knowledge he conferred with two engineers, Mr. E. H. Hurry and Captain Sankey. It seemed to him that if a shock test were to be made, some kind of machine in which the specimen was held as the customary tensile specimen was held, and subjected to a blow instead of a steady pull, might be a useful instrument; and an experimental apparatus was built on those lines according to the designs of the gentlemen referred to, which was illustrated in Fig. 38, Plate 31.

The machine itself was rooted in a concrete floor. A pillar was stayed at the top so as to make it fairly rigid, and there was a three-cornered tup which fell and hit the three-cornered plate, the plate having in it a coned hole in which the coned end of the specimen fitted. One of the specimens could be seen, in the illustration, lying on the floor at the side of the machine. When the tup came down the spring which was round the pillar was pressed to a point corresponding with the remaining energy of the blow after the specimen had been broken, and the amount of compression of the spring was measured by the shifting of a little slider on the rod shown at the side. The machine was quite elementary in its simplicity and worked very well, and he preferred it to Dr. Stanton's design, because it measured the compression of the spring while Dr. Stanton appeared to measure the recoil of the spring. He thought the more direct way was the better.

He might point out that there were certain practical difficulties, even when a machine was as simple as that shown. The tup and the pillar were made a good fit, but of course not a tight one; they could not be made loose, because the tup would not fall true and deliver the proper blow. Eventually it was found better to leave a little space, not too much, and very carefully to oil the pillar, and even then when all the things were adjusted as mechanically well as possible the blows were not quite uniform, although very nearly so. He mentioned that as showing the difficulties in arranging a machine even of that great simplicity. He had not carried out a very large number of tests with it. His first effort was to find whether a machine of that simple type would produce uniform results, and on that matter he had at once to part company with Mr. Harbord. Using an ordinary mild steel, he had a number of test specimens prepared of the kind shown in the illustration, small specimens like miniature tensile test-pieces, all from the same piece of material, and they were broken in the machine. Some were broken plain and some notched. It was quite easy to run a circumferential notch round the specimen and make a notched test.

The figures obtained were as follows. Out of a set of nine tests on a quarter-inch notched specimen he found a mean value stated in foot-lb. of 68·2, and the highest value above that was 80·2, which amounted to an error of 20 per cent., an error which he admitted was too large. That was above the mean. Below the mean the smallest value was 57·6, a 16 per cent. error. These were on notched specimens. He thought it would be admitted by all that there was much more probability of variation in a notched specimen, however carefully the notch was prepared, than there was in a specimen not notched. That was borne out by the other figures. A set of eight plain specimens were tested and the mean value of the eight came to 165·1. The highest figure above that was 175·2, corresponding to an error of 6 per cent. The lowest figure below the mean was 156·4, which corresponded with an error of 5·3 per cent. It was not what one expected in a tensile test, but it was not bad. He could not help thinking that if there were agreement with regard to an appropriate shock test, closer figures would be obtained than Mr. Harbord had been able to obtain. The tests he himself had referred to were all made on a single sample of metal, because at the time he was much more intent on seeing what the machine would do than on collecting information about steel. That was to come later.

He had already touched upon the fact that in his view the method of measuring the residual energy in the tup was preferable to that used by Dr. Stanton. It was a matter of convenience, but on the whole he thought that method was better. Table 2 of

(Mr. Bertram Blount.)
Dr. Stanton's Paper (page 900) had puzzled him considerably, and on Table 1 (page 899) there were analyses given. If anyone, who was accustomed to read mechanical tests of steel together with their chemical analysis looked at the two sets of criteria side by side, he would not know which to believe; whether the analyses were wrong or the tensile tests were wrong, or both were wrong. It would be perhaps indiscreet to indicate which in his view were likely to be most wrong, but the thing had interested him so much that taking advantage of the fact that Dr. Stanton was kind enough to give him duplicates of some of the materials, he had analysed them himself, and would in due course give the results * to Dr. Stanton. He would not be able to make a mechanical test, because he had not the material.

With regard to Mr. Harbord's Paper, it was extremely interesting, and had many points that called for comment. He thought he was right in saying that at present Mr. Harbord had confined his remarks to tests on notched bars—all his shock tests had been made on notched bars and not on plain specimens. Mr. Harbord might be justified in that, because Captain Sankey had mentioned a fact that was certainly new to most engineers. The natural wish to avoid a notch and to have a plain bar was very obvious, and one would prefer to abolish the notch if possible; but there was a difficulty to be met with, namely, what would happen to the plain specimen when it was broken. How many people could predict what would happen if sufficient shock were applied to a plain test-piece? He thought most people would say that if the shock were sufficient, if the velocity of impact were high enough, the material would snap like a carrot. But what was the fact? The specimen when broken drew out very much like an ordinary tensile specimen, and he was informed, and indeed, Sir Robert Hadfield had said much the same thing in the course of the evening, that a specimen of steel subjected to a pull so rapid as to be an explosive pull, that was to say, a specimen fired from a gun, would draw out almost like a wire. That he had heard also from Captain Sankey, and Sir Robert's statement

* The analyses referred to are as follows:—

No. 5: C 0·077, Mn 0·655, Si 0·032, S 0·063, P 0·065.

No. 6: C 0·172, Mn 0·034, Si 0·129, S 0·005, P 0·074.

entirely confirmed that view. Therefore it became extremely difficult to devise a test which could apply to a plain specimen a shock so violent and vehement as to be of value, and hence the notch. That he thought went to justify Mr. Harbord's preference for the notch, and he was only sorry Mr. Harbord had not been able to arrive at a satisfactory machine for testing steel in that way. Possibly if he had used something of the description he himself had shown with the notch he might have obtained results more regular.

Mr. MICHAEL LONGRIDGE, Member of Council, thought it was rather fortunate that the two Papers had been read together, for if members had only heard Dr. Stanton and Mr. Bairstow some might have gone away satisfied that the impact tests described in their Paper would show practically the same results as the tensile test; and therefore that they would be able by using one of the comparatively cheap and convenient impact tests to ascertain whether any sample of any steel of known analysis, tensile strength, yield-point and elongation, possessed the qualities which that steel ought to have. On the other hand, if they had heard Mr. Harbord's Paper only they might have left with the impression that impact testing was absolutely useless. So far as his own small experience went, it inclined him to take Dr. Stanton's side, and he would give the results of some tests made for him by Mr. Izod in support of his opinion. The first were made on four specimens cut from a connecting-rod bolt which broke. The bolt had been clearly broken by water in the cylinder and had stretched in breaking. He was perfectly satisfied as to what had happened, as he had been asked to decide the cause of the fracture, and had therefore taken every care to ascertain it. The tensile strength of the steel was 30 tons and the extension 37·5 per cent. in 3 inches. Four impact tests were made, giving 17 foot-lb., 17 foot-lb., 16·7 foot-lb. and 16·2 foot-lb. He thought the figures were not only remarkably concordant, but also gave a true indication of the toughness of the material. He would refer to that specimen again.

The next specimens tested were cut from a crank-shaft of foreign make with two double-sweep cranks which had broken after little

(Mr. Michael Longridge.)
more than one year's work. The fracture ran through the web of the crank furthest from the fly-wheel, which had to transmit the power from one cylinder only.

Tensile tests and analyses of two standard specimens cut from the broken web gave the following figures:—

TABLE 20.

Tensile Tests.	No. 1.	No. 2.
Initial diameter . . . . . . inch.	0·798	0·798
Proportional limit tons per square inch.	10	11
Yield-point . . " " "	14	15
Maximum load . " " "	32·88	32·66
Elongation in 3 inches . . . per cent.	19·3	22·3
Reduction of area . . . " "	20·4	25·6

Analysis.	No. 3.	No. 4.
Carbon	0·327	0·313
Silicon	0·169	0·165
Manganese	0·767	0·792
Phosphorus	0·057	0·059
Sulphur	0·086	0·086

He had numbered the analyses 3 and 4, because he was not certain which analysis was made from No. 1 test-piece and which from No. 2.

Three pieces cut from the same shaft were tested by Mr. Izod. Each absorbed 2·5 foot-lb. and broke off short at the nick. Here the impact test gave results not merely concordant but absolutely identical and highly indicative of the brittleness which was no doubt the cause of the failure of the shaft.

In the following cases the figures were not so consistent:—

Crank-shaft of high-speed engine broken after eight weeks' work. Tensile test said to have given 38·5 tons per square inch maximum load, 28 per cent. elongation in 2 inches, and 41·6 per cent. reduction of area. Carbon said to be 0·36 per cent. Three pieces tested by Mr. Izod absorbed 4·8 foot-lb., 4·2 foot-lb., 6·5 foot-lb., mean 5·2 foot-lb. Maximum difference from mean, 25 per cent. All broke off short at the notch. The breakage could not be ascribed to any specific stress. The bearings, including those for the armature spindle, had been lined and levelled when the shaft was put in. Unless the cause was cumulative vibration, it was probable that it was brittleness of the steel.

Crank-shaft of gas-engine cracked through web close to crank-pin.

Tensile tests of two standard test-pieces gave:—

TABLE 21.

Area . . . . . . square inch.	0·5	0·5
Yield-point . . . tons per square inch.	15·0	15·1
Maximum load . . " " "	28·82	28·8
Extension in 2 inches . . . per cent.	41	44
Reduction in area . . . "	52	55

Impact tests by Mr. Izod absorbed 6·4 foot-lb., 8 foot-lb., 6·1 foot-lb., mean 6·83 foot-lb. Maximum difference from mean, 14·6 per cent. All these test-pieces were cracked at the notch and bent over, but not broken clean off.

The cause of the cracks in the cranks was weakness. The life of the shaft was 10,528 working hours.

Crank-shaft of gas-engine broken in neck between crank and fly-wheel.

(Mr. Michael Longridge.)

Tensile tests of two standard test-pieces gave:—

TABLE 22.

—	No. 1.	No. 2.
Area . . . . . . square inch.	0·5	0·5
Proportional limit . tons per square inch.	15	14
Yield-point . . . " " "	15	14
Maximum load . . " " "	25·3	25·54
Elongation in 3 inches . . . per cent.	38·3	36·6
Reduction of area . . . "	65·4	63·4

Two pieces tested by Mr. Izod absorbed 4·1 foot-lb. and 5·5 foot-lb., and were bent through angles of 57° and 60° respectively, but not broken off; mean, 4·8 foot-lb.; maximum difference from mean, 14·6 per cent. The cause of the breakage was not ascertained. The life of the shaft was about nine months.

In another case, of which he could not find the particulars, three test-pieces absorbed 4·8 foot-lb., 4·7 foot-lb. and 5 foot-lb.; mean, 4·83 foot-lb.; maximum difference from mean, 3·4 per cent.

All these tests seemed to him fairly consistent. Such inconsistencies as there were seemed to result from two causes: First, motion of the whole machine when the tup struck the test-piece; in other words, insufficient weight of anvil; and, second, insufficient weight of tup to break all specimens clean.

The test-pieces he had mentioned first were not broken clean off, but were fractured at the notch and then bent over by the tup. All four showed marks of abrasion where the tup had rubbed over them in swinging forward. They had therefore acted as a brake upon the tup. Now, for practical use, these specimens were destroyed as soon as the cracks appeared at the bottom of the notches, and all the work expended in bending back the part above the notch was expended after the specimen was practically destroyed. Thus the work registered by the machine was not a true indication of the resistance of the specimen to shock, except in the case of the most brittle steels.

It seemed to him that all single-blow bending tests would be affected in a similar way. He therefore thought that single-blow tension tests would be more reliable than single-blow bending tests, but that multiple-blow bending tests with rotation of the specimen would be still better, because they approached more nearly single-blow tests to actual working conditions.

In practical work a brittle or rotten piece of steel was seldom subjected to a single blow heavy enough to break it. It was far oftener broken by a succession of blows while under stress. He therefore thought that a multiple-blow test on a specimen under tensional or torsional stress would probably be a more reliable criterion for engineers than either of the tests mentioned in the Papers. He was sorry to say he knew very little about the interpretation of photo-micrographs of polished and etched steel, and he thought many others shared his ignorance, but he had gathered the general impression that they had proved to the satisfaction of the initiated that spoilt steels were initially full of lines of half-welded crystals or fine cracks such as would be caused by segregation of sulphide of manganese, a substance which he was informed had a very low freezing point and great contraction on cooling. A small patch of such a substance would remain liquid while the material enclosing it solidified and would then cool and contract, leaving between itself and the surrounding material a small space or fine crack. These cracks would reduce the area of the section infinitesimally, and consequently the piece might be expected to give as good a tensile test as a perfectly sound test-piece. If, however, it were put under a heavy stress approaching the elastic limit and then subjected to repeated shocks, he thought members generally would agree with him that the incipient cracks, which were the causes of the rottenness of the steel, would rapidly extend and cause the specimens to fracture with far fewer shocks than if it had been sound.

Mr. Druitt Halpin said that reference had been made in the discussion to the tests of steel by other methods than tensile tests, by shock and by bending tests, and he had in his hand the first volume of the Journal of the Iron and Steel Institute, published in 1871,

(Mr. Druitt Halpin.)

in which a machine was described by the late Mr. Olrick.* He remembered seeing the machine in use. It was a pure bending machine on a small scale, and by reversing the shaft carrying the specimens a perfect indication was obtained of the difference in the metals dealt with.

With regard to the question of the velocity of breaking—not of tups or velocities of that kind—a great number of experiments were made by the Pohlmeyer and Müller machine in 1878 or 1879 at Dortmund, one of the first machines that ever had an indicator on, and a perfect diagram of the breaking was obtained. The machine worked at about 1,500 lb. hydraulic pressure, the pressure being taken from the ordinary shop mains, and a number of experiments were made at different rates of breaking; and no difference could be observed in the diagrams with the different speeds. The experimenters then went a step further and put up a hydraulic intensifier and obtained something like 4 or 5 tons per square inch, which the machine was quite capable of standing; they obtained enormous speeds, but again did not get any realisable difference in the diagrams owing to the rate of speed.

The President was quite sure the members would all agree with him they had had a most interesting discussion. Before he asked the authors to reply, he would like to remark that he most cordially agreed with Mr. Longridge in regard to the incipient defects in the internal structure of steel (page 993). He had frequently found, as Mr. Longridge said, that internal spaces had been the origin of cracks. It would be very interesting to be able to know a little better as to how to deal with boiler plates. It was difficult to get men always to heat such plates as they should do, particularly plates with thin corners. The result frequently was that, where the men had not been careful to use the same temperature for thinning the four corners, one corner had dropped off directly it had been touched with the rivet hammer, whereas the others had stood with wonderful ductility. Therefore he thought there was a good deal to be done in connection with the question, and he hoped it was not the last

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* Journal, Vol. i., page 429.

time the Institution would have brought before it information and more facts as to the handling of steel and its peculiarities.

Dr. Stanton, in reply, said there was one point in the discussion which he was very glad to be able to reply to that evening; it was contained in Mr. Jude's criticism. He was grateful to Mr. Jude for having pointed it out, because it showed there was one important quantity in the Paper that had not been made sufficiently clear, namely, what was the value of the elastic limit that had been used in calculating the proof resilience of the materials. On page 909 it was said, referring to the resilience, "where f is the real elastic limit of the material," and again at the end of the Paper he had called it f, the limiting stress. The definition he gave of the real elastic limit was as follows: if a bar were put under alternations of direct stress, equal tension and compression, and if R were the maximum range of stress which the bar would bear for an unlimited number of alternations, then $\frac{R}{2}$ was the real elastic limit of that material. For many materials it was not anything like the primitive elastic limit observed on a tensile testing-machine, which might be an artificial thing altogether. It was quite possible to produce a piece of steel which had no elastic limit in tension at all, simply because the elastic limit had been considerably raised in compression. In the case of the 0·4 per cent. carbon steel, of which he thought the range was 30 tons—that was the range of stress it could be run at indefinitely from tension to compression without breaking—he had taken the real elastic limit of the material as 15 tons. Similarly, the real elastic limit of the 9·9 per cent. copper-aluminium alloy was found to be approximately 14 tons per square inch. He thought that if Mr. Jude would recalculate his values of the resiliences from these figures they would be found to be in agreement with those given in the Paper. With reference to Mr. Jude's statement that high carbon steels for threaded and more or less notched parts had not come up to expectation, this was precisely the conclusion which he and his colleague had arrived at in their previous Paper on alternating stresses.

The facts about manganese steel to which Sir Robert Hadfield had referred were of considerable interest, and if the authors were

(Dr. Stanton.)

not already under such obligations to Sir Robert for providing them with steel for their experiments they would have asked him for some samples of this. He ought to point out that the statement as to the all sufficiency of the single-blow method, quoted from the Paper and approved by Sir Robert Hadfield, was not due to the authors, who were in favour of the many-blow method or shock fatigue test for revealing the real constructional value of an otherwise satisfactory material.

With reference to Mr. Blount's strictures on the Tables of tensile tests and analyses,* he was, apparently, of opinion that from the analysis of a steel the results of its tensile test could be predicted. This was only approximately the case, as the mechanical treatment undergone by the steel in manufacture had very considerable influence on its tensile properties. A proof of this was seen in the case of mild steel referred to on page 915 in which by a hammering process, the maximum stress had been raised from 27·3 tons per square inch to 46·0 tons per square inch, and its elastic limit in tension from 18·0 to 26·0 tons per square inch.

Mr. Harbord, in replying, said, with reference to Sir Robert Hadfield's remarks with regard to kilogrammes, he had to choose between giving foot-lb. for all or kilogramme-metres, and although he preferred kilogramme-metres, as foot-lb. was the usual term in use in England, he had expressed the results in foot-lb. With regard to Mr. Jude's remarks, after the great kindness and trouble Mr. Jude and other gentlemen who tested the pieces of steel for him had taken, he felt reluctant in publishing the results, and his only object in publishing them was that, by means of the discussion, attention might be drawn to the subject, and an attempt made to improve the sensitiveness of impact testing machines. One realised how important it was to get a simple test like an impact test that could be much more conveniently applied to small pieces, and be of value in cases where it was not always possible to have tensile tests. He quite agreed that the sensitiveness

* *See* also further Reply, page 1021.

was one of the things most important, and it was with that object he heated the bars to make them brittle, and then partly restored them to see if the impact tests would detect that difference. Curiously enough the overheated bars in some cases gave better results than the bars which had been restored. He did not think that was in any way due to any imperfections in methods of impact testing, as this result was confirmed generally by other tests, but results obtained by the heat treatment were very different from what he had anticipated.

Judging from Mr. Jude's remarks, he apparently had conveyed the impression that uniformity in results was all that was required in an impact test, but nothing was further from his thoughts. He did, however, consider it absolutely essential, before any method could be accepted as satisfactory, that duplicate tests must give fairly concordant results, otherwise we should have the same material selected by one engineer and condemned by another.

The opinion expressed in the Paper simply referred to the particular methods of testing investigated, and the results obtained by Messrs. Stanton and Bairstow had no bearing whatever on his results, as their methods of testing were entirely different. It was well known that very slight variations in form of the notch, force of the blow and other things most materially affected impact results, and his conclusions were absolutely confined to tests made under the conditions stated. One of the principal reasons for publishing the results was the hope that some modification of these methods of testing might be devised, which would remove the defects referred to.

With reference to Mr. Blount's remarks (page 986), he would have been very pleased to try his impact machine, but he did not know of it before his experiments were completed, and he then had no more steel left.

Mr. Longridge had mentioned a steel (page 990) which gave 32 tons tensile, good elongation, etc., and which under the impact test of Mr. Izod broke with 2·5 foot-lb. He did not for one moment deny that in many cases impact tests as shown by his own figures gave concordant results; in some cases they might be of great service, and enable them to detect brittleness not revealed by a tensile test. He thought, however, if more time and care were

(Mr. Harbord.)

taken than was usual in tensile testing, the load applied slowly and regularly, and care taken to distinguish between local elongation as distinct from elongation over the whole length of the parallel section, that in most cases marked examples of brittleness like that referred to would be easily detected by a tensile test. In the experiments described in the Paper the author had not relied only on tensile tests, but the material had been tested both by Professor Arnold's alternating-bending machine and by Captain Sankey's hand-bending machine, and both these methods confirmed the results obtained in the tensile testing machine; and in view of these facts, there seemed no other conclusion possible than that the steel was regular and of high class quality, and the irregular results obtained by the impact tests were not due to lack of uniformity in the material. He wished again to emphasise the point that the opinion expressed only referred to the particular methods of impact testing experimented with, and in no way condemned other methods such as those described by Messrs. Stanton and Bairstow or Mr. Blount.

Communications.

Mons. Pierre Breuil wrote to say that the trials carried out by Messrs. Stanton and Bairstow were of great value. Almost all the methods which could be applied in the technical operations of testing of metals had been considered and they had been compared amongst themselves. This procedure was seldom carried out, although it was precisely what ought to be done if it were desired (1) to show that a new method of testing put in evidence facts that were not ascertained by other methods, and (2) when it was desired to compare the results obtained by one method with those obtained by another. The authors were to be congratulated on the ingenious mechanisms they had devised; but, from past experience, one was led to expect that Dr. Stanton would devise suitable apparatus.

Broadly, the experiments proved that all kinds of tests gave parallel—if not identical—results. He was pleased that the authors had been able to exhibit this fact by means of the great variety of the trials which they had carried out; he had proved the same thing in some particular cases. This law was approximately general, but there were some exceptions. There were metals which, when tested by impact, were fractured without appreciable deformation, but when slowly broken, gave a considerable deformation. Phosphoric steels generally appeared in this category; such steels, therefore, did follow the law of similitude of effects produced by the application of sudden and of slow breaking forces; but this was the exception, and not, as has been maintained by certain authors, the rule. He desired to support this contention by means of certain experiments of his own.

He had carried out trials with four different kinds of steel, which had been broken by tension. First, ordinary tension tests had been made with autographic stress-strain diagrams; secondly, impact tension tests had been made, in which the work required for breaking and the elongation, etc., had been measured. For each kind of steel there had been a plain test-piece (i.e. without nick), and one with two lateral saw-cuts of 1·5 millimètre depth, leaving 4 millimètres of width at the bottom of the incision (the initial width was 7 millimètres). There was also a test-piece in each case with a central hole of 3 millimètres diameter, that is, the remaining section was the same as in the case of the nicked specimen. The diminution in section caused by the nick and by the hole was 42 per cent. Apart from the above the nicked specimens were identical with the plain specimens, thus a comparison was possible, the differences being only the speed of rupture and the nicks. The results of the trials were given in Table 23 (pages 1000–1001), and on examination it appeared that in the case of the plain specimens the energy per square centimètre of section required to fracture slowly was less than the energy required to fracture by impact, except in the case of phosphoric iron, which broke more readily by impact. The first portion of this conclusion agreed with that arrived at by Messrs. Stanton and Bairstow; the second portion was not indicated

TABLE 23.

(Mons. Breuil's Communication.)

Treatment of the metal.	Description of test-piece.	Nature of tensile test.	Apparent limit of elasticity per mm.² of the non-nicked section. Kgs. per mm.².	Breaking stress of the smallest initial section. Kgs. per mm.².	Elongation per cent. at rupture.	Reduction of area. $\frac{S - s}{S}$.	Energy required to break per cm.² of the smallest initial section. Kgm.
VERY MILD STEEL.							
Re-heated for 10 hours at 1000° C.	Without nick.	Slow.	20	31	31·5	0·68	48·0
		Impact.	—	—	29·0	0·74	77·5
Raw from the forge.	Without nick.	Slow.	28	38	36·4	0·73	75·5
		Impact.	—	—	31·3	0·72	107·0
Raw from the forge.	2 saw cuts 1·5 mm. deep.	Slow.	25	50	5·8	0·54	15·0
		Impact.	—	—	7·6	0·58	28·0
Raw from the forge.	One central hole 3 mm. diameter.	Slow.	23	46	4·0	—	9·6
		Impact.	—	—	3·7	—	34·0
MILD STEEL.							
Re-heated for 10 hours at 1000° C.	Without nick.	Slow.	23	51	21·8	0·54	60·0
		Impact.	—	—	20·9	0·56	77·0
Raw from the forge.	Without nick.	Slow.	35	61	24·5	0·45	84·0
		Impact.	—	—	25·0	0·51	106·0

Raw from the forge.	2 saw cuts.	Slow.	34	73	5·5	0·26	13·0
		Impact.	—	—	3·7	0·26	24·0
Raw from the forge.	One central hole of 3 mm. diameter.	Slow.	34	67	3·6	—	11·5
		Impact.	—	—	3·3	—	33·0
Hard Steel.							
Re-heated for 10 hours at 1000° C.	Without nick.	Slow.	37	75	13·6	0·36	53·0
		Impact.	—	—	16 0	0·39	71·0
Raw from the forge.	Without nick.	Slow.	56	89	11·5	0·22	55 0
		Impact.	—	—	17·5	0·33	106·0
Raw from the forge.	2 saw cuts.	Slow.	51	97	1·8	0·07	8 9
		Impact.	—	—	0·9	0·08	10·5
Raw from the forge.	One central hole of 3 mm. diameter.	Slow.	53	93	1·8	—	9·1
		Impact.	—	—	1·8	—	13 0
Phosphoric Iron.							
Re-heated for 10 hours at 1000° C.	Without nick.	Slow.	22	35	17·3	0·37	29·5
		Impact.	—	—	2·0	0·07	8·2
Raw from the forge.	Without nick.	Slow.	30	42	18·0	0·42	38·0
		Impact.	—	—	2·0	0·04	7·8
Raw from the forgo.	2 saw cuts.	Slow.	25	47	3·3	0·12	8·2
		Impact.	—	—	0·9	0·03	7·0
Raw from the forge.	One central hole of 3 mm. diameter.	Slow.	27	48	2·2	—	4·6
		Impact.	—	—	1·8	—	3·0

(Mons. Pierre Breuil.)
in their work. There were, therefore, exceptions in the comparison of slow and rapid tensile tests; there was not always parallelism in the results. This was why, in his opinion, it was desirable to make impact tests to put in evidence the properties of these dangerous metals. It ought not to be surprising that the work required to rupture nicked specimens was far less than that needed to rupture plain specimens, because the nick localised the deformation and therefore the volume of deformed metal was much less, but there was no proof that if the energy were referred to unit volume that the results would not be the same.

The tests with nicked specimens arranged the metals as to quality almost in the same order as those made with plain specimens, which also agreed with the conclusions of Messrs. Stanton and Bairstow. It must, however, be observed that the nicked specimens did not nearly so well put in evidence the brittleness to shock of phosphoric irons as the plain specimens did. In his opinion, therefore, impact tests should be made by the tension method with plain specimens identical with those that were used for ordinary tensile tests. This method of testing appeared to him preferable to that which depended on the flexure of nicked specimens. It was possible to measure the elongation and reduction of area in the same way as was done in ordinary tensile tests, and thus compare the results of sudden tension with slow tension.

In order to give an idea of the action of the various kinds of tests on these four steels, he had photographed the fractures, Fig. 39, Plate 31, and from them it was possible to observe the effect of impact on phosphoric iron. The corresponding test-pieces which had been fractured slowly and by impact, and those which were plain and with nicks had been placed side by side.

He called attention to the fact that the elongation and reduction of area for the same quality of steel were nearly the same whether the test were slow or by impact, it was therefore difficult to understand why the work required for fracture by impact was always greater than that needed for slow static fracture. Two hypotheses, however, could be made, which might assist in explaining this fact. First, the measurement of the work done by impact was less accurate than the measurement when the fracture was slowly carried out, because, in the former case, the losses due to the friction of the tup, by the vibrations, and by crushing of the ends of the test-pieces were included, and these losses might be considerable. Secondly, the heating of the portion of the test-piece in proximity to the fracture caused considerable loss of energy when the fracture took place by impact. The increase of temperature might reach from 40° to 50° C. Supposing that only 20 grammes of metal were heated, and taking the specified heat of steel at 0·1, the work required to produce this heat would be $50 \times 0{\cdot}2 \times 0{\cdot}1 \times 425 = 42{\cdot}5$ kilogramme-mètres. It would be seen that this loss was not negligible. In the slow tensile test the autographic stress-strain diagram took no account of this heating, which, moreover, did not occur in this form of test. If this amount of work were deducted from that measured in the impact test, in most cases the same amount of work would be obtained as in the slow tensile test. This did not include the special cases such as that of phosphoric iron.

In regard to Mr. Harbord's Paper, he was glad to find that the conclusions arrived at in connection with impact tests on nicked specimens fully confirmed those which he had already published. Mr. Harbord had examined with much care, very fully and quite impartially, the results obtained by four impact methods of testing, and was somewhat astonished to find that the results were discordant, and that the same method sometimes gave as much as 100 per cent. variation for the same metal. He (Mons. Breuil) had for the last five or six years pointed out to what a great extent these variations might lead one astray in the selection of metals. He had had occasion, in a Paper presented in 1904 to the Iron and Steel Institute, to show to what arbitrary conclusions impact tests with nicked specimens could lead, and he proved that making a nick of the same shape and of the same dimensions in geometrically identical test-pieces, of various kinds of metals, did not put those metals into the same condition as regards testing.

He had made the same statement in his written remarks in the discussion of the Paper by Messrs. Seaton and Jude, in December

TABLE 24 (*continued on opposite page*).

(*Mons. Breuil's Communication.*)

Quality of steel.	Average Breaking Stress. Kgs. per mm².	Average Elongation per cent. $L^2 = 66 \cdot 67 S$.	Barba-Leblant method. Weight of tup—25 kgs. Energy to break T_{mean} per cm² of section. Kgm.	Variation per cent. $\frac{T_{max.} - T_{min.}}{T_{mean.}}$
Martin steel plate for boiler fire-boxes	34	36	2·25	84·6
Martin steel plate for boilers	45	31	3·25	175·0
Martin steel plate for car-axles	50	28	4·65	92·8
Martin steel plate for locomotive tyres	76	17	0·42	41·8
Thomas steel, marked A	42	38	—	—
" " " B	42	31	—	—
Crucible steel, marked A	44	29	2·18	33·9
" " " B	46	27	0·63	150·6
Gun steel, marked A	56	25	2·12	8·6
Crucible steel, marked C	64	20	0·31	80·4
Crucible steel, about 5 per cent. Nickel	93	13	—	—
3 per cent. Nickel steel for axles	—	—	—	—
6 per cent. Nickel steel for axles	61	21	—	—

(*concluded from preceding page*) TABLE 24.

(*Mons. Breuil's Communication.*)

Frémont method. Weight of tup—10 kgs.		Charpy method. Weight of tup—18 kgs. (repeated blows).		Vanderheym method. Weight of tup—18 kgs.	
Energy to break T_{mean} per cm² of section. Kgm.	Variation per cent. $\frac{T_{max.} - T_{min.}}{T_{mean.}}$	Energy to break T_{mean} per cm² of section. Kgm.	Variation per cent. $\frac{T_{max.} - T_{min.}}{T_{mean.}}$	Energy to break T_{mean} per cm² of section. Kgm.	Variation per cent. $\frac{T_{max.} - T_{min.}}{T_{mean.}}$
41·0	29·3	26·10	99·0	12·75	59·4
35·2	30·3	23·5	9·4	20·5	82·9
27·5	43·9	22·5	60·0	15·0	43·9
29·2*	37·5	9·0	0·0	2·2	30·8
—	—	—	-	4·75	37·73
—	—	—	-	3·05	43·40
21·0	68·4	19·0	23·5	7·5	8·3
—	—	16·7	42·3	6·25	14·4
49·5	20·1	13·5	0·0	5·5	9·6
4·3†	22·3	5·7	76·0	2·0	22·3
--	—	--	—	1·15	87·0
—	—	--	-	17·5	88·0
—	—	--	—	22·0	8·0

* Test-pieces without nick. Mons. Frémont does not nick the test-pieces when the breaking stress exceeds 50 kgs. per mm.².

† Nicked by mistake.

(Mons. Pierre Breuil.)

1904,* and he had not changed his opinion since then, In a recent work published in the "Revue de Mécanique" he had proved that nicked specimens showed great variations in various metals which only exhibited slight differences when the impact tests were made with plain tensile specimens, and further, that these nicked impact tests did not put in evidence the brittleness of phosphoric metals, although the tensile impact tests showed this brittleness very clearly. (*See* the Discussion on the Paper by Messrs. Seaton and Jude, 1904.)

He was pleased, in order to confirm the results obtained by Mr. Harbord, to be able to submit a series of trials he had made with a variety of steels, using four different methods which were employed in France. The four methods were: the Barba-Leblant, Frémont, Charpy, and Vanderheym. These tests had already been published in an Appendix to "Martens' Work on Tests of Materials," which had been translated under his direction.† The results were given in Table 24 (pages 1004–1005), and the impact tests had been placed alongside the static tensile tests for comparison.

The Barba-Leblant method consisted in making two acute nicks on opposite sides of a test-piece 30 mm. by 12 mm., which was held as a cantilever, and was broken with one blow. The nicks were 0·5 mm. deep and were made with a knife-tool. Mr. Harbord had described the Frémont method; it was therefore unnecessary for him to refer to it further. The Charpy test-piece had only a single nick produced by a drill of 4 mm. diameter, and it was supported at both ends, and the section at the bottom of the nick was 600 mm^2. In this method fracture was produced by a series of blows, hence there was an uncertainty in the measurement of the work done. Finally, the Vanderheym method employed a test-piece 20 mm. by 20 mm. in section, which was placed in a lathe and a nick was made with a tool having an angle of 90°; the section at the bottom of the nick had a diameter of 16 mm. The test-piece was held as a cantilever, and was broken with one blow. In the Table referred to the test-

* Proceedings 1904, Part 4, page 1205.

† Edited by Gautier-Villars, Paris.

pieces for the same metal had been obtained from one ingot, which had been carefully prepared, and they were cut out side by side from the bars obtained from this ingot. For each kind of steel six pieces had been tested by the Charpy method; twelve by the Barba-Leblant; twenty-four by the Frémont; and six by the Vanderheym. It would be observed that there was a great difference in the various methods in the amount of work required for fracture, and that the various methods did not place the respective steels in the same order; and further, each impact method showed great variations in the results obtained with the same steel. He could quote many other examples giving similar results. A test method could not be accepted, unless it gave results having small variation for the same material. The methods referred to above must therefore be abandoned as regards their use for the selection of metals, and if it was desired to determine the resistance to shock the tensile impact method with plain specimens ought to be adopted. Methods requiring the nicking of the specimens should be reserved for pieces which had screw threads, or for any analogous cases, and it would be then necessary to try the pieces with nicks of exactly the same shape as those that would be used in actual service. It was extremely difficult to evaluate the deformation of a metal in the neighbourhood of a nick, and hence it was difficult to determine exactly the work required to deform the metal.

He was pleased that Mr. Harbord had called the attention of engineers in England to the great danger there was of adopting these new impact tests for metals, which were all the more dangerous because they appeared—although erroneously—so simple.

Mr. Henry R. J. Burstall wrote that the results given in Mr. Harbord's Paper were very disappointing when looked at from the point of view of those who had to specify materials, and also for those who had to make tests with a view to finding out whether a particular material was suited for a special purpose, or as to whether it would pass a given specification. One could hardly think that the steel dealt with as described in the Paper had varied so much in quality as the results of the shock tests showed, and one was

(Mr. Henry R. J. Burstall.)
therefore almost bound to come to the conclusion that the variation must have been in the method or the carrying out of the tests.

Shock tests should throw a great deal of light on the behaviour of materials, and no doubt did so; but as in most cases tests had to be made on a very small proportion of the material, one would have to be very sure of the test before condemning a batch of material on the results of any test in which there was the possibility of so much difference, not only between the results obtained by slightly different methods, but on tests carried out by the same method and observer. What was wanted was a test which could be relied on to give the same results, within a fair margin, when made by different observers and on different machines; until this was made a certainty it was impossible to specify such a test or to provide proper machinery for carrying out these tests.

A shock test on a notched bar had a great deal in its favour; it was simple, quick, and only involved the making of cheap and small specimens, but it was quite a question whether the notching did not introduce a condition which was not well understood, and which made the test one which departed rather widely from the conditions under which materials were used, and was therefore a test which was too hard to insist on except in special cases.

It would be interesting to see whether a properly-made tensile test, one in which the true elastic limit and the yield-point, as well as the breaking load, extension and reduction of area were determined, would not give an indication of a material being abnormally brittle. He thought it would, but of course it was to be remembered that the ordinary works test, which, from the circumstances of the case, must be made quickly, would probably not give the true elastic limit with sufficient accuracy to show up the defect. Some supplementary test to show up defective and abnormal material would be of great use, but it must be one which could be relied on, which could be repeated by other observers, and which would not condemn material which was really suitable for the purpose for which it was made.

Shock tests would be of more use for investigating failures of material and new materials than in the testing of materials to be used in construction, and were therefore even at present most valuable. It was unusual to find material in the plate or bar form (unworked) of the brittle character which was shown up by shock test and not by the ordinary tensile and bending tests. This character was most often found in material after it had been worked to form through improper mechanical or heat treatment, and so would escape any tests except the pressure or other working tests made on the finished work; these would probably not show up the particular form of brittleness, and it would be asking too much to specify that plates, etc., should be subjected to special treatment and tests to show whether or not they were liable to be rendered unreliable by bad treatment.

Mr. John A. Davenport wrote that the authors were to be congratulated upon the establishment of the result which came from the numbers given on page 909; and upon the ingenious method adopted to arrive at them. No doubt the theoretical and experimental values would be brought into closer agreement as the number of experiments increased.

In regard to the effect of the dimensions of the specimen (pages 913–914), he would suggest that the 0·4 inch diameter notch be taken with body diameters greater than 0·706 inch. The object of the notch, he gathered, was to localise the destructive effect of the impact, so that it should be concentrated at the section where fracture took place. This being so, it would seem better to take the energy per square inch of fractured area rather than per cubic inch. Then having found the body diameter such that all the energy of the blow was expended at the notch, the energy per square inch of fractured area would be the same for all sizes of specimen. Such results, if they were consistent as expected, would have a greater claim to the name standard than those given on page 914.

Lt.-Colonel Thomas English wrote that a description of a method which was devised and put into practice, just forty years ago, for the tensile test, under impact, of full-sized specimens of material intended for armour-bolts, might still be of interest;

(Lt.-Colonel Thomas English.)
especially as he saw no reason to modify the conclusions then arrived at. He therefore reproduced the first three paragraphs of a Paper "On the Statical Pressure produced by the Impact of a Falling Weight" contributed by himself to Volume XVIII of the Professional Papers of the Corps of Royal Engineers, 1870, page 122, which embodied a short description, with an illustration, which is reproduced in Fig. 40, of the apparatus used, as follows:—

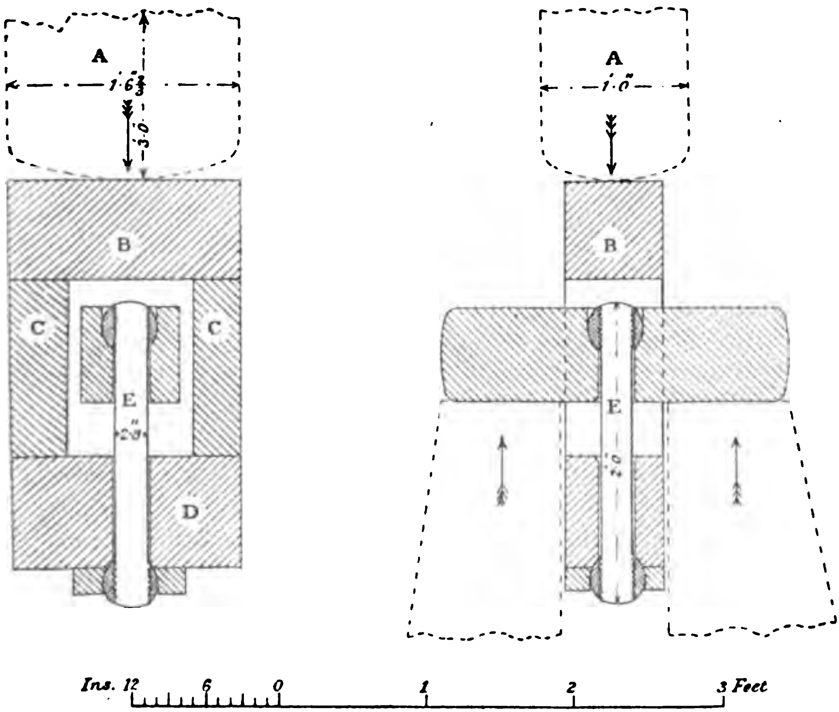
"1. In the course of the year 1867, it was found by the officers of Royal Engineers engaged in the construction of iron defences, that armour-bolts, although made of iron which well withstood the ordinary tests, sometimes failed in an unaccountable manner; and it was determined to try whether they could be tested in a way more reliable, and more resembling actual practice, under the blow given by a falling weight.

"2. After some experiments the apparatus shown in Fig. 40 was devised and erected at the various contractors' works. It consists of a cross-bar, supported firmly except at the centre, and provided there with a hole fitting the head of the bolt E, to be tested, which hangs vertically from it. A block, D, also with a hole through the centre, surrounds the lower part of the bolt, and is supported by the nut; vertical pieces, C, C, rest one on each end of this block, and these rise up above the level of the cross-bar. Another block, B, resting on the upper ends of the vertical pieces, completes the apparatus; and a weight, A, moving between guides, is allowed to fall vertically upon the last mentioned block, the impact being transmitted through this and the vertical pieces to the lower block, and thence through the bolt to the supports. The bolts tested are generally about two feet long and nearly three inches diameter, and when of good quality it is found that a weight of one ton, falling through a height of thirty feet, will pull one of them in two in six or seven blows. This apparatus is now regularly employed for testing samples of all armour-bolts made for the War Department, and a copy of it, recently erected by the Admiralty, is, I believe, to be seen in Chatham Dockyard.

"3. In the course of the experiments made with this apparatus, it was, however, noticed that many more foot-tons of work were always applied to break a bolt than the number which it would give out before breaking, under the steady strain of a hydraulic testing machine. It was also noticed that the work accumulated in one heavy blow was much more effective than the same amount

Fig. 40.

Method of conducting an Impact Tensile Test on Armour-bolts (1867).



applied in a number of light ones; and that any increase in the mass of metal interposed between the falling weight and the bolt appeared to lessen the effect upon the latter. From these, and various other indications, it was judged that a considerable amount of the work applied was absorbed in the mass through which the blow was transmitted to the bolt."

(Lt.-Colonel Thomas English.)

The remainder of the Paper was a mathematical investigation, which could not well be abridged, of the conditions determining the maxima of tensile and compressive stresses produced during an impact. The conclusions arrived at were, that, when proper precautions were taken to eliminate cross-breaking stresses, the results of a tensile impact test on full-sized specimens differed in no way from those obtained in a hydraulic testing machine, that the impact test was thoroughly trustworthy, and that the greatest tensile or compressive stress, during an impact under given conditions, could be calculated beforehand.

A crucial experiment, confirming these views, was made at Shoeburyness on 4th February, 1869, when a target consisting of three iron armour-plates, each 5 inches thick, separated from each other by 6-inch layers of a concrete material, was subjected to a single blow from a 12-inch Palliser service shot, weighing 605 lb., with a striking velocity of 1,165 feet per second, and a striking energy of 5,694 foot-tons. The target was supported by abutments placed behind the ends of the front plate, which projected horizontally beyond the other plates, and these latter were held up to their work solely by six soft-iron armour-bolts, each 32 inches in length and 2·8 inches in diameter in the shank, screwed at both ends with a thread of semicircular section 3 inches in diameter. The number and size of these bolts were calculated in accordance with the data furnished by the impact test. Each bolt was provided with two spherical nuts, 4½ inches in diameter, the front nut fitting into a recess formed in the face of the front armour-plate, and the back nut being held in a coiled iron washer with a spherical seating against the back of the rear armour-plate. The diameter of the bolt holes in the middle and rear plates was enlarged to allow about half an inch clearance round the bolt. The result of the trial was that the shot remained imbedded in the target, with its point just touching the front face of the rear plate. No bolts were broken, but all of them were, for the first time on record, permanently stretched, to an average length of 33·7 inches. A fully detailed account of this trial is published in the same volume XVIII of the R.E. Professional Papers, page 268.

As a result of the experiment, this pattern of armour-bolt and nut was adopted for all the armoured coast defences belonging to this country, and a sample length, cut from each bar intended for the manufacture into bolts, was tested in an apparatus of similar arrangement and size to that shown in the illustration. The testing was carried out, on an aggregate of a good many thousand samples, over a period of fifteen or sixteen years, until the coast fortifications were completed. The only alteration made from the original design of the apparatus was that, as it proved to be unnecessary to use finished bolts for testing, the test lengths were simply turned down to 2·8 inches diameter, and their ends secured by steel wedges fitting conical holes in the blocks B and D. This method proved satisfactory under the conditions of the test. It was distinctly necessary to test a full-sized sample from every bar, as any seam of hard material, not concentric with the bar, produced the same effect of cross-breaking stress as would be caused by a nick, inducing a crystalline fracture, with a serious reduction of elongation. It was found easily practicable to specify a contract standard for acceptance of 40 per cent. reduction of area at the point of fracture, with a fibrous fracture throughout, under this test.

Professor Robert H. Smith wrote that it did not seem probable that testing materials by impact could be reduced to an art that gave regular results, until we remedied our present lack of scientific knowledge of the real intimate nature of the stressing effects produced by collision. A search through the treatises on dynamics in English, French and German resulted in finding only the most meagre references even to the most elementary laws of collision, and these applied only to impossibly simple supposititious cases. A résumé of what had been done would be found in Chap. X in Poynting and Thomson's "Properties of Matter." St. Venant's mathematical investigation seemed to be the only serious attempt to come to close quarters with the problem. It would appear impossible to give any very accurate physical interpretation to the test results obtained in impact testing machines of the forms at present in use, because these were designed apparently without consideration of

(Professor Robert H. Smith.)
what became of the energy of the blow. After the blow this energy appeared in various forms, which might be classified in four main divisions :—

(1) Visible kinetic energy in the hammer or tup. This is usually measured; and what is tabulated as the "energy of the blow" is the excess of the original kinetic energy of the tup before the blow over the kinetic energy that remains in the tup after the blow.

(2) Vibration, heating and straining of the striking tup.

(3) Part of it passes as a wave of resilient and vibratory energy through the test-piece, through its supports, through the frame, bed-plate and foundation of the testing machine, and into the earth, where it spreads indefinitely and is dissipated.

(4) Part is spent in deforming, and finally breaking, the test-piece.

As regards (1), the process of deducting this remaining kinetic energy from the original total, first adopted on the introduction of the ingeniously simple Izod machine, involved the gratuitous assumption that this excess had taken no part in stressing the test-piece. It was commonly known that, even in the quiet testing of material, the final rupture was accompanied by a resilient kick, which was never quite wholly suppressed even in the very slow drawing out of very plastic metals. This kick meant a partial recovery of the work done upon elastic straining. The energy so recovered might be legitimately surmised to be much greater in sudden impact breakage than in slow quiet fracture. A certain proportion of this—perhaps impossible to estimate fairly—inevitably appeared as kinetic energy in the striking tup.

As regards (2), this part was assumed to be nil in the ordinary consideration of impact tests; but it was an evident error to imagine that a collision between two bodies stressed and strained only one of them. The integral stress was, of course, exactly the same in both. In some of the testing machines in use it was questionable whether the strain in the striking tup was not greater than that in the test specimen. If it were so, then the part of the energy of the blow spent in straining the tup was greater than that similarly spent on the test specimen. The construction ensured that this strain in the tup should be wholly, or nearly wholly, elastic; but this did not in the least affect the question of the proportion in which the whole work done in straining up to the instant of severest stress was divided between tup and test-piece. The resilient energy so lodged in the tup was, in the case of fracture of the test-piece, probably wholly developed subsequently in the form of vibration: possibly a small part of it in visible kinetic energy. The design of the striking tup might quite certainly be improved in the direction of lessening the proportion of the energy of the blow spent in straining it.

As regards (3), the waves of energy spoken of were transmitted at very high velocity, probably that of sound, and were partially reflected at the supports and at all the surfaces where discontinuity of form or of material occurred. In proportion as the reflection at the supports was more complete, less energy was lost to the foundation for dissipation in the mass of the earth. In some of the machines used the path of this vibration from the supports to the massive bed-plate was so tortuous and so kinematically "rickety" or "shaky" that a large proportion of the energy must have been lost in this way. The magnitude of this loss evidently depended very largely upon the small details of the design of the machine; and the writer ventured to express the opinion that the great variations exhibited in Mr. Harbord's Paper were in large measure due to differences in this respect and corresponding differences in the relative importance of this loss (3).

Assuming for the moment that the reflection of these vibrations at the supports of the test-piece was complete and perfect, the influence exerted by the existence of these vibrations through the test-piece upon the stressing caused by the impact depended largely upon the time they took to travel to and fro between the striking point and the supports. If they travelled to and fro many thousands of times during the contact of tup and test-piece, their influence in modifying the main stresses might be inappreciable; if they travelled to and fro only very few times during this contact, their influence might be great. If the impact were finished before the wave had time to complete one excursion, the character of the collision was completely altered. The time actually occupied by one excursion

(Professor Robert H. Smith.)
of this wave depended not only upon the distance between striking point and supports but also upon the shape of the test-piece and upon whether the transmission was mainly by shear, as in beam test-pieces, or mainly by direct tension and compression. The time during which contact in the collision lasted was physically determined by an equally complex combination of special conditions; as was also the amount of energy (resilient and kinetic) stored in the form of vibration per inch length of the wave. If the speed at which these vibrations travelled equalled that of sound, they advanced through the material many times faster than even the high striking velocity of 1,800 feet per second mentioned by Sir Robert Hadfield as causing the plastic crushing of the shot-cap which he exhibited.

The 30 to 50 per cent. difference shown in Fig. 8 (page 902) of Messrs. Stanton and Bairstow's Paper between the work done in static and in impact tests might be ascribed mainly to these losses of energy of blow. The important point to note was that their ratio to the total energy of blow depended in so complex a manner upon so many small details of the design and workmanship of the machine, that this ratio could not be expected to be nearly the same in different machines. Even in the same machine, unless the workmanship were very good and the joints and other parts very substantial, one would expect considerable variations in this ratio.

It seemed to be insufficiently recognised that the severest stressing in a collision occurred at the period of greatest closure between the colliding bodies, that is, before the elastic recoil began. The laws of collision during this first stage of the whole contact were very much simpler than those ruling the recoil or restitution during the second stage. In three articles which appeared in "The Engineer," on 23rd February, and 9th and 23rd March, 1906, the writer had attempted to develop the laws of collision of two masses, and he could not but think that much more definite and accurately interpretable results would be obtained from an impact testing machine, designed so that its dynamic action involved only the collision between two freely suspended masses of as simple a form as possible—suspended in such fashion as to transmit little or no vibration to the frame and foundation. The formulæ for the conversion of external kinetic energy and the maximum force at the instant of greatest closure were quite simple, and it was these only that were really relevant in testing for strength.

In the third of the above articles the writer showed that, excluding the influence of time-effects, the stress-strain diagram to be expected from repeated collisions of semi-elastic, semi-plastic bodies would be of the general form shown in Fig. 41, with straight edges and sharp corners; while, allowing for the time-effects of the development of plastic strains, this diagram would be modified by curvature of the edges and rounding of the corners somewhat as in Fig. 42. He there gave formulæ for the various physical effects of collision based upon the form of diagram Fig. 41. The area of

Stress-Strain Diagrams.

FIG. 41.

Semi-elastic, Semi-plastic Bodies.

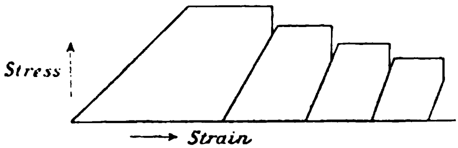
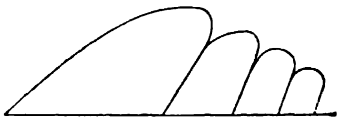


FIG. 42.

Plastic Bodies.



each loop measured the portion of the energy of one blow which was lost partly through heating by hysteresis and partly in the work of drawing the molecules asunder.

There were two comparatively simple theories of impact. The one assumed that after the first instant of contact the various stages of the gradually developing strain and stress spread through the impinging bodies (uniformly or otherwise according to their shapes) with a speed which was practically infinite in comparison with the rate at which the impinging surfaces were deformed. When the impinging masses were equal in size and physical qualities, this led to the result—

Total pressure between them at time of closest contact

$$= P = S\sqrt{\frac{E\,M}{2}}$$

where S is the striking velocity, M the mass of each body, and E the

(Professor Robert H. Smith.)
resistance modulus measured by the ratio of the pressure between the bodies to the approach (after first contact) of their mass-centres. This resistance might be partly elastic and partly plastic, and the formula assumed that E remained constant up to the maximum pressure P.

The other theory assumed that after first contact a state of compression instantly arose at the touching surfaces which remained uniform and which spread throughout the masses at the speed of transmission of sound waves, the exchange of momentum during the impact taking place by the gradual spread of the new condition of velocity and strain into more and more mass, and not by the change of that condition except as the result of the reflection of the wave at the surfaces of the bodies. This theory, applied to the end-on collision of equal-sized parallel bars of the same material, gave, during the first stage of the impact, that is, during the first excursion of the wave of new momentum and strain, the

$$\text{Total pressure } P = \frac{S}{2}\sqrt{E\,M}$$

where M is the mass of one bar and E is the modulus of elasticity.

These two formulæ coincided, except that in the one E had double the value that it took in the other, which was really due to the contraction in the one case being measured between the centres of the bars, and in the other over their extreme ends. Within the limits of their application, which coincided with the range of the straight-line law for E, or to the top of the oblique line in Fig. 41, the two theories thus yielded practically the same maximum pressure. They both made this proportional to the striking velocity and to the square root of the striking mass, that is, to the square root of the striking kinetic energy.

These formulæ thus corresponded with the ordinary expression for proof resilience $\frac{f^2}{2E}$ quoted by Dr. Stanton; but it must be remembered that they took these simple forms only for the case of the collision of two entirely equal and similar masses. For unsymmetrical conditions of collision the formulæ took less simple forms, and the assumptions on which either theory was based would no longer apply with close approximation.

As, however, all these formulæ made the maximum pressure proportional to the striking velocity, while this maximum determined the crippling of the material, it would seem safer to take the square root of the energy of the crippling impact, rather than the energy itself, as an indication of the strength of the material.

The results of the various experiments that had been made upon the impact of spherical balls were complicated by the fact that after first contact the area of contact gradually increased when curved surfaces impinged. Fortunately there was no need to introduce this element of complication into the action of impact testing machines, although it was not actually avoided in some of those in use.

Mr. C. HUMPHREY WINGFIELD wrote that it was difficult to realise the vast amount of highly specialised labour involved in carrying out and collating the experiments described in these two important Papers. Before judging results, it was of the highest importance that the reliability of the methods of experiment by which they were obtained should be beyond question. Mr. Harbord's investigation apparently ruled out all the methods he had examined, except two—those of Izod and Kirkaldy. While the latter gave rather more uniform results than the former, the Izod machine appeared more suitable for general shop use. He regretted that the scope of Mr. Harbord's Paper did not admit of trying the same materials with the Sankey machine for gradually applied alternate stresses; as such diagrams, for instance, as Fig. 189 (page 302), Proceedings 1907, showed that the results were exceptionally uniform in character; comparable indeed in this respect with Messrs. Stanton and Bairstow's Figs. 9, 10 (pages 904–905), 13 (page 910) and 22 (page 918). Such results fully justified the conclusion these gentlemen came to (page 919) that steel was more homogeneous, as now manufactured, than was generally realised.

He would be grateful for further explanation of the grounds for the conclusion (line 13, page 911) at which they had arrived, that the limiting resistances found by tests similar to Kirkaldy's, but with V instead of U notches, were in agreement with those found by

(Mr. C. Humphrey Wingfield.)

direct impact. The shape of the curves in Figs. 9 and 13, for instance, certainly had a similar appearance; but, unless the same material were used for each, he did not see how such a definite and important conclusion had been reached. The agreement in the character of the "curves" in Figs. 7 and 8 (page 902) was satisfactory and seemed to suggest that nearly identical results could be obtained from either method, provided a suitable scale were empirically found for each machine's records.

The authors had in some degree rehabilitated the reputation of "careful" static tests (page 903); but, if this qualification involved anything like so many observations as were indicated on the curves in Fig. 6 (page 901), for instance, he thought that, for the first object named on page 890, machines which could be used as easily as those of the Izod and Sankey types would hold their own. Fig. 10 (page 905) especially showed the superiority of such tests to those requiring a great number of blows or alternations. It was apparently possible, by the Sankey method, to detect previous overheating of a specimen.* He was not aware that this could be done by any of the other methods mentioned in either Paper. Such a power would be invaluable when examining the causes of engine breakdowns. Messrs. Stanton and Bairstow qualified their approval of the practical application of the "common interpretation of resilience" by stipulating that the real elastic limit should be known (page 919). Often only one, or possibly two specimens were placed in the hands of an experimenter. In these circumstances it was not easy to see how to obtain the real elastic limit.

He would like to ask if Messrs. Stanton and Bairstow would be good enough to explain further two points about the ingenious machine shown in Fig. 5 (page 897):—(1) How was the sleeve carrying the lower end of the specimen supported during a compression blow? (2) How was the up-and-down motion of the connecting-rod, seen in front of the left-hand view, converted into the horizontally rotating one of the sleeve (he supposed the reference on page 896 to the "rotation of the cross-head" was a slip)?

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* *Engineering*, 27 December 1907, page 882.

Messrs. STANTON and BAIRSTOW, in reply to the Communications, wrote that their conclusions that the limiting resistances to impact of notched specimens under repeated bending impact were in agreement with those obtained from tests of plain specimens under alternating direct impact, referred to by Mr. Wingfield, were based on the limiting positions of the curves in Figs. 12 and 13 (page 910) in which the results of the two methods were plotted. These limiting positions as given by the intersection of the curves with the vertical axis in Fig. 12, and by the ordinates of the horizontal parts of the curves in Fig. 13, gave quantities, the *relative* values of which, for corresponding materials, were approximately the same. There had been no difficulty, in either the single- or the many-blow method, in detecting low shock resistance due to overheating, the result of which, as given in the example quoted at the beginning of the Discussion, was most marked. In reply to Mr. Wingfield's question as to the method of support of the specimen in alternating direct-impact during the compression blow, this was indicated in the left-hand plan in Fig. 5 (page 897) which showed that the outer sleeve had a bridge to which the lower end (during compression) of the specimen was attached. The up-and-down motion of the connecting-rod produced semi-rotations of the sleeve backwards and forwards. The motion through the "dead point" was effected by giving the sleeve a high initial velocity, so that its inertia was sufficient to carry it over.

The authors were much indebted to Mons. Breuil for his valuable contribution to the Correspondence. The fact that Mons. Breuil had not found an agreement between the work done in static and impact tests on phosphoric steels was extremely interesting. It was possible that in such cases the single-blow tensile impact test on a plain specimen which Mons. Breuil recommended would give better results than those obtained by the authors when using this method for ordinary steels.

[*Further Note by* Dr. STANTON *before going to press.*—With reference to Mr. Blount's criticism (page 988) of the analyses (page 899), the authors wished to point out that all the material used in this research was obtained in the form of drawn bars $\frac{7}{8}$ inch diameter, so that the tensile results might be higher than would be expected from steels of the given composition in its

(Dr. Stanton.)

ordinary state. In the majority of cases there were three bars of each material, and on the receipt of the bars a tensile test was made on a specimen cut from each bar, to see if they were of uniform quality. A complete analysis was also made from one of the bars, and it was not considered necessary to repeat this for the other bars if the tensile tests agreed.

In one case, however, that of the material denoted as No. 5, "Best English Wrought Iron," the carbon appeared to be extremely variable in quantity, for, according to the analysis given (page 899), this material contained 0·195 per cent. of carbon, whereas the specimen supplied to Mr. Blount was found by him to contain only 0·07 per cent., a result with which the authors agreed.

Other results in the Table of analyses to which Mr. Blount took exception were the manganese in No. 5 "Best English Wrought Iron" which he stated to be 0·655 per cent. as against the 0·005 per cent. given in the Paper, and the phosphorus in the No. 6 "Swedish Bessemer Steel" in which his result was 0·074 per cent. against the 0·02 per cent. given in the Paper. With reference to the former, the fact that the material in question was wrought-iron had been verified by microscopic examination, and in view of this a manganese content of 0·655 per cent. would be most unusual. Both of these determinations had been made again at the National Physical Laboratory on other samples from the bars in question, and agreed precisely with the previous results, so that in these cases the authors felt satisfied as to the correctness of the figures given in the Tables.]

Mr. Harbord wrote, in reply to the Communications, that he was glad to find that Mons. Breuil's work confirmed his experiments, although he would have been better pleased if, as the result of the great amount of attention which had been given to impact testing in France, Mons. Breuil had been able to suggest a method of transverse impact testing that could be relied upon to give concordant results.

He agreed with Mr. Burstall that there was a great deal to be said in favour of shock tests, and he lived in hopes that some simple impact testing machine, either on lines suggested by Messrs. Stanton and Bairstow, Mr. Blount, or other experimenters, would be demonstrated in the near future to be thoroughly trustworthy.

With regard to Mr. Wingfield's remarks he quite agreed that impact testing might be most useful, provided always it was supplemented by other tests, and that a large number of duplicate tests were made. Mr. Wingfield would find the results of tests by the Sankey method given in Appendix II (page 969), and he regretted that he was not able to obtain these results in time to have them printed before the Paper was read.

The Institution of Mechanical Engineers.

PROCEEDINGS.

DECEMBER 1908.

An ORDINARY GENERAL MEETING was held at the Institution on Friday, 18th December 1908, at Eight o'clock p.m.; T. HURRY RICHES, Esq., President, in the chair.

The Minutes of the previous Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following forty-nine candidates were found to be duly elected:—

MEMBERS.

HAWKE, GEORGE RICHARD WILLIAM,	Perth, W. Australia.
MAY, WALTER, R.N.,	London.
RANA, Colonel KESHORE NARSINGH,	Nepal.
SAINSBURY, HENRY CECIL BAYLEY,	Bath.
SEHMER, EDUARD GEORG,	Saarbrücken.
SHARP, JOHN,	Glasgow.
THORNTON, CHARLES JAMES,	Havana.

ASSOCIATE MEMBERS.

ANDERSON, JAMES,	Manchester.
BRETTELL, JOHN ORME,	Worcester.
BROWN, HERBERT,	Dover.

Buckham, Edward Howe, . . .	London.
Campbell, Alexander William, . .	London.
Durnford, Thomas Joy, ...	Buenos Aires.
Gardner, Alfred Charles, . . .	London.
Giles, Douglas Edgar Edwin, . .	Auckland, N.Z.
Hart-Davis, Hugh Vaughan, . . .	Manchester.
Hilton, George Maxwell Brooke, . .	London.
Hinchliff, James Arthur, . . .	Worcester.
Hodges, Herbert Furmedge, . . .	London.
Johnson, Frederick Samuel Lovick, .	Sylhet, India.
Manuel, Cecil Osmond, ...	Budge Budge, India.
McCarthy-Jones, Christopher Howel, .	Rugby.
Moores, John, ...	Manchester.
Nettle, Henry, ...	Camborne.
Peacock, Joseph Frank, . . .	Bristol.
Pearsall, Ralph Howard, . . .	Chelmsford.
Peyton, William Christian, . . .	London.
Pidgen, Albert, ...	London.
Platt, Ralph Ernest, Lieut. R.A., . .	Tempe, O.R.C.
Pyne, Frederick Dennis, . . .	Rangoon.
Rickie, James Hepburn, ...	Rangoon.
Riggs, Arthur Levi, ...	London.
Saunders, Frederick Walter Theodore, .	Rangatua, N.Z.
Sayer, Sydney, ...	Khartoum.
Taite, Geoffrey Charles, . . .	London.
Waldron, Frederic Barnes, . . .	Southampton.
Wilton, William, ...	Rotterdam.

GRADUATES.

Bentall, Anthony Frank, . . .	London.
Clarke, George Puleston, . . .	Devonport.
Fenton, Colin Stanley, ...	Sheffield.
Harris, Colin Harman, ...	London.
Hartree, Raymond, ...	Doncaster.
Hooper, Sidney Herbert, . . .	Liverpool.
Kent-Norris, Henry, Jun., . . .	Devizes.

LAIDLER, CHARLES REMFRY, . . .	Gibraltar.
MILLER, LEONARD CHALLINOR, . . .	London.
SEYMOUR, CHARLES MARK, . . .	Manchester.
WHALLEY, HERMES DE, ...	Bristol.
WILLIAMS, JOHN REEVE, ...	Wembley.

The PRESIDENT announced that the following three Transferences had been made by the Council:—

Associate Members to Members.

DARLINGTON, SEYMOUR NANCE, . . .	Birmingham.
NEACHELL, EDWARD JOHN, . . .	Liverpool.
STORIE, GEORGE BRIGHT, ...	Rochdale.

The following Paper was then read and discussed:—

"Typecasting and Composing Machinery"; by Mr. L. A. LEGROS, *Member*, of Watford.

The Meeting terminated at a Quarter-past Ten o'clock. The attendance was 110 Members and 91 Visitors.

TYPECASTING AND COMPOSING MACHINERY.

BY MR. L. A. LEGROS, *Member*, OF WATFORD.

CONTENTS.

Introductory Note.—Printing surfaces may in general be divided into three classes :—

(1) Etched and engraved surfaces in which a drawing or manuscript is produced by lines which are cut below the general surface of the plate. These lines are filled with ink and a damped sheet of paper laid on the face of the plate. The plate and paper are then passed through a roller press in which a blanket is interposed between the roller and the paper and forces the latter into the depressions in the plate;

(2) Lithographed surfaces, in which there is no appreciable difference of plane, but the parts to receive the ink are greasy and the parts to refuse it wet; and

(3) Typographic surfaces, in which the printing surface is in relief and may be inked by means of an inking roller. In the present Paper the author deals with those typographic surfaces which are produced directly by movable type or indirectly by means of movable matrices. The woodcut and the process block, by which the former is now almost entirely superseded, do not present features of great mechanical interest, and do not fall within the scope of the present Paper.

History of Typography.—The consideration of the evolution of typecasting and composing machines from the earliest printed works to the present day presents the peculiar difficulty, that whereas the records of all other arts and trades are effected by means of typography, yet the records of its own progress are singularly deficient, and, for a trade of such antiquity, the data available are most meagre.

In the earliest printing, in the early part of the 15th century (apart from that of the Chinese which we need not consider), wood blocks were used for the whole of a page, and at a later stage these were replaced by separate wood characters. These proved

NOTE.—By request of the author, in the illustrations where two or more views are shown they are placed in the position usually adopted in Continental publications.

weak, and the substitution of metal (lead and tin) was a natural sequence. The type so made were not very accurate, and could not be secured by locking up as at the present day. To enable them to be handled when set up, the shank was pierced with a hole and the types threaded together with a thread or wire. As the individual type required much hand work in their making the printer could not carry a large stock, and books were at first printed page by page, the type being distributed after the requisite number of impressions had been taken from each page.

The paper used in the early days of printing was hand made, much tougher and better capable of adapting itself to the inequalities of the printing surface than the highly-glazed, machine-made papers of today. This old paper, owing to its power of adaptation to the inequalities of the printing surface, is now much sought after by artists for printing etchings. The hand-made paper of long fibre, used damp and with an elastic back, gave an impression in which the breadth of the actual lines forming the face of the type was widened, and was in fact a parallel to the actual face cut by the punch cutter. This defect contributed in a rather marked degree to legibility, as it tended to thicken the hair lines and thus render more pronounced the difference between the less dissimilar letters. The highly-glazed papers of today, of short fibre, containing much sizing and mineral matter, are not adapted for printing from such irregular surfaces; their want of flexibility requires a hard and true backing, and hence increased accuracy in the printing surface to obtain a uniformly sharp impression. Modern calendered paper has however rendered possible the reproduction of the admirable process blocks with which the current high-class papers and periodicals are illustrated. The depth of the grain in the process block is so small that the old papers could not be used effectively.

From the earliest days of printing to the present day the thickness of paper used for ordinary book work, however, has kept approximately between the same limits.

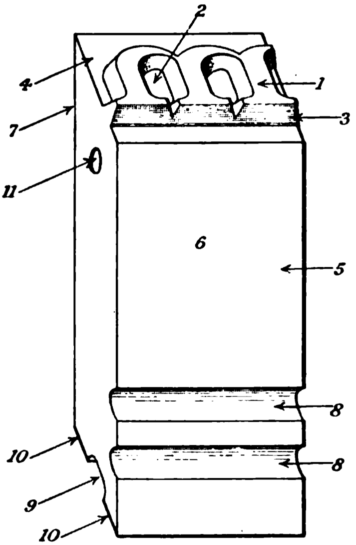
DESCRIPTION OF TYPE AND TYPEFOUNDING.

Type.—The names for the various parts of a *type* will be seen by reference to Fig. 1.

The term *face* is also generally applied to any fount of type when describing its features, *e.g.*, broad-face, narrow-face, etc.

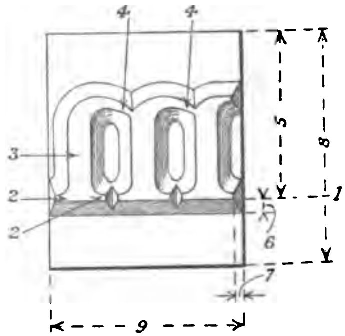
The names of the various parts of the face and of the dimensions may be seen by reference to Fig. 2.

FIG. 1.—*Perspective View of Type.*
(2½ times full size.)



1. The face.
2. The counter.
3. The neck or beard.
4. The shoulder.
5. The stem or shank.
6. The front.
7. The back.
8. The nicks.
9. The heel-nick or groove.
10. The feet.
11. The pin-mark.

FIG. 2.—*Plan of Type.*
(2½ times full size.)



1. The line.
2. Serifs.
3. Main-stroke.
4. Hair-line.
5. Line-to-back.
6. Beard.
7. Side wall.*
8. Body.
9. Set.

* This dimension does not appear to have had a name till recently, when it was called thus in the matrices of the Wicks machine.

The dimension 5 (*line-to-back*) is the datum for all measurements of a *fount* * of type and the lower-case m or cap. H are usually taken as the standard, but the difference between the body size and this dimension is also frequently referred to as a dimension and called the beard. In actually measuring type the dimension 5 is that which is measured.

The nick is in the front of the type in England, America and Germany, but in France and Belgium it is at the back.

A supplementary nick is cut, usually just below the shoulder, in the small capitals O S V W X Z to enable these characters to be distinguished from the lower case. In old style the small capital I is also so marked to enable it to be distinguished from the figure 1.

The pin-mark only occurs in certain machine-made type.

The dimension from the foot to the face is called the *height-to-paper;* the standard for this is now in England 0·918 inch.

Type Founding.—Type is generally cast from an alloy of tin, antimony, and lead; the proportions in which the various metals are used vary between rather wide limits, of which the following may be taken as examples:—

	Per cent.	Per cent.
Lead	62·7	63·7
Antimony	20·8	26·4
Tin	16·5	9·9
Total	100·0	100·0

In the early days of type founding the metal was poured by hand into the mould which was jerked upwards by the founder, so as to cause the liquid to reach the matrix at the end of the mould, and so obtain a cast of the impression previously made by the punch.

Early in the 19th century a pump, partially immersed in the metal pot, was substituted, so that the metal was injected into the mould under considerable pressure and the cast effected with greater certainty and speed.†

* Pronounced *font*, and so spelt in America.

† The U.S. Patent of M. D. Mann and S. Sturdevant of 7 Jan. 1831 shows a pump with a spring-propelled plunger. This appears to the author to forestall both the Patent of Sir H. Bessemer, No. 7585, of 8 March 1838, and the U.S. Patent of D. Bruce, jun., No. 632, of 17 March 1838, which cover a pump with spring-propelled piston and an opening and closing mould.

The gate through which the metal passes into the mould becomes also filled with type-metal and forms a projecting *tang* which must be broken from the type; the breakage leaves a ragged surface, parts of which project beyond the feet and must be removed. In the case of type cast in the simplest machines it is necessary to set up the type on a stick and to plane the heel-nick by hand, the removal of the *tang* thus requiring three operations.

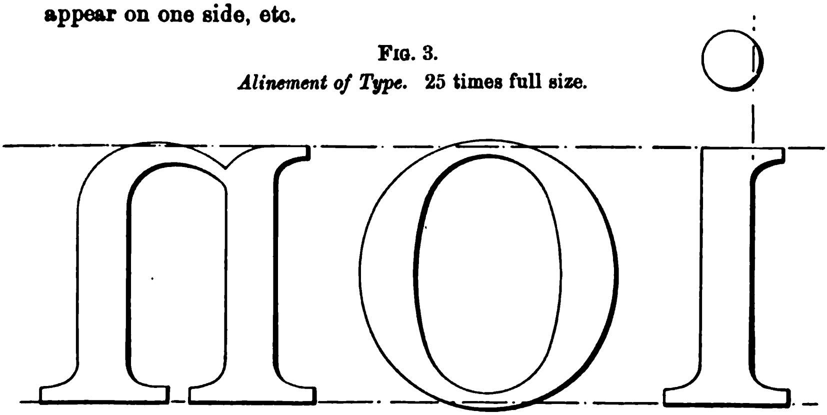
The *face* of the type is obtained from an impression, usually made by a punch, in a piece of soft copper or bronze called a *matrix*. The sides of the mould are formed of steel, ground and lapped. As the mould is opened and closed at each cast the surfaces must be so true that the liquid type-metal will not flow between them under the pressure at which it is injected into the mould, as otherwise a fin would be formed on the type at the join of the mould. The position of the matrix relatively to the sides of the mould must be very accurately determined, so that the face may be cast in the proper position on the shoulder. This work requires skill of a high order and is known as *justifying*. It is performed by casting a type from the mould, and comparing it with a standard lower-case m and correcting the matrix till the face of the trial type agrees with the standard for alinement, and occupies its correct position on the shoulder, so that the proper amount of side wall is given on each side.

In justifying and in punch-cutting it is necessary to remember that type must not be made so as actually to be in alinement, or so that the characters shall be of equal size, but they must be made *to appear so*.

Probably not one reader in a thousand appreciates the degree to which he is critical on size and alinement of type; the ease with which the eye detects want of alinement in two contiguous lines, used by the engineer in the vernier for obtaining accuracy, here acts conversely in requiring it. A difference of one or two thousandths of an inch in alinement is readily apparent, and a difference of two or three thousandths of an inch in the size of a character is easily noticeable; not only must the characters be of the correct size and truly placed, but the proper proportions of thickness of stroke, length of serif, etc., must be maintained throughout the fount.

If the characters were made equal in their dimensions and true they would appear unequal. Fig. 3 shows the relative magnitude of the errors which must be introduced in order to make the characters of uniform appearance. Almost all the characters in a fount have some peculiarity which must be retained if they are to appear true; e.g. the round sorts must be larger than the square sorts and come below the line; the lower case t must not be vertical in the main stroke, or it will appear to lean back; the dot must not be placed centrally over the main stroke of the lower case i or it will appear on one side, etc.

FIG. 3.
Alinement of Type. 25 times full size.



Founts of Type.—A fount of type comprises all the characters which occur commonly in books and papers. A fairly complete fount adapted to casting machines for ordinary purposes is given in Table 1 (page 1036).

In addition to these characters, *spaces* and *quadrats* (or *quads*) must be provided for separating the words and spacing out the lines. These usually have the following *set* widths: hair space = $\frac{1}{8}$ body, thin space = $\frac{1}{5}$ body, middle space = $\frac{1}{4}$ body, thick space = $\frac{1}{3}$ body, en quad $\frac{1}{2}$ body,* em quad = the body, two-em quad = 2 × body,

* It might be inferred that these quads are of the same set as the n or m, but this only occurs under exceptional circumstances. Owing to modern conditions of noise in the printing works, and to make orders clear on the telephone, these are better called "nut" and "mutton" quads respectively.

TABLE 1.

Kind.	Characters.	Number.
Roman lower case .	a to z and æ œ ff fi fl ffi ffl	33
Roman small capitals .	ᴀ to ᴢ and ᴁ ɶ &	29
Roman capitals . .	A to Z and Æ Œ &	29
Roman figures . .	1 2 3 4 5 6 7 8 9 0	10
Fractions . . .	½ ¼ ¾ ⅓ ⅔ ⅛ ⅜ ⅝ ⅞	9
Roman points . .	. , ; : - ’ ! ? ([	10
Roman accents . .	á à â ä ã é è ê ë í ì î ï ó ò ô ö ú ù û ü ŵ ŵ ç ñ Ç	26
Peculiars . . .	* † ‡ § ‖ ¶ ⁀ ^ ‿ - — …	12
Commercial signs . .	@ ℔ ℔ / £ $ % + − × ÷ =	12
Italic lower case . .	*a to z and æ œ ff fi fl ffi ffl*	33
Italic capitals . .	*A to Z and Æ Œ & £*	30
Italic figures . .	*1 2 3 4 5 6 7 8 9 0*	10
Italic points . .	*; : ! ? ([*	6
Italic accents . .	*á à â ä ã é è ê ë í ì î ï* *ó ò ô ö ú ù û ü ŵ ŵ ç ñ Ç*	26
Total		275

three-em quad = 3 × body and four-em quad = 4 × body. In most cases where typecasting machines are concerned it is not necessary to consider the quads larger than the em, which are usually of softer and cheaper metal and cast separately.

The "*height-to-paper*" of quads varies according to the purpose for which they are intended. Where the type is to be printed from direct the height-to-paper of quads is 0·75 inch, but where stereotypes are to be taken the height-to-paper is 0·83 inch.

UNITS, LIMITS OF ACCURACY, AND SPACING.

Units.—In order to appreciate fully the difficulties to be contended with in typecasting and composing machines, the degree of accuracy required must be first considered.

The unit for measurement in this country and in America is the pica which is approximately one-sixth of an inch; until quite recently the size of the pica varied from 0·1678 inch to 0·1664 inch, but now most founders are in agreement and the size 0·16604 inch adopted in America has become standard.

The size of pica as made by the leading English type-founders recently varied as follows * :—

Maker.	Pica ems per foot.	Size of pica : in.
Standard size . . .	72·272	0·16604
Stephenson and Blake .	72·125	0·16638
Caslon	71·875	0·16696
Figgins	71·708	0·16735
Sir Chas. Reed and Sons	71·667	0·16744
Miller and Richard .	71·500	0·16783

The pica is divided into twelve points (= 0·013837 in.). The sizes of the various bodies are measured by points and are as follows :—

* *See* Southward. "Modern Printing," Vol. I, p. 110 *et seq.*

TABLE 2.—*Body Sizes of Type.*

Name.	Example.	Used in	Points.	Body. Inch.
2-line Pica [1] .	Typecas	These larger sizes are mainly used for display purposes.	24	0·33209
2-line Small Pica [1]	Typecasti		22	0·30441
Paragon . . .	Typecasting		20	0·27674
Great Primer [2] .	Typecasting		18	0·24907
2-line Brevier [4] .	Typecasting an		16	0·22139
English . . .	Typecasting an	Scotland for Legal Reports.	14	0·19372
Pica [1] . . .	Typecasting and c	Parliamentary Reports.	12	0·16604
Small Pica [1] . .	Typecasting and co	Text books and novels.	11	0·15221
	Typecasting and com	Patent specifications.	10½	0·14529
Long Primer [2] .	Typecasting and comp	Text books and novels.	10	0·13837
	Typecasting and comp	Proc. Inst. Mech. Eng.	9½	0·13145
Bourgeois [3] . .	Typecasting and compo		9	0·12453
	Typecasting and composi	"Times" leaders.	8½	0·11761
Brevier [4] . . .	Typecasting and composi	"Punch."	8	0·11070
Minion . . .	Typecasting and composing	"Times."	7	0·09686
Nonpareil [5] . .	Typecasting and composing m	"Engineering" ads.	6	0·08302
Agate . . .	Typecasting and composing mac	Used in America.	5½	0·07610
Ruby . . .	Typecasting and composing mach	"Times" ads.	5¼	0·07264
Five Point . .			5	0·06919
Pearl . . .	Typecasting and composing machin	"Bradshaw."	4¾	0·06573

[1] Pronounced *Pie'ca.* [2] Pronounced *Prim'er.* [3] Pronounced *Bur-joice'.* [4] Pronounced *Bre-veer'.* [5] Pronounced *Non'parel.*

The relative importance of the various body-sizes may to some extent be gauged by the following Table which shows how many different faces of each body the American type-founders supply according to their specimen book:—

Body.	Faces.	Body.	Faces.	Body.	Faces.	Body.	Faces.
3-pt.	1	6-pt.	27	9-pt.	22	12-pt.	19
4-pt.	2	7-pt.	19	10-pt.	28	14-pt.	5
5-pt.	5	8-pt.	28	11-pt.	17	15-pt.	1
5½-pt.	9						

From this Table it will appear that the even-point bodies are most in demand. Of these 183 faces 99 are modern and 84 old style.

Much confusion and trouble has been caused in the past through want of adherence to a definite unit, and some evidences of this remain in the half-point sizes, e.g. small pica (10½), long primer (9½) and bourgeois (8½) still in use in England. In America the point system is now universally adopted. The French point system which is of much earlier origin is described in Appendix I (page 1142). (The cicero or "corps 11" measures 0·1628 inch, and is therefore nearly equal to the English pica. The French point is 0·01480 inch, whereas the English point is 0·013837 inch.)

Limits of Accuracy.—The greater portion of printed matter is set in type of the sizes comprised between english and ruby, and it is generally with these and the intermediate sizes that typecasting and composing machines deal. A column of newspaper commonly measures about 22 to 25 inches in height and is very usually set in brevier or minion; it will therefore contain from 200 to 250 lines. The type must be sufficiently parallel in body to lock up in the forme. A uniform error of one ten-thousandth of an inch in parallelism would result in the end lines being inclined each over 0·01 inch from the vertical. Greater inclination would interfere with the truth of impression and with safety in handling, therefore every

TABLE 3.

Set Widths of a Pica Fount* (MODERN) *without Spaces and Quads.

Set.	Characters.	Matrices.	Type.
0·16604	W Æ Œ + − × ÷ = — … @ ℣ ⁀ ^ ⁀ *W Æ Œ* . . .	18	10,770
0·13145	K M ﬃ ﬄ m ℔ *ﬃ ﬄ H K M N X* .	13	26,650
0·12453	H G N U X $ *m A D U V Y* .	12	14,750
0·11761	A D E O Q R V Y w œ *ff E F R* ẃ ŵ	16	38,270
0·11070	B C F L T æ W Æ Œ % £ ¶ & *w œ œ & B G L P T Z £* Ç *ẃ ŵ* .	27	25,900
0·10378	P Z *fi fl C J O Q Ç* . . .	9	4,965
0·08994	S J b d g h k n p q u ff fi fl K M *a d n u x S* ñ ú ù û ü *á à â ä ã ñ ú ù û ü*	37	206,655
0·08302	V X Y G H N U X 1 2 3 4 5 6 7 8 9 0 * † ‡ § ‖ – *h k p y I* ½ ¼ ¾ ⅓ ⅔ ⅛ ⅜ ⅝ ⅞ *1 2 3 4 5 6 7 8 9 0* . .	48	82,190
0·07610	a O Z A D E O Q R V Y *b f g q* á à â ä ã ó ò ô ö	24	118,270
0·07264	e C B C F L P T Z & *o r v ?* ç é è ê ë *ó ò ô ö*	23	125,700
0·06573	I r s ? J S *c e s z ç é è ê ë* . .	15	108,680
0·05535	f j t *i j í ì î ï*	9	80,920
0·04843	i l - / [ ) *l t !])* ı í ì î ï . .	16	100,120
0·04151	. , : ; ’ ! : ;	8	56,160
		275	1,000,000

Length a to z = 12·50 ems.

Length 1,000,000 type = 77,630 inches = 467,600 ems.

TABLE 4.

Set Widths of a Pica Fount (OLD STYLE) *without Spaces and Quads.*

Set.	Characters.	Matrices.	Type.
0·17296	W Æ Œ *M W Æ Œ* . .	7	4,970
0·16604	… — + − × ÷ = ⌢ ^ ⌢ ℣ .	11	5,880
0·13837	H M m œ @ ℔ ¶ ﬃ ﬄ *X D ﬃ ﬄ*	13	27,910
0·13145	D G K N O Q R X W & W Æ Œ *H K N R & m* ẃ ŵ . .	21	39,530
0·12107	A C T U V Y æ *A B G L P U V Y* Ç *w ẃ ŵ* . . .	19	21,830
0·11416	B E F L P Z £ $ M *C E F O Q T Z £ ﬀ æ œ Ç* . . .	21	21,685
0·09340	S b d g h k n p q u x ﬀ ﬁ ﬂ D G H K N R U & *S J g y ﬁ ﬂ* ñ ú ù û ü	33	205,180
0·08648	a O V y A B C E L O P Q T V X Y Z *a d h k n p u x* á à â ä ã ó ò ô ö *á à â ä ã ñ ú ù û ü* . .	44	161,855
0·08302	1 2 3 4 5 6 7 8 9 0 * † ‡ § ‖ % – ½ ¼ ¾ ⅓ ⅔ ⅛ ⅜ ⅝ ⅞ *1 2 3 4 5 6 7 8 9 0*	36	43,380
0·07264	J c e z F S *I b q r v z ? [* ç é è ê ë	19	117,880
0·06054	I r s t - / ? J *c e f j o s t) ç é è ê ë ó ò ô ö*	25	180,990
0·05189	f i j l) [I *l i !* í ì î ï *í ì î ï* . .	18	112,750
0·04151	. , ’ ; : ! *; :*	8	56,160
		275	1,000,000

Length a to z = 12·99 ems.

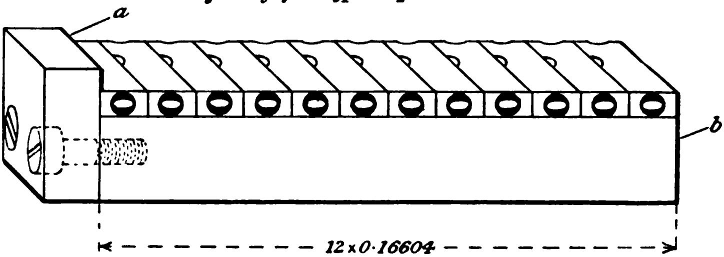
Length 1,000,000 type = 77,300 inches = 465,600 ems.

endeavour must be used to keep the body of the type uniform and the product of every machine has to be continually checked. This can readily be done in practice by means of an ∟ gauge, Fig. 4, measuring about 2 inches but actually made to the calculated length of the type to be received.

The type are carefully cleaned from grease and small particles of metal and then pressed firmly against the stop *a* with the fingers. The finger nail is then passed over the flat surface *b* of the end of the gauge and the end of the line of type where a total difference of one-thousandth of an inch in the total body and of inequality in parallelism can easily be felt. Such a gauge would measure 1·9924

FIG. 4.

Body Gauge for Type. 1½ times full size.



inches for 12 pica, for 18 brevier or for 24 nonpareil; a gauge 2·0340 inches would serve for 14 small pica or 28 ruby and also for 21 minion. In this connection it should be noted that the multiples of the decimal sizes given in Table 2 (page 1038) do not agree exactly, but this gauge should be 147 points in length. The variations in approximate decimal sizes have proved a great stumbling block to some founders who have first worked out the decimal approximation for the body and then multiplied it thereby obtaining varying results, which would be avoided entirely by working from the point as the unit.

In setting up tabular work it is necessary that the points, figures, and fractions should all agree, so that the figures may fall vertically under each other and the columns be of equal width. For this reason the figures and two-figure fractions ($\frac{1}{2}$, $\frac{1}{3}$) are almost invariably made on the *en-set*; the diagonal and other fractions

($\frac{1}{2}$, $\frac{3}{16}$, $\frac{21}{32}$) on the *em-set*; and those points used in tabular work, e.g. the full point (which inverted becomes the decimal point), the comma, the colon and the semi-colon are usually placed on the same *set* as the *middle* space, namely one-fourth of the body.* The same gauge that is used for the body will serve for checking the *set* of these particular characters, but as a column of matter is seldom more than four inches wide, a larger error is here admissible than in the body size.

Spacing.—The width of a column of newspaper or a printed page of a book generally lies between 14 and 40 ems. Where this is ordinary reading matter each line will contain on the average from 7 to 10 words. As the letters are not only unequal in *set*, and since the widths of *set* generally bear no particular relation to the em (or body), it follows that the spacing has to be done after the line has been composed. If the line (made up with thick spaces in hand composition) comes short or long the spaces must be some or all removed and replaced with others.† The spacing must therefore be obtained by the use of the thin, middle and thick spaces forming $\frac{1}{5}$, $\frac{1}{4}$ and $\frac{1}{3}$ of the body respectively. Obviously the minimum error obtainable with such a system is the fraction given by the least common multiple of these used in combination, i.e. $\frac{1}{60}$ em. The line cannot be made longer than the allowed width, therefore the amount of admissible error based on practical experience may be taken at $\frac{1}{60}$ em, and it is probable that it frequently amounts to $\frac{1}{30}$ em. This in pica becomes about $\frac{1}{180}$ inch and in nonpareil about $\frac{1}{360}$ inch.

The problem of spacing is one of the most serious difficulties met

* Some founders place these points on the *thick* space *set* (or $\frac{1}{3}$ body), but with this arrangement spacing is more difficult, as the column can only be made a multiple of the en or em by adding two *thick* spaces, whereas with the points on the *middle* space the addition of a single *middle* space will bring the column to a multiple of the en.

† The hair space is not used for this purpose, but only for spacing out between the characters of words where a very narrow column of matter runs alongside a block or table, and occasionally its use is allowed to obviate over-running where author's corrections occur.

TABLE 5.

Self-Spacing Type.

Set.	Characters.	Number.
2 body	2 em quad	1
$\frac{7}{6}$ body	W Æ Œ ﬃ ﬄ *W Æ Œ*	8
body	em-quad m ﬃ ﬄ H K M X lb ℔ @ ... — × + − ÷ = ½ ¼ ¾ ⅓ ⅔ ⅛ ⅜ ⅝ ⅞ *m H K M X*	32
$\frac{5}{6}$ body	w æ œ A B D E F G N O P Q R T U V Y & H K M W Æ Œ *w æ œ ff fi fl A B D E F G N* *O P Q R T U V Y & ẃ ŵ ẃ ŵ* . .	51
$\frac{2}{3}$ body	3-to-2-em quad a b d g h k n o p q u v x y ff fi fl £ $ C J L S Z A B C D E F G L N O P Q R T U V X Y &) }) .. (leader) — (rule) 1 2 3 4 5 6 7 8 9 0 *C J L S Z a b d g h k n o p q* *u v x y I 1 2 3 4 5 6 7 8 9 0* ä á à â ã ñ ö ó ò ô ü ú ù û Ç ç *ä á à â ã ñ ö ó ò ô ü ú ù ú Ç*	120
$\frac{1}{2}$ body	en-quad c e r s t z J S Z I ? ( ] * † ‡ § ‖ ¶ *c e f r s t z ? ( ]* ç ë é è ê *ç ë é è ê* . .	40
$\frac{1}{3}$ body	3-to-em space f i j l I . , ; : ' ! - / *i j l ; : ! ï* í ì î *ï í ì í*	28
$\frac{1}{6}$ body	Hair space	1
Total .	Spaces and quads, 6. Characters, 275 . .	281

with in composing machinery; it is here called *line-justification* throughout, but is known to printers by the unfortunate term "justification" which is used elsewhere throughout this Paper for those manufacturing operations which are also so called. Various attempts have been made to effect the spacing more readily than by the crude trial and error method just mentioned. It is, however, by no means a simple problem. If all letters were equal in *set* (as in the case of most typewriter faces), there would be a variable number from 0 to 8 spaces * to be added and inserted with those already in he line. These spaces would generally make large, irregular, and unsightly white gaps over the page. The nearest approach to accurate spacing of type is afforded by the American so-called *self-spacing* type invented by Benton. In this all characters are made on *set* widths each multiples of one sixth of the body, so that any combination can be made up to a multiple of the em by the addition of some of the *self-spacing* spaces which are also equal multiples of the sixth of the body.

The provision of so small a number of *set* sizes results in the production of characters which do not conform to those ordinarily in use sufficiently closely to secure the general adoption of the system, and the difficulty, which will be apparent in comparing Table 5 with Tables 3 and 4 (pages 1040–1041) becomes even more marked with the italic sorts.

Kerned Type and Italics.—Some of the italic sorts (and, in the early type cast in the hand-mould, sometimes the roman lower-case f and j) project beyond the sides of the body, Fig. 5 (page 1046); these are known as kerned characters. The projecting kern requires to be dressed by hand so as to clear the shoulder of the adjacent sort; in early printing some of the characters kerned above or below the body, and this was liable to cause fouling where an ascending or a

* Taking a line ending in the longest indivisible word known to the author in English, "strength," there are 8 letters, and if this comes at the end of the line and proves one letter too long there are still 8 spaces to deal with since one space precedes the last word.

descending kern in one line came immediately under a descending or over an ascending letter in the next line. In modern type, kerning above and below the body is rare; the only notable exceptions are accented capitals,—the use of which is now being abandoned by the French *—and the very ingenious two-line letter for commencing

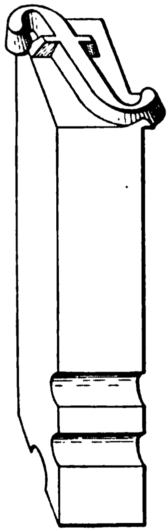


FIG. 5.

Kerned Type: Perspective View.

About 2½ times full size.

advertisements introduced by the Linotype Co., which is further described below.

Characters kerned in *set* are however still common in the case of many of the best book founts; they present a serious difficulty to

* The French have for many years abandoned the grave accent on A while retaining it in the lower case. "A Paris il faisait beau, à Londres un brouillard."

In the headlines of the French newspapers, while the accent is now almost universally omitted on A, one finds accents sometimes on other characters; but the influence of the composing machine is to be seen in the gradual abandonment of accented capitals, which is now in progress.

For example: L'ANGLETERRE REFUSE LE SYSTEME METRIQUE ......car la plus grande partie du commerce extérieur britannique intéresse des pays qui n'ont pas le système métrique....*Le Matin* 23 *Mar* 1907.

most typecasting and composing machines. Where the type is ejected through the length of the mould, as in the Wicks machine, they cannot be produced.

In any case the weakness of the kern renders such italic type easily damaged in distributing and composing, and it is probably only a matter of time for the kern to be abandoned, except in the case of the highest classes of printing and in artistic work where appearance is the most important factor.

Example of kerning italic :—

The ejection of kerned italic type offers difficulty.

Example of non-kerning italic :—

The ejection of non-kerned italic type offers no difficulty.

The principal difficulty in designing a non-kerning italic lies in the ascending and descending sorts and particularly in the letters *f* and *j*; these have to be somewhat modified from the more familiar shape. Whereas the slope of the italic main strokes in the kerning type will be found frequently to be as much as 1 in 3, it is necessary to reduce it to about 1 in 5 in designing a non-kerning fount, and 1 in 4 is about the maximum slope permissible. With this the *f* requires to be considerably distorted and shows excess of side wall and consequent space between it and the adjacent characters.

TYPE FACES, SERIES, PROPORTIONS, AND WEIGHT.

Variety of Faces.—Type faces may be divided into three main groups so far as they concern the maker of typecasting and composing machines.

(a) Old style faces. Example :—

Notice the short serifs and the ample fillet connecting each to the main stroke. These features tend to durability as well as to legibility. 1 2 3 4 5 6 7 8 9 0.

Old Style Pica (Miller & Richard).

(b) Modern faces. Example:—

Note how thin are the hair lines, how long are the serifs, and how small the fillet connecting each to the main stroke. Wear takes place more rapidly, and legibility is sacrificed. 1 2 3 4 5 6 7 8 9 0.

Modern Pica (Miller & Richard).

(c) Fancy faces. Example:—

Our eyesight is one of our most precious assets, and the designer of type should therefore consider legibility as of greater importance than artistic effect.

Blackfriars Pica (Wicks Type Foundry).

The faces may be extended or condensed, and the strokes may be fat or lean. The faces used for the greater part of the printed matter of the day are either old style, or modern, or follow the leading features of one or the other very closely.

(a) *The old style face* has thick hair lines and a large radius connecting the serif with the main stroke. These features render it more legible and durable. On the other hand the old style figures are irregular, and owing to the smallness of some sorts their legibility is no greater than that of the modern figures. Moreover, the fact that they comprise ascenders, descenders and small sorts makes them unsuitable for most scientific works. Old style founts are therefore frequently ordered with modern figures.

(b) *The modern face* is very largely used; the defect from which it suffers has arisen from the endeavour to obtain a more highly finished outline without regard to the ultimate object in view. Thicker hair lines and a larger radius connecting the serif and main stroke increase both the clearness and the durability of the type, and a face produced with these features is very suitable for most newspapers, periodicals, magazines, text books and novels.*

* *See* T. L. De Vinne. "Plain Printing Types"; De Vinne not only draws attention to the requisites for legibility but has himself produced some of the best examples of easily-readable type faces.

(c) *Fancy faces.*—There are so many varieties of fancy faces and they differ so widely that they rarely come into question under conditions which permit of their production in large quantity. These faces are used chiefly for advertisements, circulars, bill-heads and titling, where any particular fount occurs usually in such small quantity that hand composition is the only effective method of setting. Probably less than 10 per cent. of all printed matter is set in fancy faces.

The large amount of time spent by nearly all persons in reading makes the question of clearness of type one of enormous importance, though it has hitherto passed almost unnoticed. It is quite as necessary that the characters should be plainly dissimilar in form and appearance as that a body should be used of the maximum size which the nature of the work will permit.

At present there is no uniformity in the *set* widths of the various faces, but it should be possible to cover all requirements by the adoption of the strengthened modern face in three widths, viz.: extended, standard, and condensed, each bearing a definite ratio to the other. The only convenient unit for gauging whether type is extended, standard, or condensed, is by the measure of the alphabet (a–z) in ems.* In making such comparison, however, it must be noted that it is only possible to compare founts of the same body and style by this measure.

Series.—Founts of different bodies but of faces made to appear similar are said to form a series. A fount of smaller body generally has a greater number of ems to the alphabet than a larger body of the same series.

It has been the custom of type-founders to have the punches cut so that the size of the small sorts is proportionately larger as the body diminishes, the length of the ascending and descending characters being correspondingly altered.† This may be explained by

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* By em is meant the em quad. The total aggregate set of the alphabet is consequently expressed as a multiple of the body.

† *See* measurements of series of type (page 1038).

reference to Tables 6 and 7 (pp. 1052 to 1055). It will be seen that nearly all the vowels and most of the more frequently occurring consonants are small sorts, and this is not only the case in English but also in the languages of the other countries in which typefounding has been longest established (France, America, Germany). In the English language in 10,000 lower-case characters there are on the average 5830 small sorts and 40 ascending and descending characters, but only 3510 ascenders, and 620 descenders. It is the influence of the greater number of the small sorts and the adoption of as large a size as possible for the small sorts, in order to obtain legibility, which is responsible for this change of shape as the size of the face is reduced and for the descenders being more shortened in proportion than the ascenders.

Series of Type Faces.—Owing to the enlargement of the small sorts and to the fact that the hair line is the minimum width of line which will give a good impression,* it is not possible to use the same *formers*† for a large range of reduction, but, in order that the type may appear similar, other formers must be provided of the proper proportions. It will be found in practice that the same formers can be used for pica, small pica, and long primer; a second set is required for bourgeois, brevier, and minion; and a third set for nonpareil and ruby.

The *set* widths of the second set of formers will be from 8 to 10 per cent. greater than those of the first, and the *set* widths of the third set from 16 to 20 per cent. greater than those of the first.

The relative appearance of the characters of the three sets of formers is shown in Fig. 6.

The a–z length for a standard face in pica is about 12·5 to 13 ems,‡ in brevier about 13¾ to 14¼ ems, and in nonpareil about 15 to 15⅔ ems.

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* The minimum width usually permissible for the hair-line in modern faces is 0·002 inch.

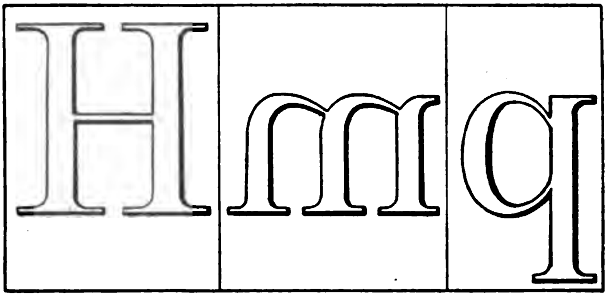
† *See* description of punch cutting machine (page 1059).

‡ Owing to different characters being affected by differences in set, 13 ems old style will average nearly the same length as 12·5 ems modern. (*See* foot of Tables 3 and 4, pages 1040–1041.)

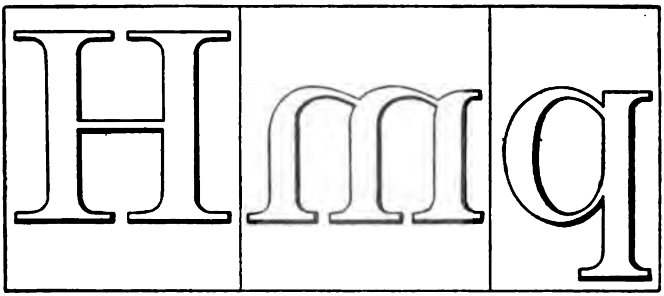
Fig. 6.

Type Series.

12 point (Pica) *9 times full size.*



9 point (Bourgeois) *12 times full size.*



6 point (Nonpareil) *18 times full size.*

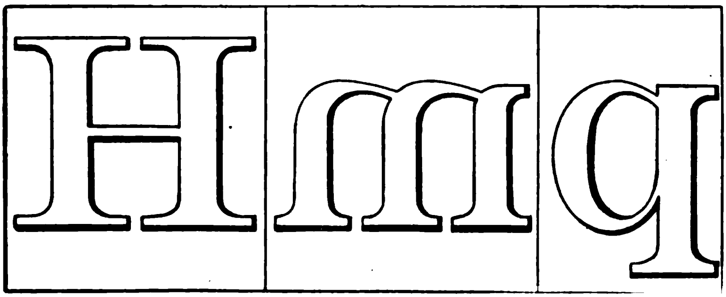


TABLE 6 (*continued on next page*).

***Bill of* 1,000,000 *type, exclusive of spaces and quads.* (*England.*)**

Roman lower case.		Roman small capitals.		Roman capitals.		Roman figures. Fractions and points.		Roman accents.	
m	16,780	A	2,510	A	3,900	1	3,900	á	250
a	50,330	B	1,510	B	2,510	2	3,350	à	1,200
b	11,180	C	1,960	C	2,800	3	3,350	â	600
c	22,370	D	1,960	D	3,070	4	2,800	ä	250
d	27,960	E	2,510	E	4,200	5	2,800	ã	200
e	78,300	F	1,680	F	2,510	6	2,800	ç	250
f	16,780	G	1,510	G	2,510	7	2,800	é	1,200
g	11,180	H	1,680	H	2,510	8	2,800	è	600
h	33,550	I	2,510	I	5,020	9	2,800	ê	400
i	50,300	J	1,120	J	1,680	0	3,900	ë	600
j	2,800	K	1,120	K	1,680	½	840	í	250
k	4,470	L	1,680	L	3,070	¼	840	ì	250
l	27,960	M	1,680	M	3,630	¾	840	î	250
n	44,740	N	1,960	N	3,070	⅓	280	ï	250
o	44,700	O	1,960	O	3,070	⅔	280	ñ	200
p	13,420	P	1,510	P	2,800	⅛	280	ó	250
q	3,360	Q	670	Q	1,120	⅜	280	ò	250
r	39,150	R	1,850	R	2,800	⅝	280	ô	300
s	44,740	S	1,960	S	3,320	⅞	280	ö	300
t	55,930	T	2,350	T	4,440	.	16,780	ú	250
u	25,170	U	1,340	U	2,000	,	25,170	ù	250
v	8,390	V	1,120	V	2,000	;	4,470	û	300
w	13,980	W	1,510	W	3,070	:	3,350	ü	300
x	2,800	X	670	X	1,120	-	5,600	ẃ	200
y	13,980	Y	1,120	Y	2,000	'	4,470	ŵ	200
z	1,680	Z	670	Z	840	!	1,120	Ç	50
æ	1,120	Æ	330	Æ	560	?	1,680		
œ	560	Œ	330	Œ	560	(	2,240		
ff	2,240	&	1,120	&	1,680	[	1,120		
fi	2,800								
fl	1,680								
ffi	1,680								
ffl	1,120								
Total	677,200	Total	43,900	Total	73,540	Total	101,500	Total	9,400

TABLE 6 (*concluded from opposite page*).

***Bill of* 1,000,000 *type, exclusive of spaces and quads:* (*England.*)**

Peculiars and commercial signs.		Italic lower case.		Italic capitals.		Italic accents.		Italic figures and points.	
*	1,400	*a*	5,030	*A*	390	*á*	25	*1*	390
†	560	*b*	1,120	*B*	250	*à*	120	*2*	330
‡	560	*c*	2,240	*C*	280	*â*	65	*3*	330
‖	560	*d*	2,800	*D*	310	*ä*	25	*4*	280
§	560	*e*	7,830	*E*	420	*ā*	20	*5*	280
¶	370	*f*	1,680	*F*	250	*ç*	25	*6*	280
⌢	280	*g*	1,120	*G*	250	*é*	120	*7*	280
⁀	280	*h*	3,350	*H*	250	*è*	50	*8*	280
⌒	280	*i*	5,030	*I*	500	*ê*	40	*9*	280
-	560	*j*	280	*J*	170	*ë*	65	*0*	390
—	2,800	*k*	450	*K*	170	*í*	25	;	450
...	560	*l*	2,800	*L*	310	*ì*	25	:	350
@	280	*m*	1,680	*M*	360	*î*	25	!	110
℞	280	*n*	4,470	*N*	310	*ï*	25	?	170
℔	280	*o*	4,470	*O*	310	*ñ*	20	)	220
£	1,120	*p*	1,340	*P*	280	*ó*	25	]	110
$	560	*q*	340	*Q*	110	*ò*	25	Total 4,530	
%	560	*r*	3,910	*R*	280	*ô*	30	Totals.	
/	560	*s*	4,470	*S*	330	*ö*	30	R. l. c.	677.200
+	280	*t*	5,590	*T*	440	*ú*	25	R. s. c.	43,900
−	280	*u*	2,510	*U*	200	*ù*	25	R. c.	73,540
×	280	*v*	840	*V*	200	*û*	30	R. figs. & pts	101,500
÷	280	*w*	1,400	*W*	310	*ü*	30	R. accs.	9.400
=	280	*x*	280	*X*	110	*ẃ*	20	Pec & coml.	13.810
		y	1,400	*Y*	200	*ŵ*	20	Ital. l. c.	67,720
		z	170	*Z*	80	*C*	5	Ital. c.	7,460
		æ	110	*Æ*	55			Ital. accs.	940
		œ	60	*Œ*	55			It. figs. & pts.	4,530
		ff	220	*&*	170				
		fi	280	*£*	110				
		fl	170						
		ffi	170						
		ffl	110						
Total 13,810		Total 67,720		Total 7,460		Total 940		Grand Total	1,000,000

TABLE 7 (*continued on next page*).

Bill of 1,000,000 *Type, inclusive of Spaces and Quads.* (*England.*)

Roman lower case.		Roman small capitals.		Roman capitals.		Roman figures. Fractions and Points.		Roman accents.	
m	13,230	A	1,990	A	3,000	1	3,110	á	200
a	39,700	B	1,190	B	1,980	2	2,640	à	950
b	8,820	C	1,540	C	2,420	3	2,640	â	470
c	17,630	D	1,540	D	2,420	4	2,200	ä	200
d	22,040	E	1,990	E	3,300	5	2,200	ã	160
e	61,710	F	1,320	F	1,980	6	2,200	ç	200
f	13,230	G	1,190	G	1,980	7	2,200	é	950
g	8,820	H	1,320	H	1,980	8	2,200	è	470
h	26,450	I	1,990	I	3,960	9	2,200	ê	300
i	39,680	J	880	J	1,320	0	3,110	ë	470
j	2,200	K	880	K	1,320	½	660	í	200
k	3,530	L	1,320	L	2,420	¼	660	ì	200
l	22,040	M	1,320	M	2,840	¾	660	î	200
n	35,300	N	1,540	N	2,420	⅓	220	ï	200
o	35,270	O	1,540	O	2,420	⅔	220	ñ	160
p	10,580	P	1,190	P	2,200	⅛	220	ó	200
q	2,640	Q	530	Q	880	⅜	220	ò	200
r	30,860	R	1,460	R	2,200	⅝	220	ô	230
s	35,270	S	1,540	S	2,640	⅞	220	ö	230
t	44,090	T	1,860	T	3,520	.	13,230	ú	200
u	19,840	U	1,070	U	1,540	,	19,840	ù	200
v	6,610	V	880	V	1,540	;	3,530	û	230
w	11,020	W	1,190	W	2,420	:	2,650	ü	230
x	2,200	X	530	X	880	-	4,410	ẃ	160
y	11,020	Y	880	Y	1,540	'	3,530	ŵ	160
z	1,320	Z	530	Z	660	!	880	Ç	40
æ	880	Æ	260	Æ	440	?	1,320		
œ	440	Œ	260	Œ	440	(	1,760		
ff	1,760	&	880	&	1,320	[	880		
fi	2,200								
fl	1,320								
ffi	1,320								
ffl	880								
Total 533,900		Total 34,610		Total 57,980		Total 80,030		Total 7,410	

TABLE 7 (*concluded from opposite page*).

Bill of 1,000,000 *Type, inclusive of Spaces and Quads.* (*England.*)

Peculiars and commercial signs.		Italic lower case.		Italic capitals.		Italic accents.		Italic figures and points.	
*	1,110	*a*	3,970	*A*	300	*á*	20	*1*	310
†	440	*b*	880	*B*	200	*à*	90	*2*	260
‡	440	*c*	1,760	*C*	240	*â*	50	*3*	260
‖	440	*d*	2,200	*D*	240	*ä*	20	*4*	220
§	440	*e*	6,170	*E*	330	*ã*	15	*5*	220
¶	300	*f*	1,320	*F*	200	*ç*	20	*6*	220
⁀	220	*g*	880	*G*	200	*é*	90	*7*	220
⁀	220	*h*	2,650	*H*	200	*è*	40	*8*	220
⁀	220	*i*	3,970	*I*	400	*ê*	35	*9*	220
-	440	*j*	220	*J*	130	*ë*	50	*0*	310
—	2,220	*k*	350	*K*	130	*í*	20	*;*	360
...	440	*l*	2,200	*L*	240	*ì*	20	*:*	260
@	220	*m*	1,320	*M*	280	*î*	20	*!*	90
℔	220	*n*	3,530	*N*	240	*ï*	20	*?*	130
lb	220	*o*	3,530	*O*	240	*ñ*	15	*(*	180
£	880	*p*	1,060	*P*	220	*ó*	20	*[*	90
$	440	*q*	260	*Q*	90	*ò*	20		
%	440	*r*	3,090	*R*	220	*ô*	25		
/	440	*s*	3,530	*S*	260	*ö*	25	Total	3,570
+	220	*t*	4,410	*T*	350	*ú*	20		
−	220	*u*	1,990	*U*	155	*ù*	20		
×	220	*v*	660	*V*	155	*û*	25		
÷	220	*w*	1,100	*W*	240	*ü*	25		
=	220	*x*	220	*X*	90	*ẃ*	15	Totals.	
		y	1,100	*Y*	155	*ŵ*	15	R. l. c.	533,900
		z	130	*Z*	65	*Ç*	5	R. s. c.	34,610
Total	10,890	*æ*	90	*Æ*	45			R. c.	57,980
		œ	50	*Œ*	45			R. figs. & pts.	80,030
Spaces.		*ff*	180	*&*	130			R. accs.	7,410
Hair	13,230	*fi*	220	*£*	90			Pec. & coml.	10,890
Thin	35,270	*fl*	130					Spaces	211,600
Middle	35,270	*ffi*	130					Ital.	53,390
Thick	88,150	*ffl*	90					Ital. c.	5,880
Enquad	26,450							Ital. accs.	740
Em quad	13,230							It. figs. & pts.	3,570
Total	211,600	Total	53,390	Total	5,880	Total	740	Grand Total	1,000,000

Proportions in which Type is Usually Supplied.

*Bill of Fount.**—Type is usually supplied according to a scheme which determines the proportion each character bears to the whole. In some cases the order is for a certain total weight of type and this is translated by the type-founder into a bill of so many ems. In this case it is the lower case m which is taken as the standard of demand and the bill is for 3,000 or 5,000, etc., m's; for this reason the lower-case m is placed first in the bill. The spaces and quads are usually reckoned separately from the characters. For many of the problems which arise, in the design of typecasting and composing machinery, it is necessary to consider the total number.

The author has calculated Tables 6 and 7 which show the number of each character in a million type in the two cases *exclusive* of and *inclusive* of spaces and quads up to the em quad. Although these proportions are followed very closely in making up an order, the trade recognise the possibility of irregularity in the demand; for example directories and voters' lists will require an abnormally large supply of capitals and small capitals, while almanacs and some scientific works require an excessive quantity of figures.†

Machines and Processes Employed for producing Punches, Matrices, and Moulds.

Punch-Cutting.—In the process of cutting a punch by hand the end of a piece of steel about 2 inches long and ¼ inch square (in the case of pica and smaller bodies) is filed up square to two adjacent faces which have been squared up. This face is ground true on an oil stone by means of the stone-facer of hardened steel shown in Fig. 7 (page 1058). The character is then marked out on the face of the

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* Known in America as a *scheme*.

† It happens, however, that printers occasionally require abnormal quantities of some particular character, of capitals, of small capitals or of figures. By the custom of the trade the printer is entitled to be supplied with "sorts" at the same rate as paid for the fount, provided these are ordered within three months of the date the fount is supplied.

TABLE 8.

Approximate Weight of 1,000,000 *Type in lb. Exclusive of Spaces and Quads.*

	Points.	Lengths a–z in ems.								
Modern . .	—	8·75	10·00	11·25	12·50	13·75	15·00	16·25	17·50	18·75
Old Style . .	—	9·10	10·40	11·70	13·00	14·30	15·60	16·90	18·20	19·50
Gt. Primer . .	18	6,050	6,770	7,490	8,210	8,930	9,650	—	—	—
Two-line Brevier	16	4,780	5,350	5,920	6,490	7,060	7,630	—	—	—
English . . .	14	3,660	4,100	4,530	4,970	5,400	5,840	—	—	—
Pica	12	—	3,010	3,330	3,650	3,970	4,290	4,610	—	—
Small Pica . .	11	—	2,530	2,800	3,070	3,340	3,600	3,870	—	—
	10½	—	2,300	2,550	2,790	3,010	3.280	3,530	—	—
Long Primer .	10	—	2,090	2,310	2,530	2,760	2,980	3,200	—	—
	9½	—	1,890	2,090	2,290	2,490	2,690	2,890	—	—
Bourgeois . .	9	—	—	1,870	2,050	2,230	2,410	2,590	2,770	—
	8½	—	—	1,670	1,830	1,990	2,150	2,310	2,470	—
Brevier . . .	8	—	—	1,480	1,620	1,760	1,910	2,050	2,190	—
Minion . . .	7	—	—	1,130	1,240	1,350	1,460	1,570	1,680	—
Nonpareil . .	6	—	—	—	910	990	1,070	1,150	1,230	1,310
Agate . . .	5½	—	—	—	760	830	900	970	1,040	1,110
Ruby	5¼	—	—	—	700	760	820	880	940	1,000
Five Point . .	5	—	—	—	—	680	740	800	860	920
Pearl	4¾	—	—	—	—	620	670	720	770	820

The stepped columns between the heavy lines show type which would appear in series.

In this Table due allowance has been made for the commercial signs, figures and points remaining constant in *set* width.

punch with a scriber and the counters struck in by means of "counter punches" used by hand with a hammer. The punch is kept true on the face by occasionally rubbing on the oil stone in the stone-facer and the sides are trimmed off with gravers and engraving tools. The production of the work requires the continued use of a magnifying eyeglass combined with the artistic ability to produce the correct curves and the accuracy to obtain the result to 0·0003 inch. There are not many good punch-cutters * and it can be easily understood that a punch-cutter capable of working to this degree of accuracy earns about £4 to £6 per week. Moreover the amount of

FIG. 7.

Stone-facer for Punches, or Jointer.

Half size.

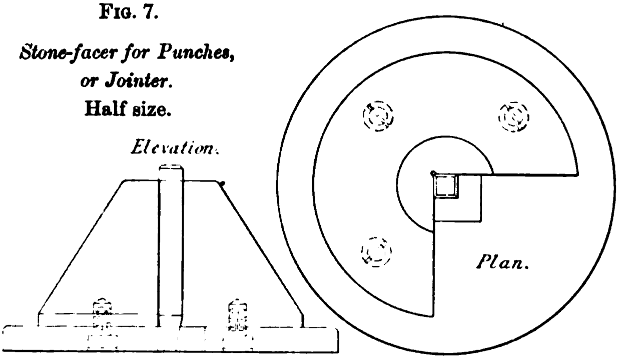
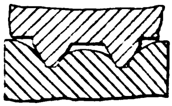


FIG. 8.

Bad Striking Metal: Section.

5 times full size.



work finished by this method is not large and the punches of a fount so cut by hand will be found to have cost on the average from 12*s.* to 15*s.* each; to the engineer who has purchased a small complete alphabet of 27 punches with a set of 9 figures for 5*s.* or 6*s.*, this cost, without further explanation, will appear absurd. As the engraving of the punch is proceeded with, the face is smoked and an impression taken on a piece of fine-surface paper alongside an impression similarly taken from the corresponding standard character, the **H**, o, m, or p, according to the character which is being cut. The smokes are examined with the magnifier and the

* Anthony Bessemer, the father of Sir Henry Bessemer, cut a number of faces for Messrs. Caslon, and subsequently engaged in typefounding himself. *See* Life of Sir Henry Bessemer, p. 60.

work continued till the result agrees to the desired extent. Since the punch is the first stage in the process and from it a matrix must be obtained in which again the type is cast, the problem is one of cumulative error. In the case of the punch, the very thin film of deposited carbon forming the smoke enables a higher degree of accuracy to be obtained than prevails with the inked impression made from the type. The hand-cut punch when finished has a long taper ½ inch to ⅝ inch in length and the bevels of the actual strike are seldom constant in slope. Moreover the face does not occupy a definite position with regard to the sides of the shank. Owing to the great expense of cutting punches by hand, the hand-cut punches for the vowels and the n are usually ground away flat on the back to enable them to be used in conjunction with separate punches for the accents. This first step towards economy in punches gives very unsatisfactory results.

Striking.—Matrices are now usually struck in a press. The punch is forced into the soft matrix metal which must be of such quality that it will readily flow. It is quite possible to obtain metal which will take the impression to the required depth without injuring the punch and yet will not flow sufficiently freely under the pressure to fill the counter as shown in Fig. 8 (page 1058).

Owing to the unsymmetrical form of the character the pressure applied in striking causes the punch to spring, and this is particularly the case with the hand-cut punch which has the long taper portion unsupported. In the case of the accented sorts this difficulty is increased and the two parts of the punch tend to separate, to give unequal depths and an irregularity which is inadmissible. This leads to increased cost in finishing the matrices, and as most typecasting machines use matrices in quantity, it is necessary to obtain cheaper, more accurate and readily interchangeable punches.

Punch-Cutting Machine.—The Benton-Waldo punch-cutting machine is of American invention and an adaptation of the pantograph. Instead of the model and its reduction being in one plane, the punch is arranged vertically over the model or *former*. The machine, Fig. 9, consists of a vertical frame 1 which carries the table 2 on which the *formers* are secured. The frame is also fitted with a slide 3 in which the watchmaker's lathehead 4 can be placed in position. Several of these heads are required for each machine, and they must be made interchangeable so that the axes of the milling, the roughing, and the finishing cutters all agree within the permissible error. At the top of the frame is fixed the top gimbal plate 5 in which is pivoted the outer gimbal ring 6. At right angles to the fixed axis of the outer gimbal ring and in a plane passing through that axis are the centres of the inner gimbal ring 7 to which the four slide-rods 8 are secured. These slide-rods are ground true and parallel and are a sliding fit in the lower outer gimbal ring 9, the holes in which are fitted with bushes lapped true. The lower inner gimbal ring 10 is pivoted to the outer gimbal ring and also to the sliding head 11, the axes of the centres being parallel to those of the upper gimbal ring. The sliding head is fitted with large flanges above and below the adjustable slide frame 12, the surfaces being ground true and parallel. The slide frame has large vertical bearing surfaces on the sides of the frame, and can be rigidly clamped at any desired height. The height is usually determined by bringing the frame down on a gauge 13 of the requisite size placed on the stop 14. The four slide-rods 8 are rigidly connected at their lower ends to the follower head 15, to which is secured the follower stem 15*a*. The upper part of the follower head is cup shaped; it catches the shavings which fall from the tools and so keeps the *former* 18 clear. The lower end of the follower stem is bored up with an axial hole in which slides the follower carrier 16; a spring 16*a* keeps the follower carrier pressed down on the *former* 18. The end of the follower carrier below the button fits into the holes in the larger followers 17, Fig. 10, of which there are some twenty ranging from 3 inches to 0·13 inch in diameter, the end of the follower carrier is 0·10 inch in diameter, and some ten followers 17*a* of smaller diameter fit inside the axial hole in the follower carrier which then compresses the spring 16*a* to a greater extent. The sliding of the follower carrier in the follower stem ensures exact proportionate movement of the punch when the axis of the follower head is inclined to the vertical.

FIG. 10. Enlarged View of Follower Stem.

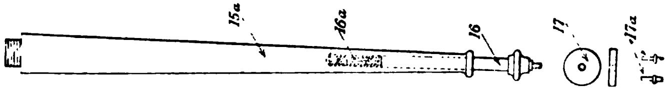
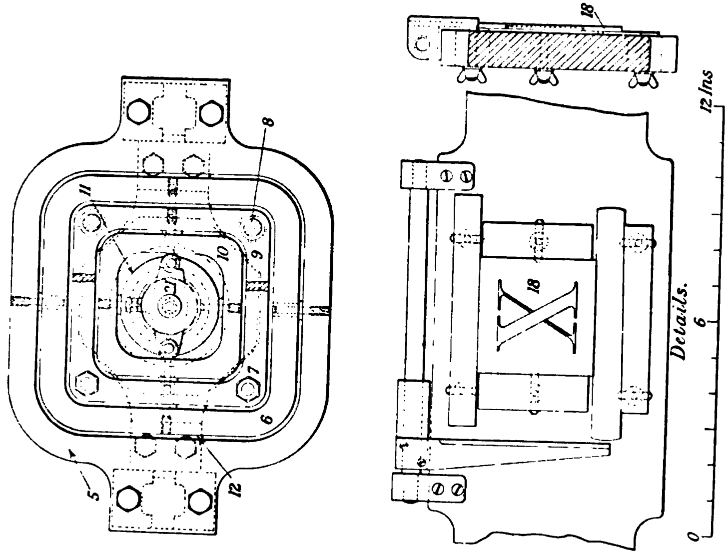
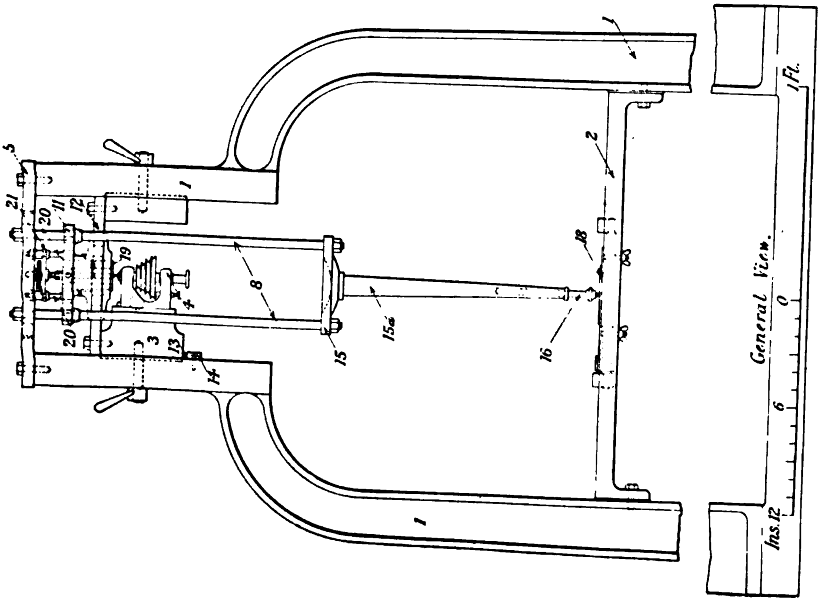


FIG. 9. Punch-Cutting Machine (Benton-Waldo). Enlarged Details.

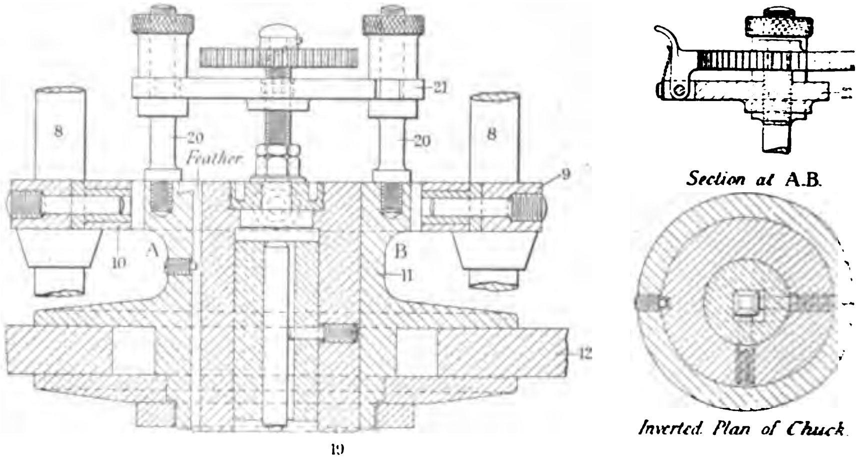




The sliding head, Fig. 11, is bored and lapped axially with the lower gimbals, and the chuck of hardened steel 19 fits in this hole; it is prevented from rotating by a ground and lapped feather fitting without shake. On each side of the chuck are distance pillars 20 shouldered at the top ends to receive the bridge piece 21 carrying the chuck setting-screw. The chuck setting-screw is fitted with a divided wheel graduated to correspond to $\frac{1}{4}$ thousandth of an inch of

Fig. 11.

Detail of Sliding Head and Chuck Fig. 9 (*Benton-Waldo Machine*). Half size.



depth; the divisions are figured on the top and milled in the edge as nicks by which a spring latch locks the wheel to the bridge. Thus the chuck can be instantly removed, the punch inspected and accurately replaced as the work proceeds. Owing to the high degree of accuracy required, these machines cost some £800 each a few years ago; the author recently found however that it was possible to reduce this to about one-third of that sum while obtaining the same degree of accuracy.

The milling cutter used in punch-cutting is shown in Fig. 12; it is parallel and about 0·06 inch in diameter. The other cutters used are the roughing and finishing cutters. These are of peculiar shape, the four faces being cylindrical; the cutting edges which are

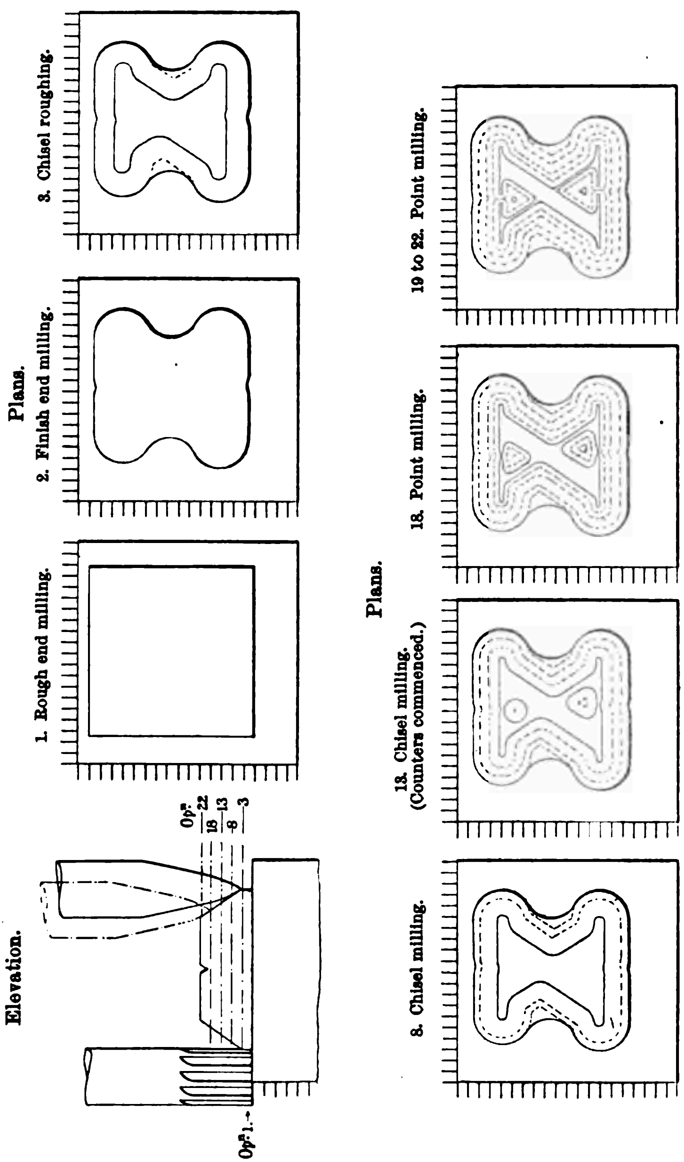


FIG. 12.—*Operations of Punch-Cutting (Benton-Waldo Machine).* (About 4 times full size.)

Fig. 13.

Roughing (or Chisel) Tool for Punch-Cutting Machine (Benton-Waldo).
20 times full size.

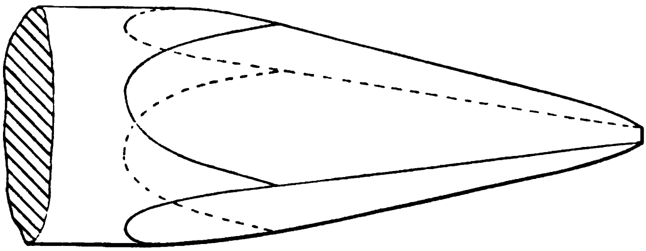
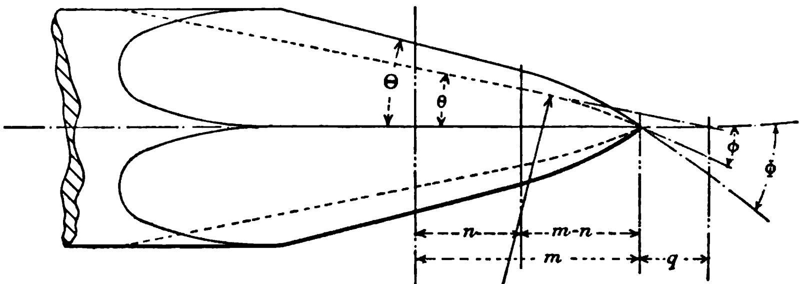


Fig. 14.

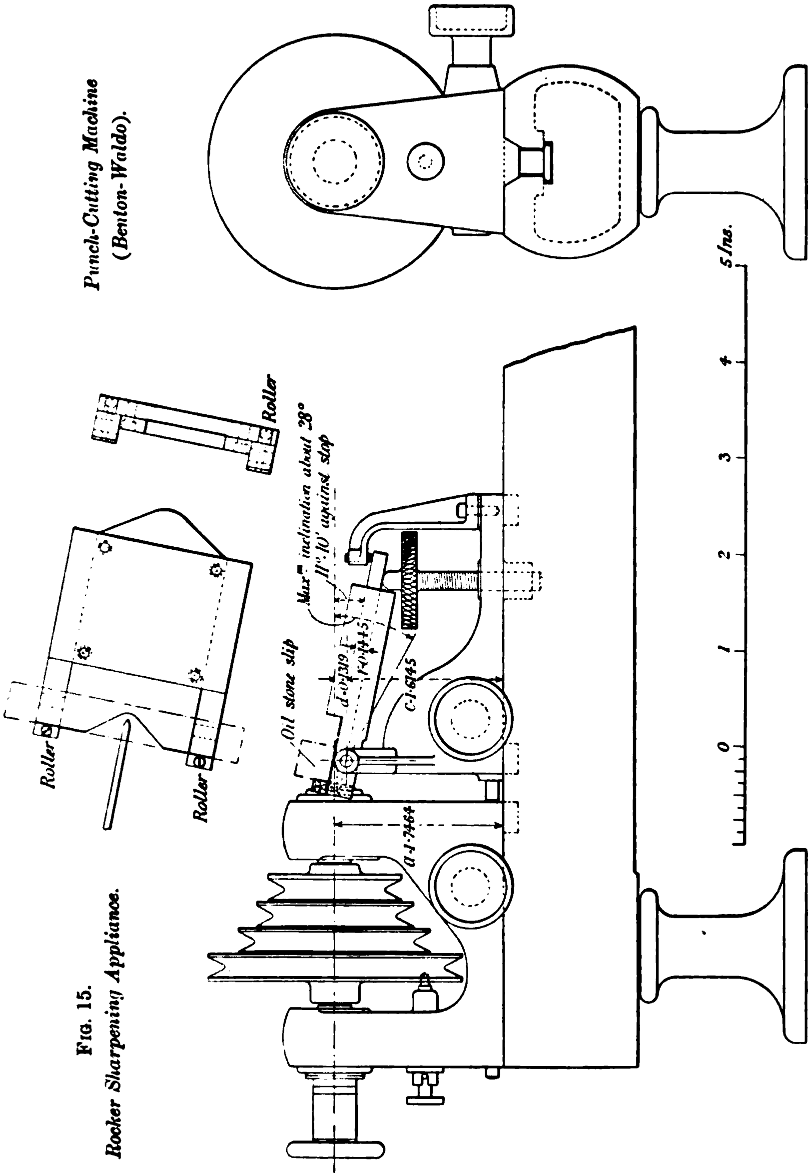
Cutter for Punch-Cutting Machine (Benton-Waldo). 20 times full size.



$\theta = 11° \, 10'$
$r = 0 \cdot 1445$ in.
$c = 1 \cdot 6145$ in.
$m = \sqrt{r^2 - d^2} = 0 \cdot 0590$ in.
$n = r \sin 11° \, 10' = 0 \cdot 0280$ in.
$m - n = 0 \cdot 031$ in.
$m - n + q = (r \cos 11° \, 10' - d) \cot 11° \, 10' = 0 \cdot 0501$
hence $q = 0 \cdot 0191$ in.

tan angle at vertex $\phi = 0 \cdot 445$, whence $\phi = 24° \, 0'$ and over cutting edges, $\tan \Theta = \sqrt{2} \tan \theta$, hence $\Theta = 15° \, 30'$ and $\tan \Phi = \sqrt{2} \tan \phi$: hence $\Phi = 32° \, 20'$.

$a = 1 \cdot 7464$
$b = 1 \cdot 7590$
$a - c = d = 0 \cdot 1319$



Punch-Cutting Machine
(Benton-Waldo).

Fig. 15.
Rocker Sharpening Appliance.

formed by the intersection of each pair of cylindrical surfaces are therefore elliptical. In the roughing cutter which has a small chisel edge, Fig. 13 (page 1064), two of the opposite cylindrical faces have their axes in a different plane to the other pair. In the finishing cutter the axes are all in one plane and a pointed symmetrical cutter results, Fig. 14. To obtain the cutting edges accurately true to position, a hardened steel rocker plate is used in conjunction with an oilstone slip. The rocker plate is secured against its upper surface in the rocker frame, Fig. 15 (page 1065), so as to admit of repeated regrinding to flatness. The oilstone slip is moved to and fro on the hardened steel surface which is cut away to clear the cutter. Both the rocker and the lathe heads fit interchangeably on a watchmaker's lathe bed. The heads are divided in four divisions, so that each face of the tool can be brought uppermost, and while the oilstone is applied the elevating screw is worked up and down by one finger of the operator, so that the plane of the oilstone is successively tangential to each portion of the cylindrical surface which forms the face of the cutter. To obtain the chisel face of the roughing cutter, the position of the lathe head relatively to the rocker is varied slightly for two of the opposite faces by inserting a thin distance-piece between the head and the stop on the rocker.

The punch is cut in the following manner. Pieces of steel are cut off to a given length, annealed and ground true and square on two adjacent sides and on the end. To save work on the punch-cutting machine the ends of the blanks are rough milled to certain simple forms, according to the body of the fount worked on. The punch is held in the chuck against these true faces of the stem by the pressure of two grubscrews, and then is rubbed down true on an oilstone, the chuck acting as the stone facer described above. The first operation in the punch-cutting machine after setting it to the proper reduction ratio for the fount is to mill round the outline to the depth of strike desired; a follower is used of the proper diameter to prevent the mill cutting away any of the beard. For this operation the parallel end-mill is used.

The roughing cutter is next used, and two or three cuts taken round the periphery of the punch, thereby finishing the beard next to the shoulder. The depth of cut is then reduced and a smaller follower used, the depth (corresponding to each diameter of follower) being obtained from a table which is prepared for each body; thus a series of approximations are made to the plane face of the beard, Fig. 12 (page 1063). Some twenty-two cuts in all must be taken round the outside of the character, and some of these also inside the counter; the finishing cutter is used at the end of the process in order to obtain the outline at the surface of the punch. Fig. 12 shows the path of the point of the cutter at five different depths. The punch must be examined under the microscope to see that no error has been made in the cutting. The net labour up to this stage costs about 2*s.* per punch. The next operations are hardening and tempering. These do not appreciably distort the character itself, but they introduce errors of three kinds into the punch, and these prevent it being held perfectly true in the striking press. The face becomes out of square to each of the originally true sides, and the line is no longer square to these faces. To justify the punch the author, with the assistance of Mr. C. Colebrook, of the Wicks Co., designed a small vice swung on gimbals, the two movements of inclination being each operated by a separate micrometer screw. To use this the errors of the punch are measured on two adjustable squares, in each of which the face of the punch is set true by a micrometer screw giving identical readings for the same angles as those operating the vice adjustments respectively. The swing vice is secured to the table of an ordinary surface grinding machine, and one side of the stem of the punch is ground true to the face. The next side is similarly treated, and the depth of cut taken so arranged as to justify the character in respect to these two sides. The trueing up of the remaining two sides to size then requires no special skill, a batch of punches being ground up together on a magnetic chuck.

The *formers* are secured in place on the table of the machine by a pair of folding wedges. They are justified on the two sides which correspond to the trued sides of the punch blank, so that the character which rises about $\frac{1}{16}$ inch above the base of the *former* occupies the desired position in respect to these edges. The base of the *former* is about $\frac{3}{32}$ inch thick. In the case of accented sorts the upper part of the *former* is cut away to receive the accent *former*, so that. the number of *formers* required can be kept a minimum. Special accents are required for the i owing to its small *set*, and a blank piece of equal size for the production of the non-accented sorts. With the exception of the i the accents can be made interchangeable.

A few of the *formers*, such as the mathematical signs, can be conveniently made on ordinary machines out of two thicknesses of metal riveted together, but for the majority a different method is usually employed.

A *drawing* of the character is made about five times the size of the *former* required. The edges of the *former* are shown on this drawing to scale and in their proper position. The drawing is then fastened on the table of a pantograph under the tracing pin. The marking head of the pantograph is fitted with a plain cylindrical tool. The ratio of the pin diameter to the tool diameter is the same as the ratio of the pantograph. It is essential that there should be no backlash in the pantograph, and that it should be extremely rigid. The author with Mr. Colebrook designed a pantograph which has given very satisfactory results. The frame was made of bicycle tubing with steel single and double joints brazed in, the centres being all made adjustable double cones like lathe centres.

The *formers* are produced by electrotyping in the following manner. Type-metal plates of equal and uniform thickness are coated with a wax composition which is shaved off on a machine to the thickness of the raised portion of the letter. The pantograph tool is lowered so as to pierce the wax and pushes its way through it, the first tracks being kept a small distance away from the finished line. After the character has been roughed out the wax surface is rubbed true by going round with the outside of the tracer pin touching the line on the drawing. The burr on the wax is dressed off on the shaving machine; the wax is examined and any holes stopped. The whole is then blackleaded and electrolytically coated with copper to a thickness of about 0·03 inch. The shell is removed by warming the wax, the rough edges are trimmed, it is then tinned inside and filled with lead. The filled *formers* are milled off on the back to thickness, and squared up on the justified edges so that the character is truly in place in respect to these edges.

The "hand" and size of the character as compared to pica body varies through these and the following operations thus :—

(1) Drawing . . .	inverted	90 times full size.
(2) Wax mould for *former*	inverted, but reduced to .	18 " " " *
(3) Electrotyped *former*	erect	18 " " "
(4) Punch	inverted	natural size.
(5) Matrix	erect	" "
(6) Type	inverted	" "
(7) Printing . . .	erect	" "

In the case of newspapers and many books two more reversals occur, a mould in flong (which somewhat resembles papier mâché) being taken from the type and a stereotype cast from this.

Matrices (Figs. 16 to 21, page 1070).—In consequence of the care expended on the punch, the actual impression made in the matrix when the punch is struck is practically as accurate as the punch when the mass of the matrix metal is large, but in some cases the metal in the centre of the strike rises under the action of the internal stresses caused by striking, with the result that the character cast in it is hollow in the face. Such difficulty may be dealt with successfully by drilling a hole transversely in the matrix blank below the centre of the strike as shown in Fig. 18. The form of the matrices varies greatly with the machine in which they are used ; the simplest form (generally of copper) is that shown in Fig. 16, and is used in the simple typecasting machine for casting one character at a time. The matrix for the Wicks machine is struck in the end of a long stem of brass which

* In the case of pearl the reduction in the punch-cutting machine is about one forty-fifth.

***Matrices.* Full size.**

FIG. 16.

Titchener.

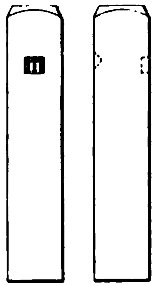


FIG. 17.

Wicks Rotary.

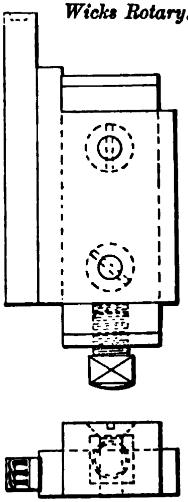
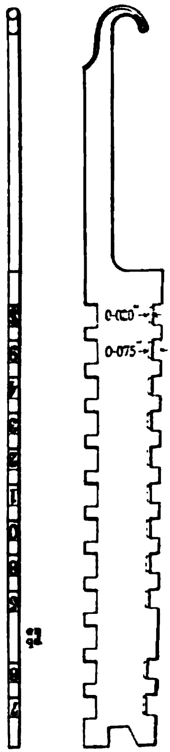


FIG. 18.

Lanston Monotype.

FIG. 19.

Monoline.



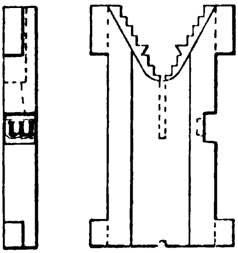


FIG. 20.—*Linotype*

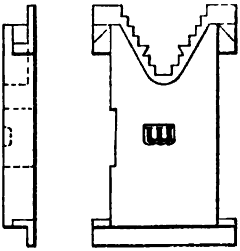
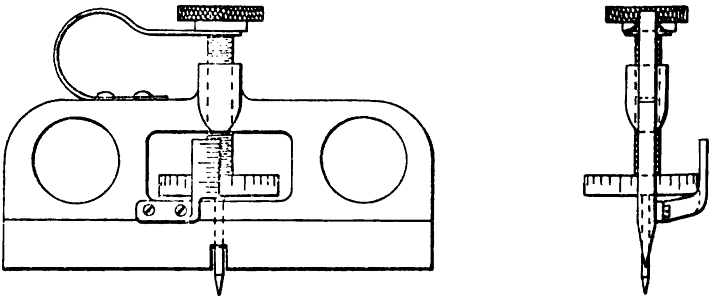


FIG. 21.—*Stringertype.*

FIG. 22.—*Needle-Point Micrometer Depth Gauge.* **Full size.**

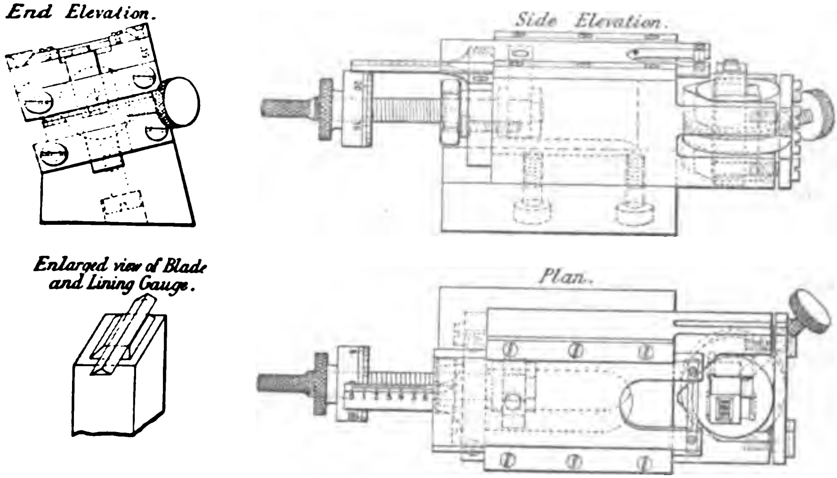


is machined on its sides, Fig. 17. The Lanston Monotype matrix, Fig. 18, is struck in the end of a small square block of bronze. The Linotype matrix is struck in the edge of a sheet brass stamping, Fig. 20. The Monoline machine uses a compound matrix having several strikes on one bronze bar, Fig. 19, and the Stringertype matrix is struck on the flat side of a brass stamping, Fig. 21.

FIG. 23.

Micrometer Measurer for Punches and Type.

Half size.



Justifying.—The operation of fitting or machining the surrounding metal so that the face of the strike, which is at the bottom of the depression in the matrix, is accurately placed in respect to the exterior is known as justifying. The matrix is tested by taking a trial cast, comparing this with a standard letter, usually the lower case m, and measuring it with various appliances. A needle point micrometer, Fig. 22 (page 1070), is used for the depth and a bevelled edge micrometer, Fig. 23, is used for measuring the face. Squares are used for testing the face, the type being sighted against the light in two directions at right angles to each other. In the case of the simple matrix shown in Fig. 16 the trial and error method suffices, but in the

Wicks matrix a number of milling operations are necessary. The trial type must be measured, and the matrix stem bent and twisted to bring the strike true for squareness of face and line. Cuts are then taken off the sides of the matrix and off the base; trial type are again taken, and the matrix further corrected if found necessary; finishing cuts are taken, and last the matrices are gang-milled to length and end-milled to body. With hand-cut punches some twenty-three operations were necessary; with machine-cut punches the number was reduced to about seventeen; the various operations are shown in Fig. 24. The work of justifying is very highly skilled, a good justifier earning £3 10s. to £4 per week; it is therefore of great importance to reduce this work to a minimum. The reduction in number of operations was largely effected by rigidly holding the punch close to the face, by rigidly holding the matrix close up to the strike, by supporting the metal on all sides, and by accurately setting the punch in position before striking. The saving in justification was effected by elimination of some of the earlier roughing operations.

In the case of matrices which are required in large quantities for matrix composing machines, the adjustment of the striking press must be made by the justifier, and when set the product controlled from time to time. The larger the number of matrices to be struck and justified, the more important it is that the punches be themselves accurately justified and accurately set in the press. In the earlier matrices made for the Wicks machine the author used a light, overhung striking press weighing only some 100 lb.; for the later matrices made in quantity, a press with symmetrical slides and a central plunger was used weighing some 30 cwt., the extra rigidity contributing greatly to saving in justifying.

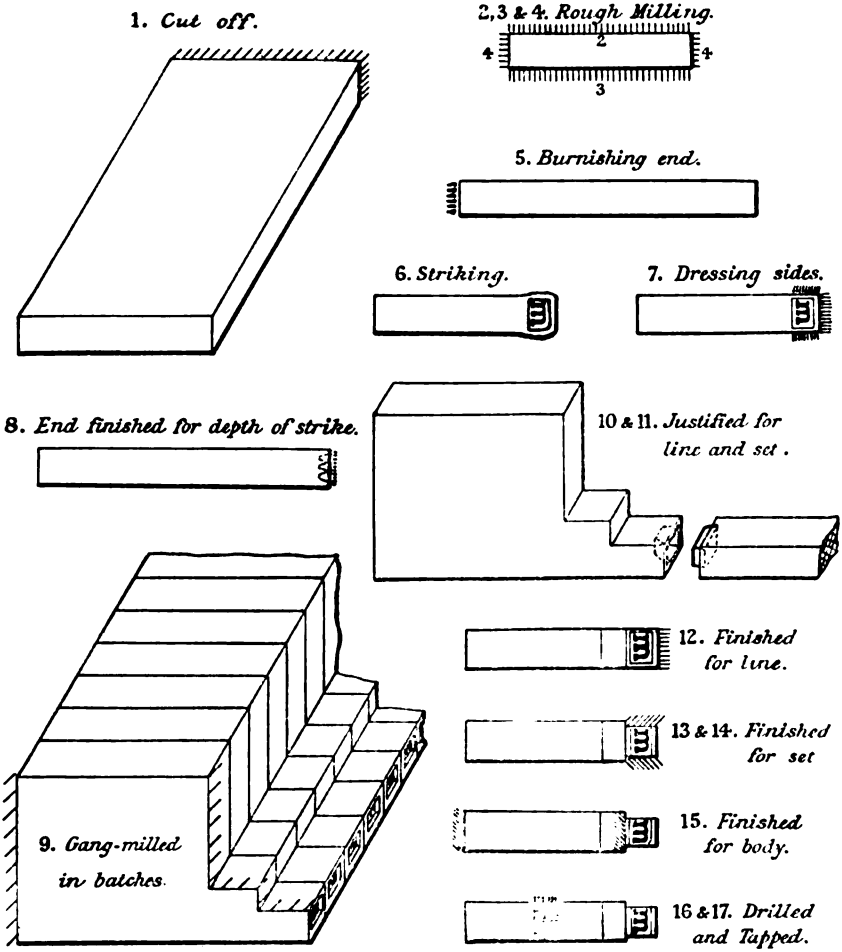
Depth of Strike.—The depth of strike in ordinary matrices is usually 0·045 to 0·050 inch. It is, however, less in the matrices of several of the casting and composing machines; it attains its minimum 0·02 inch in the Linotype and Monoline.

Engraving Matrices.—A method of manufacturing matrices has been introduced in the last few years, in which the operation is

Fig. 24.

Operations in Machining Matrices.
(Wicks Typecaster.)

Full size.



performed by a small high-speed cutter carried on a pantograph; a *former* is used and the process is the converse of that employed on the punch-cutting machine.

The Ballou Engraving Machine for Matrices.—The problem of engraving the matrix is much simpler than that of cutting punches. The character can be cut out of metal plate like a stencil and then secured by riveting or tinning to the backing. The follower may be of constant diameter, but must be sufficiently small to allow it to follow the outline in the hair lines. The shape of the cutter can be that obtained by grinding a small amount off two of the opposite faces of a square pyramid, so that these faces meet in a line, the length of which is in the same ratio to the follower as the reduction ratio on which the machine is to work. The depth of cut is constant, the flat surface of the main stroke being obtained by traversing ten or more times to and fro over the length. The complex settings of the Benton-Waldo machine are here unnecessary, and since the material to be cut is soft the cutter lasts a long time without sharpening, and the sharpening itself is a comparatively simple matter. The machines when set and adjusted by skilled mechanics can be operated by girls.

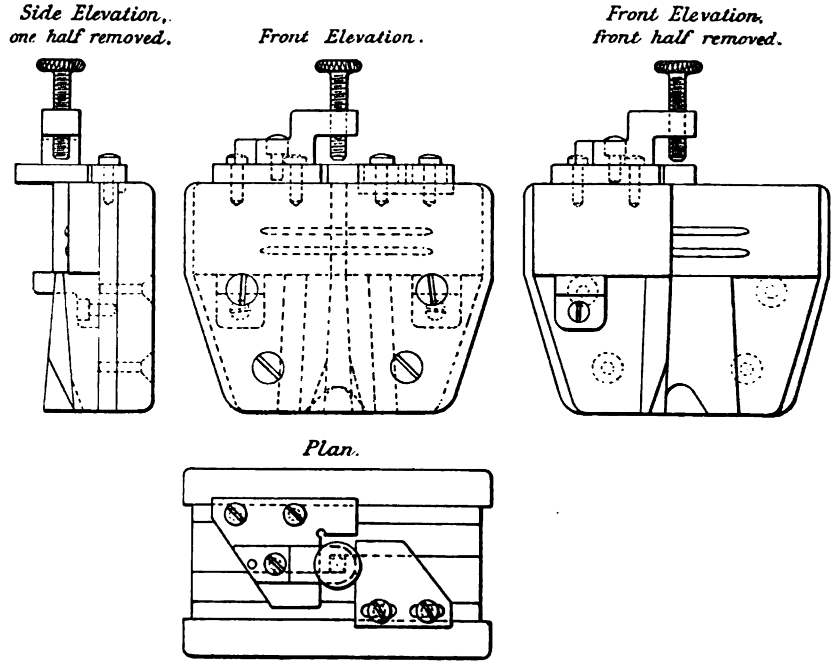
A similar machine known as the Dietrich was introduced about 1899. It was arranged to operate successively on four matrices.

Electrotyping Matrices.—The easiest method of making matrices for the simple typecasting machines is by electrolytic deposition of copper. A type of the desired character can be surrounded by two pieces of type-metal of similar form to the mould, and the *face* of the matrix is thus obtained true in the first place; the rough deposited sides of the matrix are filed or machined true subsequently. There can be no objection to the use of this method in cases of urgency or repetition, for example when a punch has been damaged or broken, but it has been resorted to by less-principled founders in copying the founts of the leading founders. For the matrices used in the later forms of typecasting machinery electrolytic copper is not generally hard enough to stand the wear, and the rough deposited surfaces require too much and too troublesome machining. A new process has recently been introduced in Germany by which the matrices are deposited in nickel much harder than the bronzes hitherto in use, and it appears to the author that this may be of considerable importance in the manufacture of machine matrices.

Moulds.—The simplest form of mould consists of two halves which are nearly alike. Both are built up of pieces of hardened steel ground and lapped true, and screwed together. The mould thus made is of definite size for *body* but variable for the width of *set*, the parts being fitted with stops which close on the matrix and obtain from it the correct *set* width, the width of each matrix being therefore the *set* + a constant. In the direction of the height of the type the mould is wider than the length of stem, so as to provide for the gate for the injection of the molten metal. In one part of the mould are inserted the raised beads for producing the nicks in the type, and in the counterpart grooves are ground and lapped to fit the raised beads which are exposed in the mould for a greater length as the *set* of the type to be cast is increased. The author has found that type-metal under the conditions of typecasting machines will flow into an opening between surfaces varying from 0·0005 inch where the surfaces are water-cooled internally, to 0·0002 inch (and even less) where the mould is allowed to become warm. This inflow of metal will cause difficulty in ejecting the type, and will give it a fringe or ragged edge. In moulds of the kind just described, where no provision is made for continuously cooling the mould, the type cast from the mould before it has attained the working temperature are not accurate for size; the speed is limited to that at which the mould does not overheat unduly, and in practice it is kept from overheating by stopping the machine from time to time and cooling with a wet rag. Some idea of the difficulty and expense of mould making may be gathered from Fig. 25, which shows a mould for type with two nicks (the average number). The one half consists of at least five pieces while the counterpart carries in addition the beads and the stop. The beads for forming the nicks contribute greatly to the difficulty, since the hole is partly in each of

Fig. 25.

Justifier's Type Mould.
Half size.



two pieces of hardened steel which must be finished before the hole is lapped out, and the wire, which is made a gauge fit, must have its axis parallel to the surface within the degree of accuracy required for tightness in respect to the melted metal. As the mould undergoes some distortion when heated, and some due to wear, the fit when new requires to be within 0·0001 inch. Mould making as a trade is over

200 years old, and as in the case of lapidaries' work the finishing is usually done by means of lead laps; the skill attained by the workmen in this trade is remarkable.

The Wicks Mould (Fig. 48, page 1096).—Difficulties, however, beset on all sides the inventor and the engineer who have to design and make moulds of forms different from those to which these workmen are accustomed. The mould of the Wicks machine will serve as a particular example. The moulds of the Wicks machine are of the form of 100 radial grooves in a disk 20 inches in diameter. The groove, three inches in length, forms three sides of the mould (the back and sides of the type). The matrix, Fig. 17 (page 1070), slides in the mould; the top cover, *c*, Fig. 48 (page 1096), which is fixed and under which the mould passes, forms the remaining side of the body (the front of the type) and the shield, *q*, through which the molten metal is injected forms the foot.*

The first attempts to build a mould not proving successful, the next step taken was an attempt to mill and lap out the grooves in the disk. This also failed to give satisfactory results, and recourse was again taken to building up the mould. The mould-wheel in this form was as shown in Fig. 29 (page 1079). The mould-wheel was built up of a cast-iron wheel in which an annular groove formed the water space, which was covered by a cast-steel foundation ring turned all over, the latter being secured by studs to the upper surface of the cast-iron wheel.

The upper surface of the foundation ring was turned flat and scraped true; the wheel was then mounted on a division plate and dowel holes drilled through a jig carried on the central column of the division plate. Dowel pins were driven into the holes in the foundation ring and the segments (also drilled in the jig) pressed down into place; tapped holes were also necessary in the segment to enable it to be drawn off the dowels for grinding and for lapping the

* The error introduced through the foot having a 10-inch radius is very small. A pica em quad has for sagitta of the arc forming its base a length of only 0·00035 inch, which is less than the permissible error in height-to-paper for type.

sides. To obtain squareness in the parts of a mould, the knife-edge square, Fig. 26, was used; for straightness of the faces the knife-edge triangular straight-edge, Fig. 27, was employed, and to measure the width of the mould at various parts of its length, folding-wedge gauges divided on the upper sides were used as shown in Fig. 28. The segments were made of cast steel and left soft. Allowance for grinding was made on the thickness of the segments and the aggregate top surface ground true in place. This wheel gave fairly satisfactory results, but the top of the segments

FIG. 26.—*Diamond Square.*
Half size.

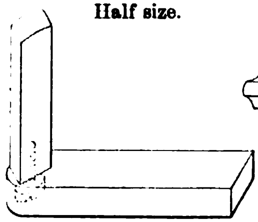


FIG. 27.—*Knife-edge Straight-edge.*
Half size.

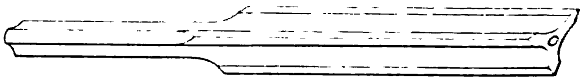


FIG. 28.—*Folding-wedge Gauges for Measuring Type-moulds (taper 1 in 100).*
Full size.

wore rapidly under the top cover which was kept in contact by spring pressure. The next improvement was to adjust the top cover by means of folding-wedges and a screw adjustment so arranged that the cover could be brought down into contact with the segments and then backed off some 0·0002 inch to 0·0003 inch. This did not, however, stop the wear of the segments owing to the difficulty of lubricating sufficiently and yet obtaining perfect type. The next step consisted in milling dove-tailed grooves in the foundation ring, and in fitting the hardened steel base pieces which were secured by dowel pins, Fig. 30. The whole surface of the foundation ring was then ground true in place on its column, transferred to the division plate and hardened steel segments fitted. These segments were

Details of Rotary Typecasting Machine (Wicks). Full size.

FIG. 29.—*Soft Moulds.*

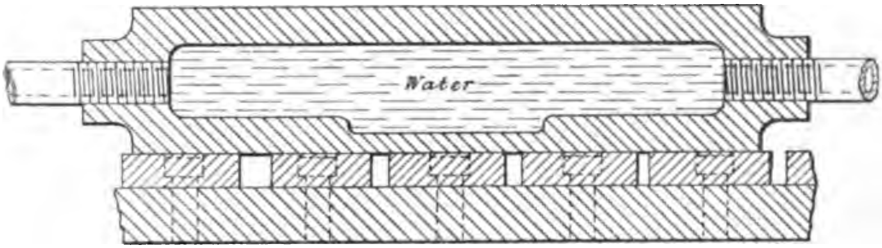


FIG. 30.—*Hard Moulds.*

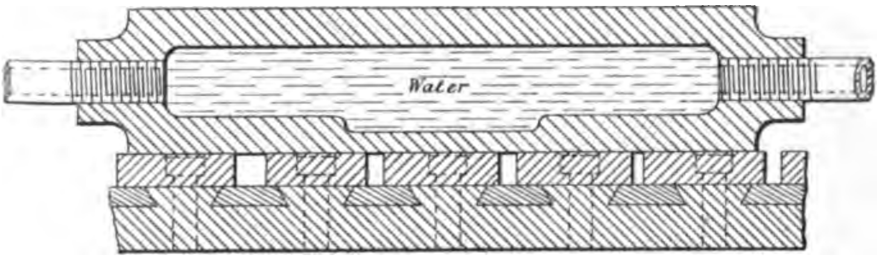
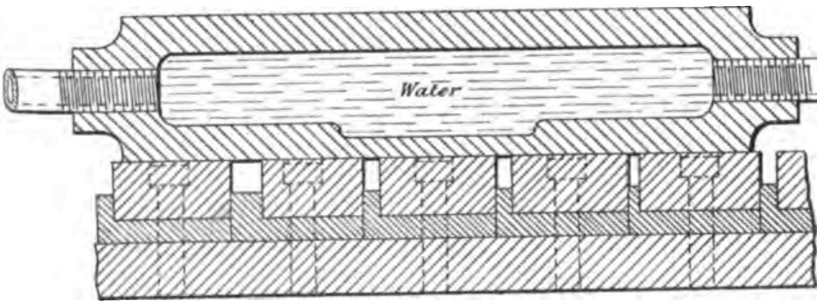


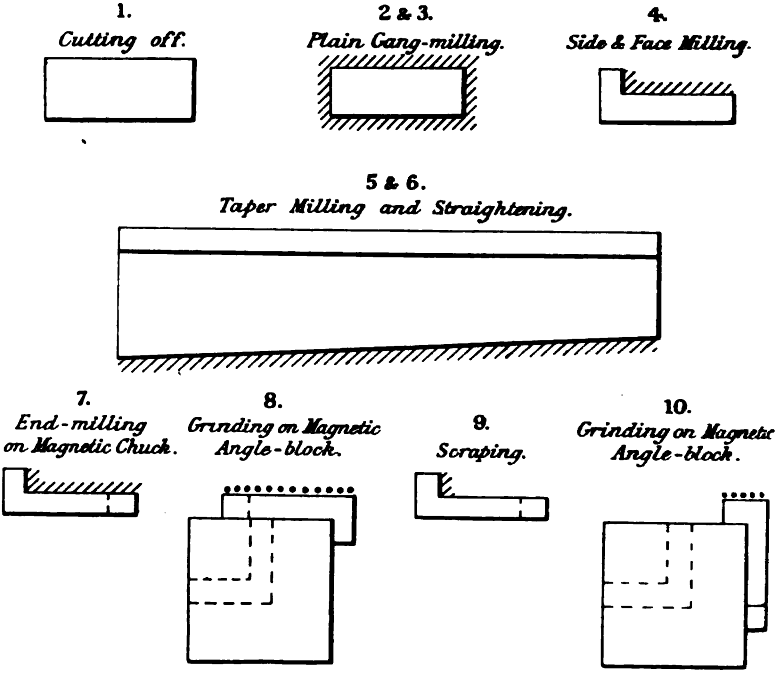
FIG. 31.—*Angle-base Moulds.*



secured by dowels and screws as in the case of the soft segments just described. This wheel was extremely costly to make, and when put to work showed appreciable wear in so short a period of time that the amount of type produced before the wheel required new segments would not have been sufficiently large to ensure commercial success.

FIG. 32.

Angle-Base Operations. *Rotary Typecasting Machine* (Wicks). Full size.



A number of machines had now to be constructed in a limited time, and the problem was dealt with by the author in the following manner. The surface of the foundation ring was turned and ground true in place on its column, and the mould was built up of two segments as shown in Fig. 31 (page 1079). The angle-base segments were of annealed cast steel and produced by the following operations, Fig. 32. (1) cut roughly to length; (2) and (3) rough gang-milled all over; (4) reduced over part width by milling; (5) tapered by milling in batches; (6) straightened; (7) end-milled in angle on magnetic chuck; (8) ground on back on magnetic chuck; (9) scraped straight on short vertical face; and (10) ground to *set*-width on magnetic angle-block.* The top segment operations consisted in (1) cutting to length; (2) and (3) rough gang-milling; (4) tapering; (5) straightening; (6) and (7) grinding on flats; (8) and (9) grinding on edges. Both top and bottom segments were at this stage about ½ inch longer than necessary for the reason that the bottom segment, if made to the standard dimension from the centre of the mould to the edge at the periphery of the wheel, would fail to make up the width should the next preceding segment be narrower in *set* of the mould of which it forms the base.

Assembling.—The first operation consisted in drilling and tapping the foundation ring; the drilling was performed by aid of a jig carried on the division plate and the tapping was done by an automatic tapping-head. The drilling jig was then removed and a segment put in place which had been already drilled by the setting jig while clamped on the plate; each segment was numbered as put in place; this setting jig had gauge surfaces a constant distance, C, from the centre of the mould; gauges were used for the setting of a width equal to C − ½ (*set*). The setting ring was then put on the outside

* The surface of the ordinary magnetic chuck, Fig. 33, will probably be familiar to many Members of this Institution, but for the class of work now in question it was frequently necessary to grind segments on the edge; also, owing to the high degree of accuracy required, the surfaces of the vice on which the segments were placed required re-grinding whenever the magnetic vice was replaced after being removed from the machine. The author designed the two kinds of magnetic angle-blocks shown in Fig. 34, which have proved useful for a number of purposes. The blocks each consist of two soft mild steel bars of good permeability milled out to └ or └┘ shape and cross-milled with cuts which leave space for the complete separation of the two pieces of mild steel. The ends are secured by brass plates and screws, and the whole of the interspace is run up with white metal. The block is placed on the magnetic chuck, so that its poles respectively come over the poles on the chuck. The exterior can then be ground true, in place, on the surface grinder.

of the wheel and secured roughly true by means of four set-screws; this ring carried 100 screws, each of which served to adjust a segment in place by sliding it along the preceding segment; and as each was brought to position, it was then clamped by a temporary clamping

Fig. 33.—*Magnetic Chuck, Plan.*

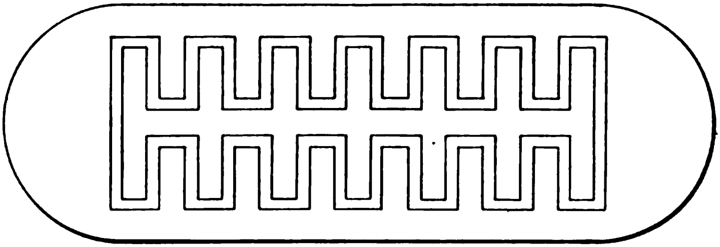


Fig. 34.—*Magnetic Angle-Blocks.*

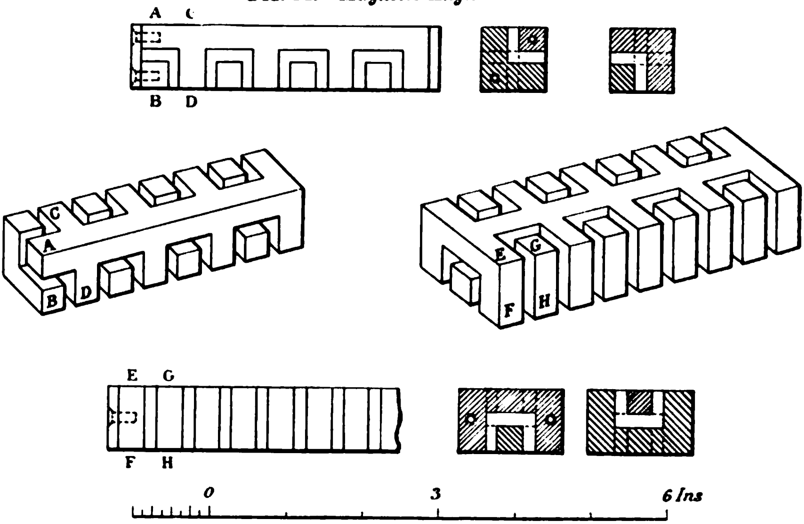
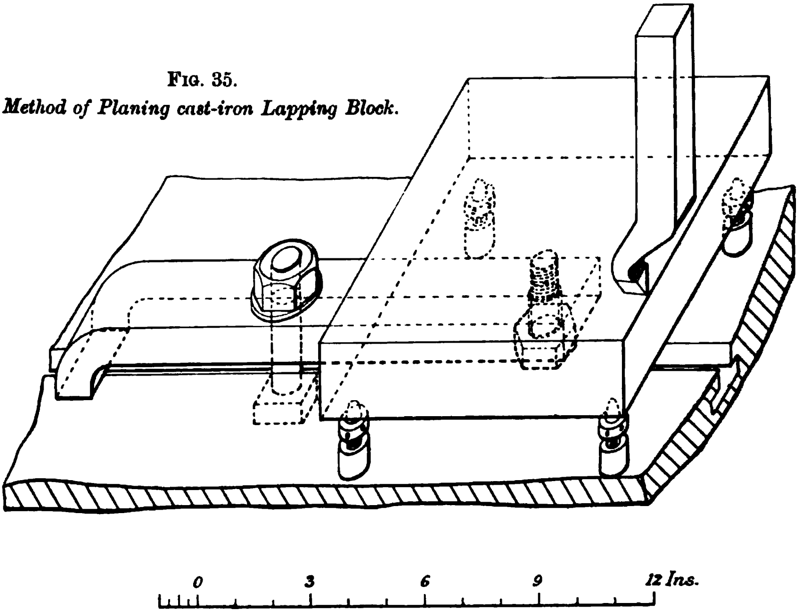


plate and screw at the inner end. The setting having been completed, a sensitive drill, used in conjunction with the drilling jig, drilled the necessary holes in each segment, viz. three clearing holes for the holding-down screws, one hole for dowelling the angle base to the foundation ring and one hole dowelling the top segment to the angle base, one forcing screw-tapping hole for removing the angle base from its dowel; and, in every tenth segment, a seventh hole for clearing the supporting stud of the matrix guide-ring. The angle bases could now be removed from the wheel, cut to length, and the burrs removed; the tapping could be performed and the straightness checked; if found necessary the short vertical face was again scraped. The setting ring was then raised and clamped roughly true so that the centres of the screws came opposite the *top* segments. The bottom segments were replaced on the wheel and secured by temporary screws through the clearing holes. One angle base being dowelled to the wheel, a top segment was placed on this and another top segment on the next consecutive angle base, each top segment having been lapped true on its vertical faces. The top segments were pressed towards the centre of the wheel by the setting screws, and the width of the mould formed by them was measured by means of the folding-wedge gauges, Fig. 28 (page 1078). The angle base was then forced off its dowel and lapped on the vertical face, until the mould obtained was a gauge fit through its length. Each mould was thus finished in turn and the top segments as finished were dowelled to the bottom segments, each being numbered as put in place. The top segments were then all removed, and the angle bases secured by temporary screws with thin flat heads; the wheel was transferred to its own central column on which the foundation ring had been ground true. The tops of the angle bases were now ground true in place, the top segments replaced and also ground true, the depth of the mould or size of body being thus obtained. The wheel was then ground true on the periphery and the shield scraped to fit. The underside of the wheel was also ground true, to give a bearing for the lower bearing surface carried by the shield. These adjustable folding-wedges are shown at o_3, o_4, Fig. 48 (page 1096).

The soft wheel, however, did not meet all requirements. The body-size could be restored a large number of times by grinding the tops of the angle bases and the tops of the segments; but the top segments wore after a considerable period, so that the less important dimension, the *set*, became large; but the greatest difficulty to be met was the provision for the nicks in the stem. Experiments made on a wheel with soft segments demonstrated the possibility of casting the nicks instead of milling them, and thus obtaining type more free from burr, with a nick more acceptable to the compositor, and with less risk of breakage of the thin sorts.

The necessity for hard top segments now became apparent. In making these the first five operations were the same as in the case of the soft segments. The sixth operation consisted in drilling in a

Fig. 35.
Method of Planing cast-iron Lapping Block.



jig, in which the segment was set in place with allowance for grinding, according to the sizes of the preceding and succeeding moulds of both of which it formed part. The seventh operation was cutting to length, and the eighth hardening. The tempering was performed by heating in an oil bath at a temperature of about 320° F. for some four hours. By this method the hardness could be adjusted with great nicety and equality, for the whole of the wheel. The inner ends of the segments, in which the hole for the dowel pin had not yet been drilled, were softened. The segment was then rough ground on both flats, rough ground on the edges, re-ground on the faces after an interval of time for recovery, re-ground on the vertical faces, and finally lapped on these faces.

The wheel being assembled, the nick grooves were ground in with a fine emery wheel turned to shape on the edge to give the required section and depth. The beads in the top cover were produced in the following manner. The top cover was mounted on the circular rotary table of a vertical milling machine; a small cutter spindle, driven by an electric motor, was used to mill out a groove of the required width for the bead and to the correct radius from the axis of the wheel. The bead was made of hardened steel wire ground and lapped cylindrical and subsequently ground flat on two faces to fit the milled groove tightly. At the one end the milled groove was tapered by hand to permit of removal of the bead for fitting. The final fitting was done by lapping the face of the wire opposite the bead. The curvature of the groove in the top cover was so slight that the bead wire could be sprung into place without difficulty. The nick bead is shown at *e*, Fig. 48 (page 1096).

The Linotype Mould is shown in Fig. 36 (page 1086). As in the case of the moulds already described, it is built up of several pieces of hardened steel. The special features of its construction, will, however, be seen best by reference to the drawing of the type slug cast from it, shown untrimmed in Fig. 38 (page 1087). The cross projections at the foot of the slug prevent the slug from being sucked forward through the mould when the matrices are withdrawn from the face. These projections are removed by the end trimming knife, during the partial revolution of the mould wheel; to prevent the nozzle drawing the slug back, each end of the mould is formed with a small projection at the foot. The grooves in one long face of the mould form raised ribs on the back of the slug; in ejection from the mould these pass through between the trimming knives which shave them down, and ensure correct body size when the slugs are placed in column.

In the limited space of this Paper the author cannot describe in detail the moulds of all other typecasting machines, but single type

FIG. 36.

Mould and Mould-Wheel (Linotype Machine).

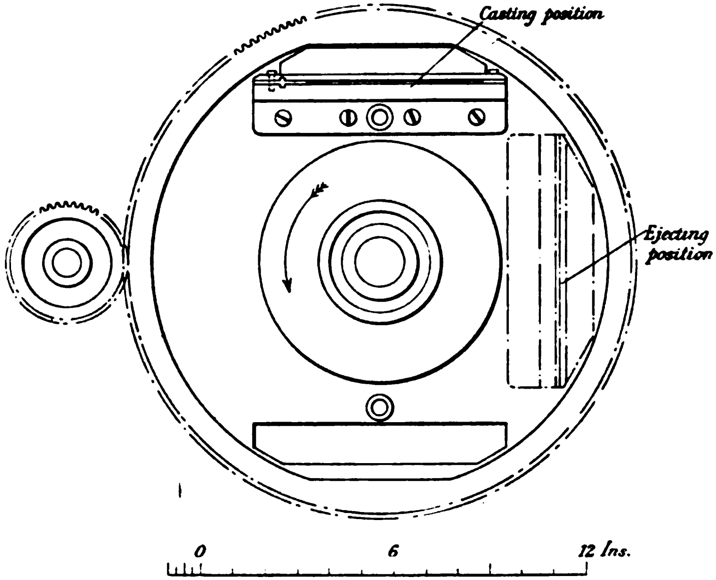


FIG. 37.

Interrupted-revolution Driving Gear of Mould-Wheel (Linotype).

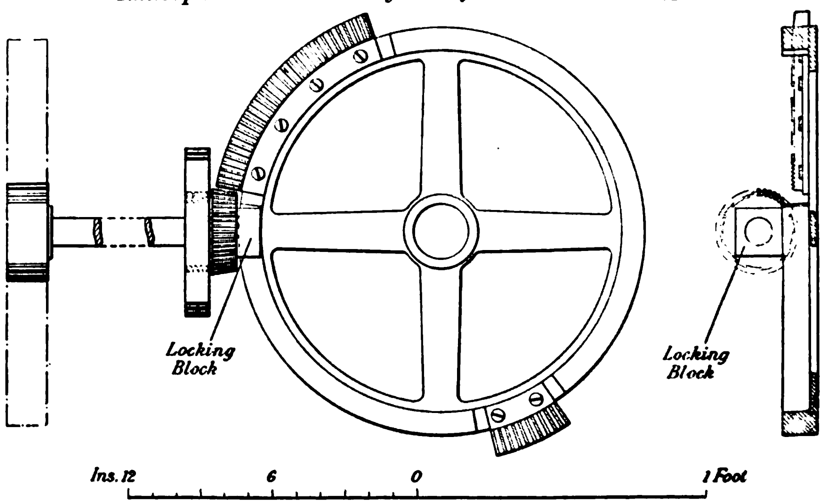


FIG. 38.—*Type Slug as cast in Machine before trimming (Linotype).*

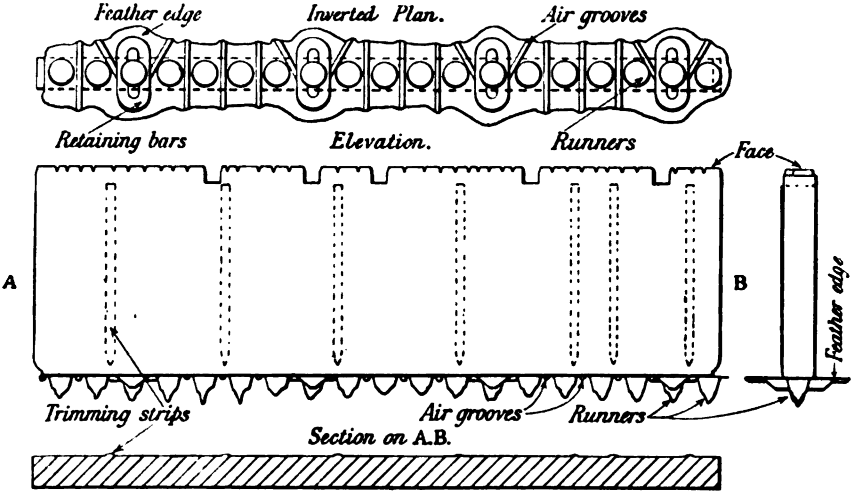


FIG. 39.—*Type Slug finished (Linotype).*

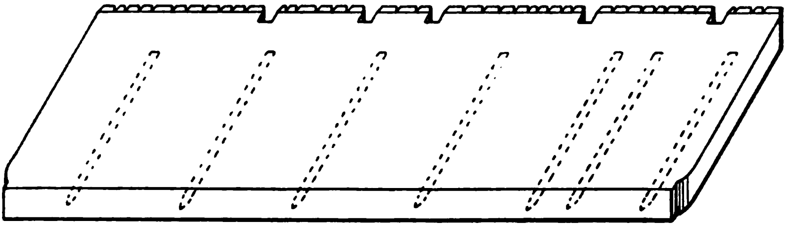


FIG. 40.—*Type Slug finished (Monoline).*

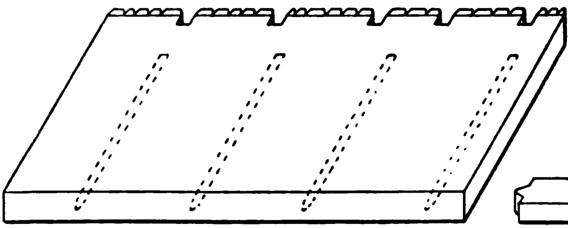


FIG. 42.
Type (Stringertype). As cast.

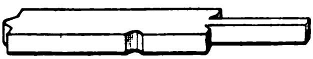


FIG. 41.—*Type as Cast in Machine (Lanston Monotype). Tang and jet shown dotted.*

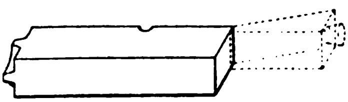
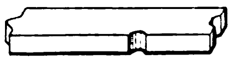


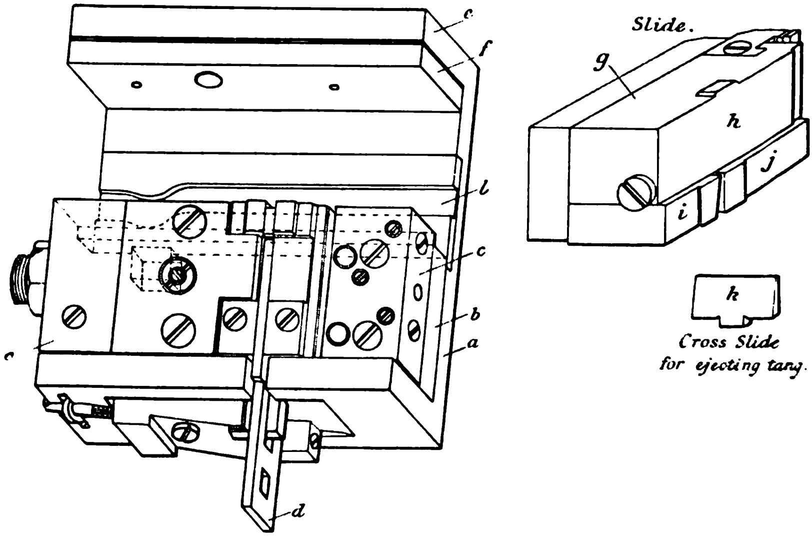
FIG. 43.
Type (Stringertype). Tang broken off.



as cast in two of the machines mentioned in the Paper are shown in Figs. 41 to 43.

The Mould of the Lanston Monotype Machine, Fig. 44, is built up of several pieces. In the foundation plate of the fixed part is the hole for the injection of metal from the pump; this hole is coned to

FIG. 44.—*Casting Machine* (*Lanston Monotype*).
Perspective View of Mould.



a. Foundation plate.
b. Intermediate plate.
c, *c*. Body blocks.
d. Rectangular sliding plate.
e. Vertical plate.
f. Hardened steel bearing plate.
g. Slide.
h. Main portion of slide.
i, *j*. Tang pieces secured to main portion of slide.
k. Tang cross-slide.
l. Cam groove.

fit the end of the pump nozzle which is elevated into place before starting the machine. To the foundation plate is secured an intermediate plate, and on the top of this are fixed two body-blocks which form respectively the back and front of the type; between these blocks, through which water is circulated, slides a rectangular plate of the same section as the type measured from foot to shoulder. The position of this slide is regulated by means of wedges, as described below, so as to give the required *set* width to the type to be cast. A vertical plate is secured to the end of the foundation plate opposite to the mould, and a hardened-steel bearing plate is secured to this by dowels. In the space between this bearing plate and the face of the body-blocks the slide travels to and fro for each character cast. The slide itself is built up of a number of pieces, two of which, fixed to the main portion, form the front and back of the tang of the type; a tang-slide working between these forms the side of the tang. The fourth side of the tang is formed by the vertical face of the intermediate plate between the foundation plate and the body-blocks. The slide is guided by the projection of the tang pieces below the body-blocks; the tang cross-slide is moved by a projection fitting in the cam groove milled out of the foundation plate.

The operation of casting is performed as follows: the slide comes to rest with the tang opening opposite the mould; the cross slide moves to the *set* width required, which is generally determined by the position of the matrix grid; the matrix grid descends on to the top of the mould and is brought to true position by means of the conical hole in the back of the matrix, Fig. 18 (page 1070). The pump plunger makes its stroke and fills the mould and tang. The matrix grid is lifted and the slide moves to the right, shearing off the tang from the type and the jet; as the slide continues its movement the tang cross-slide moves towards the body-blocks, ejecting the tang through the hole in the intermediate plate. When the slide has travelled clear of the type, the cross-slide ejects the type from the mould into the type carrier which delivers it to the galley; the slide then returns to the casting position. The whole cycle is repeated for each type cast.

Pumps.—Some of the greatest difficulties in the design of typecasting and matrix composing machines are to be found in the pump. They are generally of three kinds: (*a*) freezing of the jet, (*b*) stoppage of the jet by accumulated oxide (which occurs in pumps of intermittent action), and (*c*) difficulty in getting rid of the air which fills the pump delivery-pipe and mould and causes blowholes in the type.* These difficulties are met by various expedients; the jet is separately heated by gas burners, and is so arranged that metal does not remain adhering to the orifice and there become oxidised; the plunger throughout the working length is immersed below the oxidised surface in the metal pot and the surplus metal which is pumped is returned to the pot without exposure to the external air; the metal is delivered in large quantity and continuously, so that but little heat need be supplied by extra burners under the jet; and last, in some cases (e.g. the Linotype machine), special provision is made for clearing the air by fine grooves cut on the face of the nozzle.

The pump employed on the simplest typecasters consists of a single plunger mechanically fitted and spring operated. The pressure on the plunger at the commencement of the stroke is about 60 lb. per square inch, and falls during the stroke.

The Wicks Rotary Typecasting Machine Pump has four plungers about 1 inch diameter by 2 inches stroke, each driven by an eccentric and rod from a belt-driven shaft. The plungers are a mechanical fit in holes in a steel block forming the cylinders; the inlet and delivery valves are flat-seated disks enclosed in cover-plates bolted to the pump body. The delivery pipe is fitted with a vertical branch which forms a cylinder in which a mechanically-fitting plunger operates; this plunger is loaded by a lever and dead weight through the intervention of a long coiled tension-spring; at the top of the travel of the plunger in the cylindrical bore is a cross hole; the plunger thus serves the double purpose of accumulator and relief valve. The pump runs normally at 100 revolutions per minute, and the relief valve works at a pressure of 150 to 250 lb. per square inch. The diameter of the jet is about 0·1 inch. The pump delivers a large surplus of metal through the jet, which is returned through a shoot to the metal pot of pressed steel in which

* In his typecaster Sir H. Bessemer created a vacuum in the mould immediately before casting; although this method appears to have been successful in his case, it has no practical application at the present time so far as the author is aware. *See* "Life of Sir Henry Bessemer," p. 38 *et seq.*

the pump body is immersed. The metal is kept at a temperature of 700° to 800° F. by gas burners beneath the pot.

Linotype Pump.—This pump plunger is shown in Fig. 45, and the jet in Fig. 46. The plunger is made an easier mechanical fit than in the pumps previously described, and depends largely on the effect of the grooves. This method will be familiar to many Members of the Institution from its adoption some 25 years ago for the piston-rod in some tandem steam-engines. The pump is spring operated, the pressure being about 27 lb. per square inch at the commencement

FIG. 45.—*Pump Plunger (Linotype).* Half size.

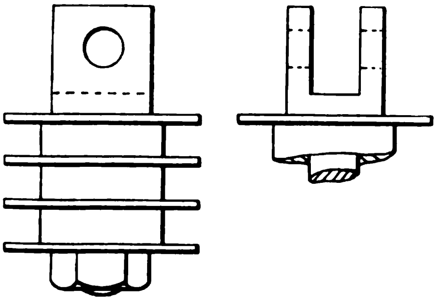
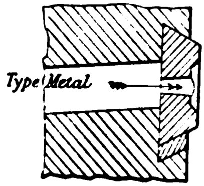


FIG. 46.—*Metal-Pot Mouth: Section (Linotype).* Nearly full size.



of the stroke and about 16 lb. per square inch at the end. The metal used is softer and has a lower melting point than that used in the other pumps described above.

The Pump of the Lanston Monotype Casting Machine delivers the metal vertically upwards into the mould, see Fig. 44 (page 1088).

CLASSIFICATION OF TYPECASTING AND COMPOSING MACHINERY.

There are four operations usually required in the composition of printed matter: (*a*) typecasting; (*b*) composing; (*c*) line-justifying;* and (*d*) distributing.

The machines may be divided into four classes according to the number of these operations performed by each.

* To avoid confusion with the *justification* of type previously referred to, this term, when used in this Paper in reference to justification of line, is called *line-justification*.

CLASS I.—These are the simplest machines; they deal with one operation only.

Examples:—

I a. Simple typecasting machine (Titchener) (single mould).
Foucher typecasting machine (double mould).
Wicks Rotary typecasting machine } (multiple mould).
Bhisotype* (Prof. S. A. Bhisey) } (multiple mould).

I b. Kastenbein, Wicks and Pulsometer composing machines.

I c. Stringer automatic line-justifying machine.

I d. Empire and Pulsometer distributing machines.

CLASS II.—Two-operation machines.

II a. Machines in which composing and line-justifying only are effected.

Examples:—

The Empire and the Dow composing and line-justifying machines.

II b. This comprises those machines in which the cycle is divided into two parts; generally the composition is effected on one machine and the record (in which the line-justification is provided for) is transferred to the second machine, on which the casting and line-justifying are performed automatically, the type being delivered in lines into a galley. In such machines the type is not usually intended to be distributed, but to be remelted. It follows that in general such machines are interdependent and designed to work together.

Examples:—

The Lanston Monotype composing and casting machines, the Tachytype (F. A. Johnson), the Graphotype† (G. A. Goodson), and the Dyotype* (J. Pinel).

CLASS III.—Three-operation machines.

III a. Machines in which type is distributed, composed and line-justified.

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* See Appendix V (page 1163).

† See Discussion (page 1203).

Examples:—

The Thorne and the Paige distributing, composing and line-justifying machines.

III b. Machines in which matrices are composed into line and line-justified, a slug being then cast from the complete line. There can obviously be no distribution, and the slugs are remelted. Distribution of the matrices is effected after each line is cast.

Examples:—

The Linotype (O. Mergenthaler), the Monoline (W. S. Scudder), and the Typograph* (J. R. Rogers).

CLASS IV.—Four-operation machines.

IV a. Machines in which the matrices are composed into line and line-justified; single type are cast from the matrices (the spaces being of the width determined by the line-justification of the matrices) and delivered into a galley. The single machine performs the whole of the work which, in Class II b, is divided between two machines. The type is not generally intended to be distributed, but to be remelted. Distribution of the matrices is effected after each line is cast.

Example:—

The Stringertype typecasting and composing machine.

IV b. No machine performing the four different operations of casting, composing, line-justifying and distributing is known to the author.

CLASS IA. TYPECASTING MACHINES.

The Simple Typecasting Machine is usually known in England as the Titchener machine; this is substantially the same as the Bruce machine, invented and used in America prior to 1845. In this machine the mould is very similar to the justifier's mould shown in Fig. 25 (page 1076). The two halves of the mould are mechanically operated, so that they are brought together and held in contact by the pressure of a spring with the gate of the mould pressed against the nozzle of the pump. The pump plunger, which is at the top of its stroke, is now allowed to descend under the action of its spring; after the completion of the stroke the mould is drawn away, and

* See Appendix V (page 1169).

the two halves separated, the type with the tang attached falling into a tray. A different mould is required for each body, but the mould is adjustable for those variations in *set* which occur in a fount of type; a different mould is also required for quads, on account of the difference in height-to-paper. As the nicks differ for different faces of the same body, a suitable mould is required for each different arrangement of nick. The nicks on the body are produced in casting, but the removal of the tang and the cutting of the heel-nick must be performed subsequently. The type, after the tang has been broken off, are arranged by hand on a stick for the operation of planing the heel-nick, which is also performed by hand. The machine is belt driven, and the movements of the pump plunger and mould are effected by ordinary cam mechanism presenting no remarkable features of interest. The output of the single mould typecasting machine varies from about 3,000 per hour in pica, to 4,000 per hour in smaller bodies.

The Wicks Rotary Typecasting Machine represents the highest development at the present time of machines for producing finished type, Fig. 47, Plate 32. The machine has 100 moulds mounted in a wheel which is revolved continuously by worm gear, the number of moulds of each particular *set* being determined by the demand for type of that *set* size. The last columns of Tables 3 and 4 (pages 1040–1041) show the normal demand based on the bill of fount,* and the number of moulds of each *set* must be determined from this so as to give the minimum of waste due to overproduction of certain sorts. It is moreover necessary that some of the matrices should be changed at suitable intervals, so that the proper proportional number of each

* Although type is produced by the Wicks Rotary Typecasting Machine at a much lower cost than by the single-mould machine, it is obvious that the machine cannot cope with a heavy demand for extra sorts if these are of a *set* width of which there may happen to be but few moulds in the mould wheel. Hence it is a commercial necessity that a foundry equipped with Wicks Rotary casting machines should have, in addition, some single-mould machines; these may, however, be adapted to use the Wicks matrices by providing suitable moulds.

character may be cast. From these considerations it follows that, if more than one face is to be cast in the wheel, these faces must be so designed that they agree closely in total demand for each *set* width. Type of different faces may be distinguished by supplementing the cast nicks with a cut nick, produced by a milling cutter in a similar manner to that used for producing the heel-nick.

The sequence of operations in the Wicks machine is as follows:— After the type has left the mould *m*, Figs. 48 and 49 (pages 1096–1097), the matrix *s* is gradually withdrawn by a cam carried on the head *a* of the machine and bearing against the hard steel surface of the matrix jacket *j*. The matrix is guided on the stem by the mould, and at the upper part by a groove in the matrix guide ring *r*. After passing the withdrawing cam *w*, Fig. 49, the matrix is slightly advanced towards the periphery of the wheel by the height-to-paper cam *h*, Fig. 48, which acts on the screw *g* in the matrix jacket; a light plate spring *b* carried on the top cover *c* presses against the outer surface of the matrix jacket *j* ensuring contact with the screw, and so secures uniformity in height-to-paper. Before reaching this point the end of the matrix stem *s* has been covered by the top cover, and the end of the mould has also been covered by the shield *q* which is mounted under an adjustable sliding-head *u*. On nearing the centre of the shield the port *p*, in which the stream of metal delivered by the pump is playing, becomes uncovered and the metal enters the mould. The type sets in a very short interval of time after the mould has closed the port in the shield,* since the mould-wheel *fn* and top cover *c* are both cooled by water circulation. As the revolution proceeds the type is carried round in the mould, and, when it is clear of the shield, the ejecting cam (not shown in the drawings) begins to operate on the matrix jacket, causing the matrix and the type *t* with it to move outwards. When ejected about 0·05 inch, and therefore well supported in the mould, the heel-nick is cut in the foot of the type by a rapidly revolving milling cutter; when further ejected (to about

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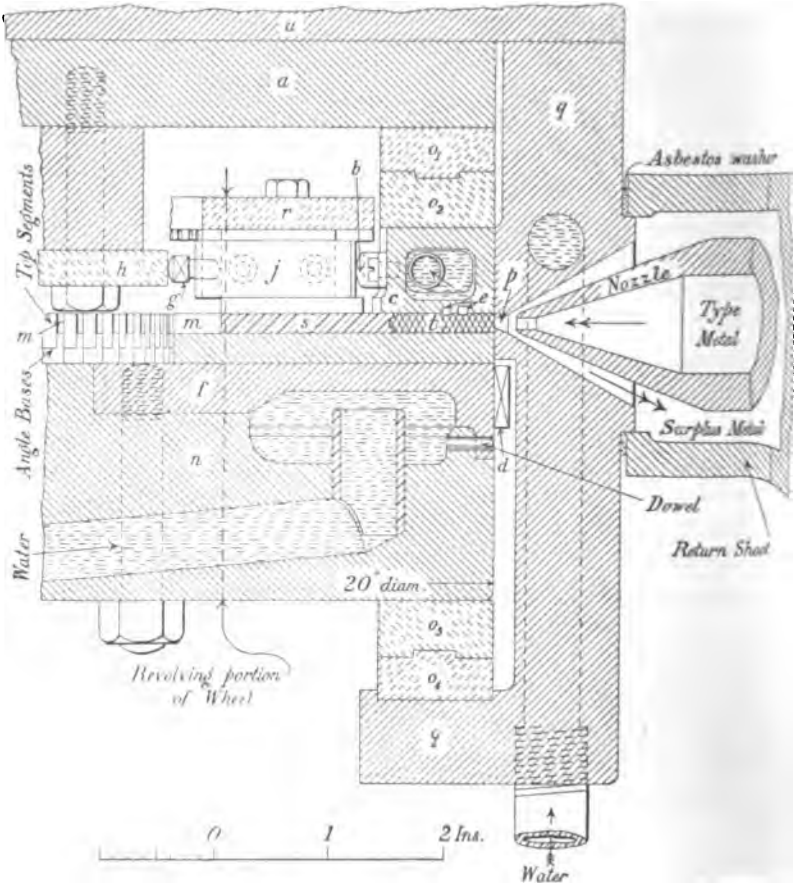
* So far as the author can ascertain, the type sets in less than 0·03 second in a water-cooled mould, for bodies not larger than long primer.

Fig. 48.

Section through Mould at Casting Point. Rotary Typecaster (Wicks).

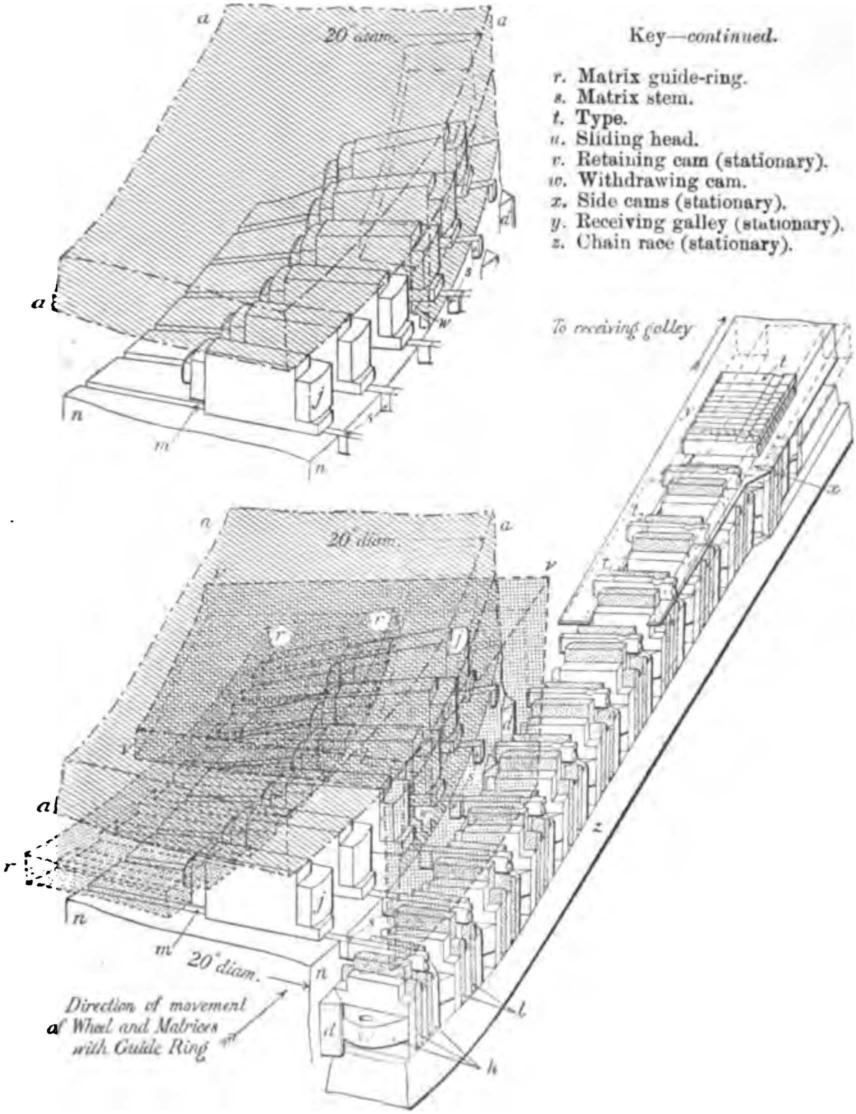


Key for Figs. 48 and 49.

a. Cam head (stationary).
b. Plate spring.
c. Top cover.
d. Chain driving teeth.
e. Nick beads.
f. Foundation ring.
g. Height-to-paper screw.
h. " " cam.
j. Matrix jacket.
k. Chain link.
l. Chain leaves.
m. Mould.
n. Mould wheel.
o_1 o_2 o_3 o_4. Folding wedges.
p. Port.
q. Shield.

Fig. 49.

Delivery of Type from Rotary Typecaster (Wicks).



0·20 inch) an extra body-nick for distinguishing founts may be milled in if required. The ejection continues with the revolution of the wheel, and the end of the type when ejected about 0·35 inch enters the space between the leaves *l* of the chain link *k* corresponding to its mould, Fig. 49. The chain consists of 100 links and is driven by the teeth *d* cut on the periphery of the mould-wheel. The ejection continues till the type is just clear of the mould, when the retaining cam *v*, carried by the head of the machine *a*, engages with one of the body-nicks in the type and prevents the type from being drawn back with the matrix under the action of the withdrawing cam *w*. The cycle of operations with the matrix is now repeated.

The type which has left the mould is carried by the leaves *l* of the chain link *k* to the receiving galley *y*; this is slotted so that the type t_1 t_2 is supported at the ends on the galley plate, while it is propelled along the galley, and supported from tilting by the leaves *l* of the chain; near the end of the slot in the galley plate the leaves of the chain, which have up to the present been carried on the chain race *z*, drop so that the upper ends clear under the galley plate; side cam pieces *x*, which bear on the rounded shoulders of the leaves, control the dropping, Fig. 49. The type is now free in the galley along which it is impelled by the next succeeding type. The stream of type is received on a stick of L section, and removed by a boy who places the type either 300 or 400 at a time in a type galley in which they occupy the same relative positions. The recurrence of the largest *set* size or of a sequence of characters of large *set* serves as a guide to the boy in sliding the type along on to the stick, and at the same time gives stability to the last line in the galley.

The type as received in the galley form a block, the appearance of which is shown by the portion printed as Fig. 51 (page 1100). The number of lines in which the blocks are made up is so chosen as to give a nearly constant width of block body-wise (about 4½ inches). The blocks are then divided by cutting them up at right angles to the direction of the lines of which they are made up. This work is performed by girls who insert thin strips of metal or celluloid between the rows of different characters, and add the lines of the same character

FIG. 50.—*Operations in Machining Chain-links for Rotary Typecaster* (Wicks).

Half size.

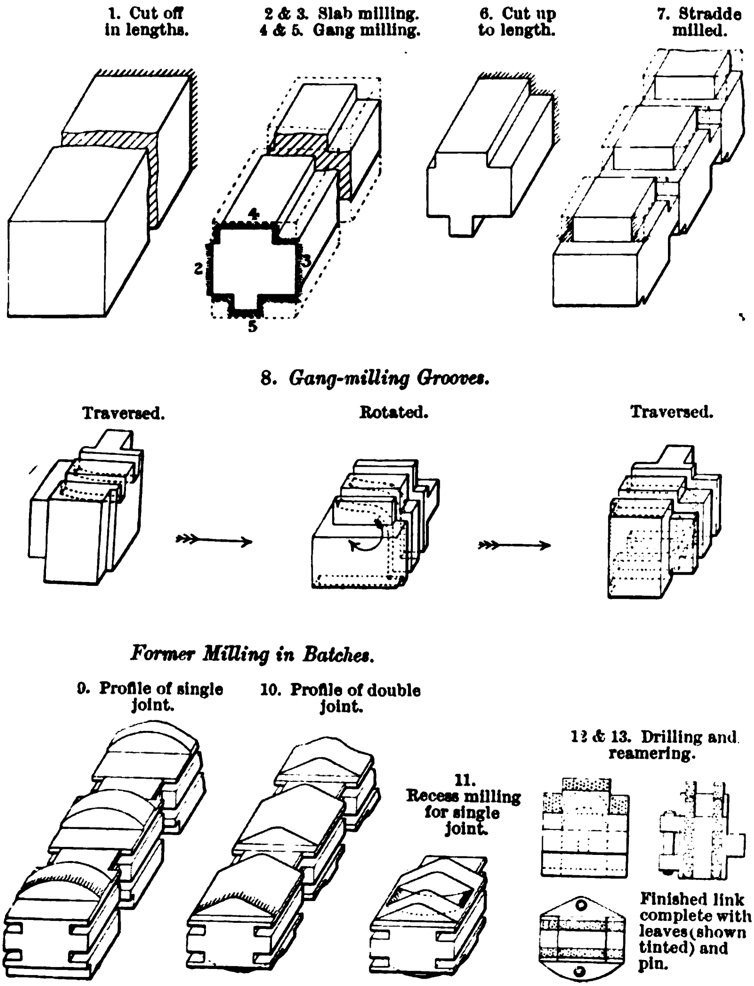
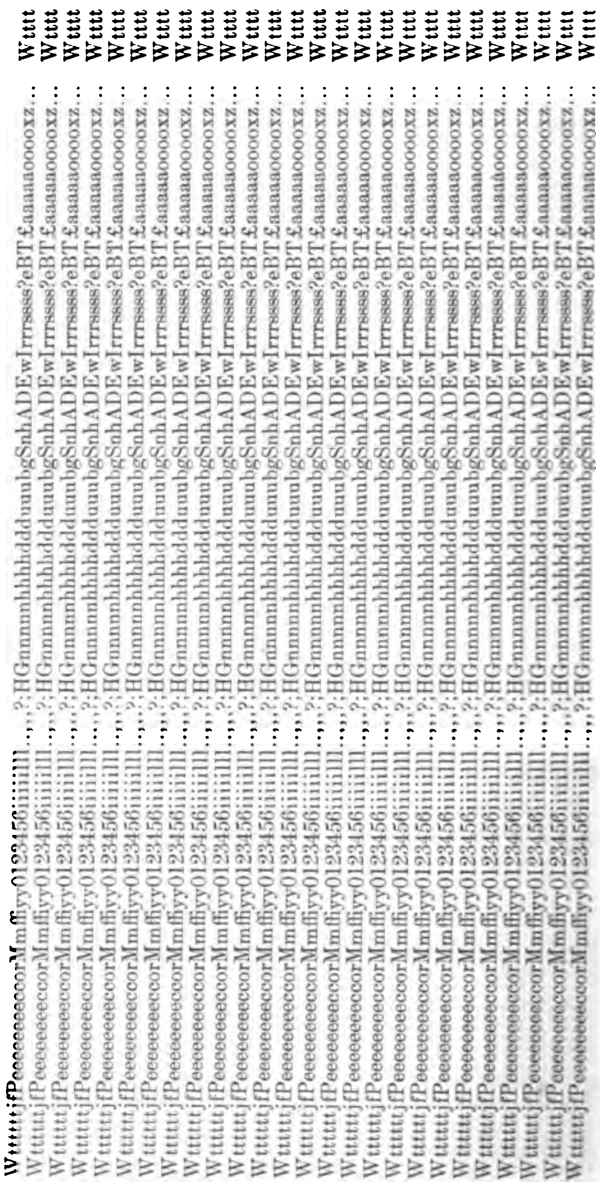


FIG. 51.

Block of Type as delivered by Rotary Typecasting Machine (Wicks).



together in small galleys to form *pages* of an approximately constant width. These *pages* are examined for defective type which are replaced; the *pages* are then tied round with string and packed in thick whitish paper. The handling of several lines of separate type between two flat pieces of metal requires a peculiar knack which the girls acquire easily.

The casting machine is operated by one skilled type-founder who attends to the lubrication, to the maintenance of the metal in the pot at the correct temperature and level, to the exact adjustment of the top cover so that the body-size is maintained, and to the finish of the type left by the milling cutter. One boy takes off the type, and four to five girls distribute the output of each machine.

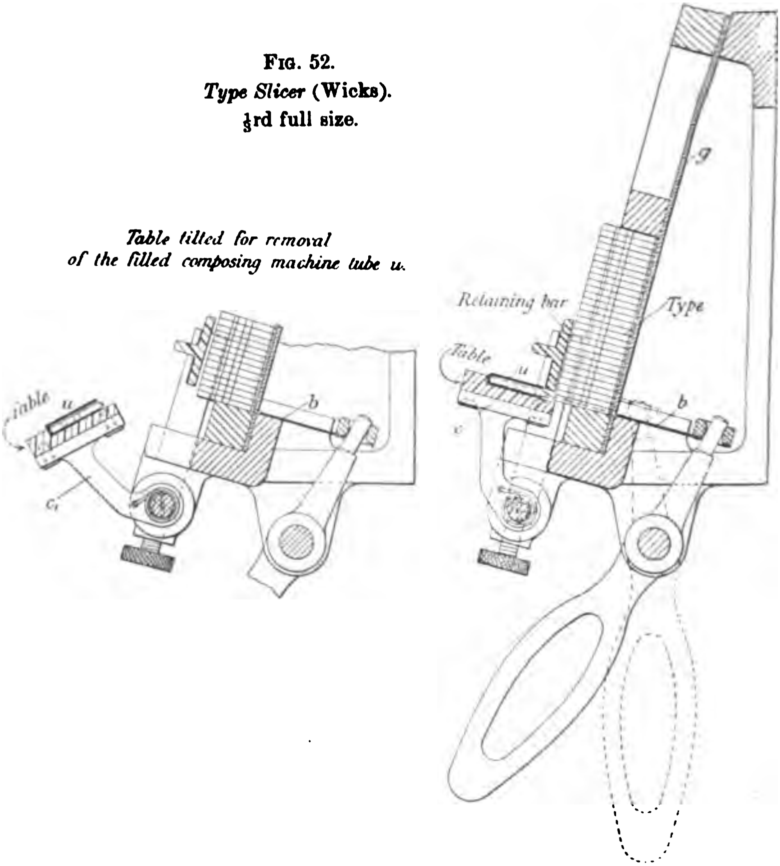
The output of the Wicks machine is from 60,000 to 70,000 finished type per hour for bodies from ruby to long primer, and falls with larger bodies to about 35,000 for pica.

The pump runs at 100 revolutions per minute and requires about 0·7 H.P. The machine runs normally on bodies up to long primer at 10 revolutions per minute and takes about 1·1 H.P. The total power required to run both the machine and the pump is 1·8 H.P.

It was the original idea of Mr. Wicks that type could be produced so cheaply by this machine that it could be replaced by new type for less than the cost of distributing. The cost of distributing by hand is generally 25 per cent. of the cost of composing by hand, or about 2½*d.* per 1000 type. The type when so distributed is not, moreover, in lines in the form required by composing machines, and a small further expenditure would be necessary to set up the type in the composing machine tubes. The author is of opinion that, if the Wicks machine had been brought to the present state of perfection some fifteen years earlier and a foundry equipped with a large number of machines, the system adopted by *The Times* of employing fresh type every day and distributing by remelting would have found favour with a large number of the most important daily papers.

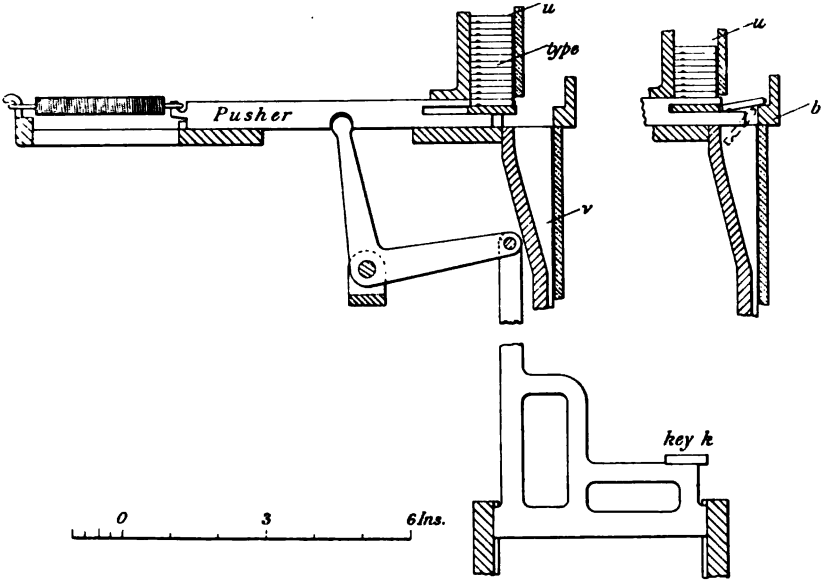
Type Slicing Machine.—For charging composing machine tubes with type an auxiliary appliance has been designed by Mr. Wicks, and is shown in Fig. 52. The lines of type are transferred from the galley in which they are received to a slotted galley *g* in which the faces are turned towards the galley. The slot is temporarily covered with a slip of metal which rests on the lower edge of the galley when

FIG. 52.
Type Slicer (Wicks).
⅓rd full size.



placed on the slicer, and is ejected at the first stroke of the blade. The blade *b* is drawn back by means of the handle, a tube *u* is placed on the hinged carrier *c* in front of the machine, and charged by the next stroke of the handle. The end type in the tube are pressed towards each other by the fingers of the operator, and at the same time the hinged carrier is brought forward (as at c_1), till the type are inclined upwards, when the tube can be lifted off and transferred to the magazine of the composing machine, Fig. 52. About 200 of these machines are in use at the printing office of *The Times*.

FIG. 53.—*Type-Freeing Mechanism for Composing Machine* (Kastenbein).



CLASS IB. TYPE-SETTING OR COMPOSING MACHINES.

The earliest machine with the guide plate and many other features of subsequent type-setting machines is probably the Young and Delcambre setter, which was used for setting the *Family Herald* as early as 1842.*

The Kastenbein Composing Machine invented prior to 1870 was brought into practical working form at the *Times Printing Office*, and, with some modifications there introduced, is used for composing

* Many of the details of this machine were worked out by Sir Henry Bessemer. *See* "Life of Sir Henry Bessemer," p. 43 *et seq*.

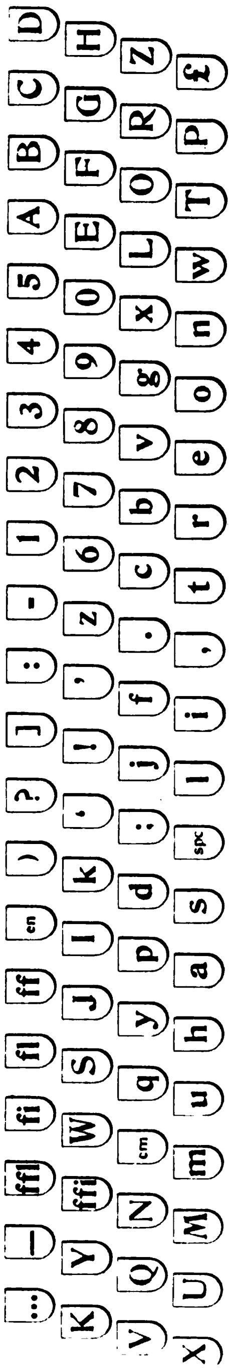


FIG. 54.—*Keyboard of Composing Machine* (Kastenbein). ⅓rd full size.

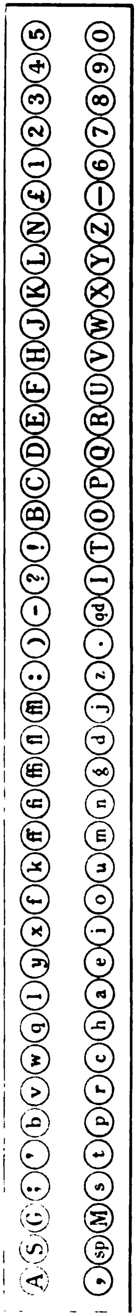


FIG. 56.—*Keyboard of Composing Machine* (Wicks). ⅛th full size.

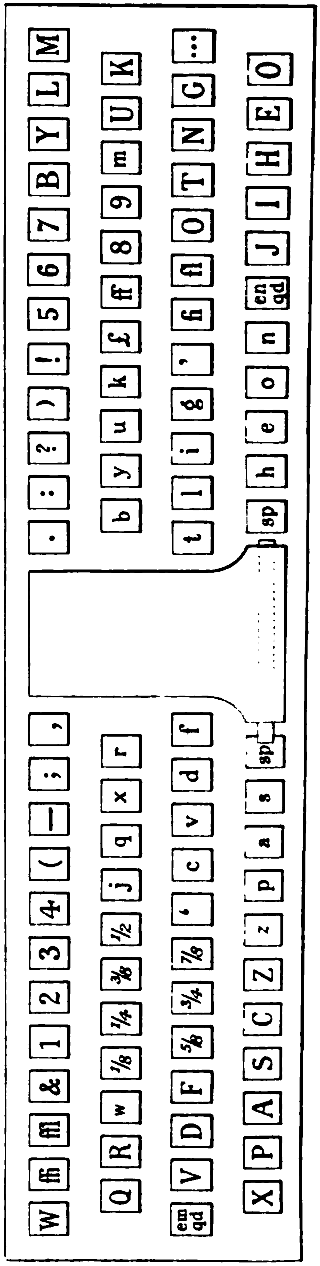


FIG. 57.—*Keyboard of Composing Machine* (Pulsometer). ⅓rd full size.

almost the whole of *The Times* and many other publications printed in the *Times Office*. The tubes *u* are U shaped, the type are arranged *set*-wise, all the nicks being downwards and the faces towards the operator, when the tube is placed in the vertical position it occupies in the machine. The depression of a key *k*, Fig. 53, pushes the lowest corresponding type forward by the foot towards the front of the machine; when more than half ejected, the front end comes over a bar *b* running along the front of the machine; when the type is fully ejected it overbalances backwards from this bar (as shown dotted) on the release of the pusher, and falls feet downwards down a guiding groove in the guide plate *v* of the machine. A lightly-balanced lower lever arm against which the type bears in falling into the race corrects any tendency to turn. The type as they arrive at the level of the race are pushed forward by a continuously-driven reciprocating plunger having a stroke a little greater than the body-size of the type. The type are thereby delivered along a type race from which they are drawn by hand by a second operator who performs the *line-justifying*. The keyboard of the Kastenbein machine is very compact, and comprises eighty-four keys arranged in four rows as shown in Fig. 54 (page 1104).

The power required is less than 0·1 H.P.

The Wicks Composing Machine.—In the Wicks composing machine, Fig. 55, Plate 32, the keyboard is of great length with only two rows of keys, Fig. 56 (page 1104), the arrangement resembling more closely that of the piano than that of the typewriter. The keys *k* operate vertical rods *q*, Fig. 58 (page 1106), which are jointed to plunger sectors of helical strip *p* working in the spaces of a coarse square-thread screw *s*. Two quarters of round bar with screws milled out are arranged, the one right hand and the other left hand facing each other, and are machined so as to form a pair of races (between which is an intervening strip *r*) inclined at 45° to the horizontal for the type to slide down. The type *t* are contained in U-shaped tubes *u* of tin or thin brass inclined at 45° to the horizontal (and at 90° to the race). The type are arranged in the tube body-wise, i.e. the nicks lie against one side of the U. The depression of a

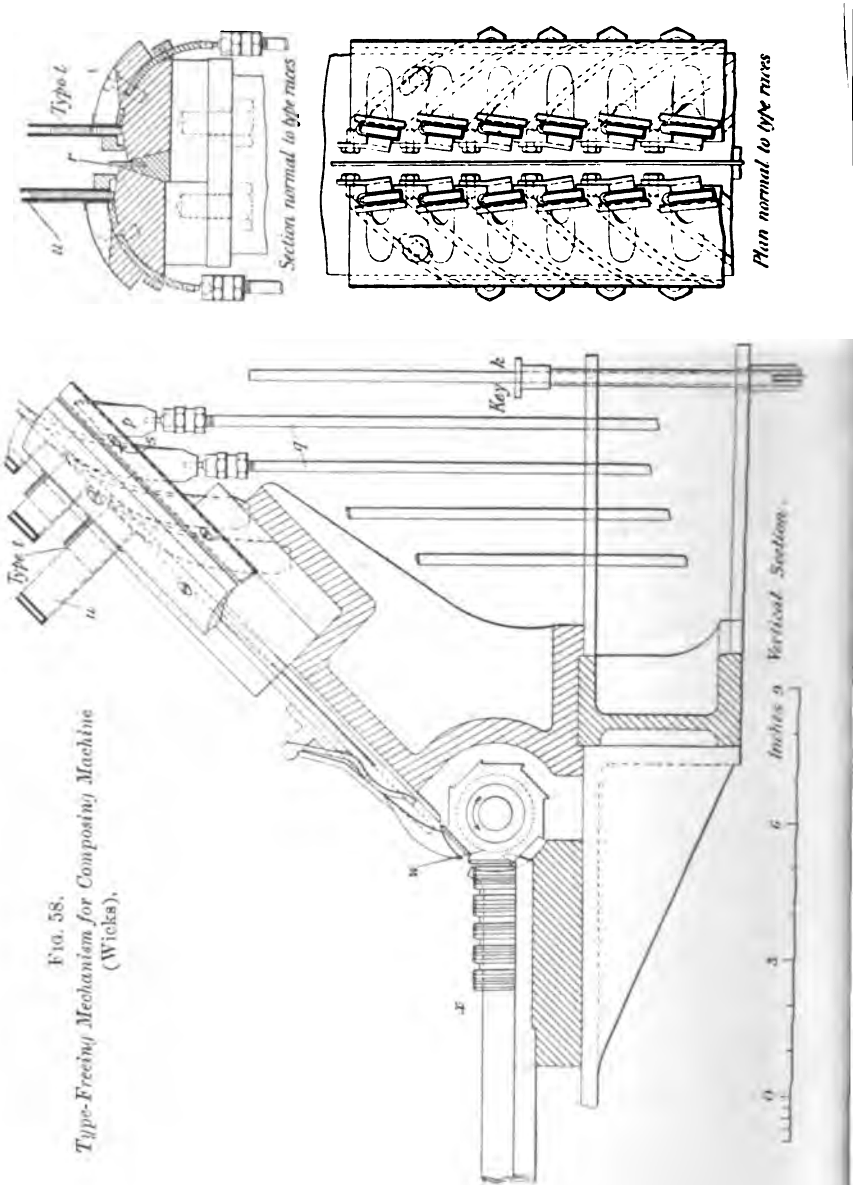


Fig. 58.
Type-Freeing Mechanism for Composing Machine (Wicks).

key causes the plunger, the end of which is reduced to the *set* width of the type, to remove the lowest character from the corresponding tube and push it into the race down which it slides on its side by gravity to the nose of the machine where a star wheel *w* catches it, brings it to an erect position and pushes it in place against the line accumulating in the type race *x*. The star wheel is driven continuously by a pedal or a small electric motor. Sections of the line are drawn away by a second operator who *line-justifies* each line and transfers it to a galley in exactly the same manner as in the other machines of this class.

The Wicks machine is interesting chiefly for the reason that the keyboard was designed so as to enable a number of the most-frequently-occurring combinations of characters to be obtained by the simultaneous depression of two or more keys, for example *the*, *ing* and *and*.* While this effects some saving of time, the long distance which the more remote characters must travel under the action of gravity makes the machine slow in such cases, though this is said to be compensated for by the advantage gained on the chords; also the distance through which the operator must move his hand is greater than in those machines which have a compact multiple-row keyboard.

The power required is less than 0·1 H.P.

The Pulsometer Composing Machine, Fig. 59, Plate 33.—The type *t* are contained in horizontal tubes *u*, and the contents of each tube or trough are kept pressed towards the front of the machine by a weighted follower *f*, Fig. 60 (page 1108); the type are supported by a front plate *v*, which extends about 0·50 inch in height above the bottom of the tubes and is bevelled at the top to a knife edge. The depression of a key *k* causes the front type in the corresponding tube to be raised till it clears the knife edge, when the action of the follower ensures this type being projected over the edge of the front plate. It now falls freely down a vertical groove in the front plate or apron *v* of the machine, which is shaped as an inverted triangle. At the lower end

* *See* Appendix III, *Logotypes* (page 1148).

of the vertical groove it is guided by the inclined raceways, into which it falls, to a central channel, and thence to the entrance to the composing race, into which it is pushed by a continuously-revolving eccentric. The front plate is covered with a sheet of plate glass *g* to keep the type from turning, and to enable the operator to see that the apron grooves do not become blocked. A continuously-driven

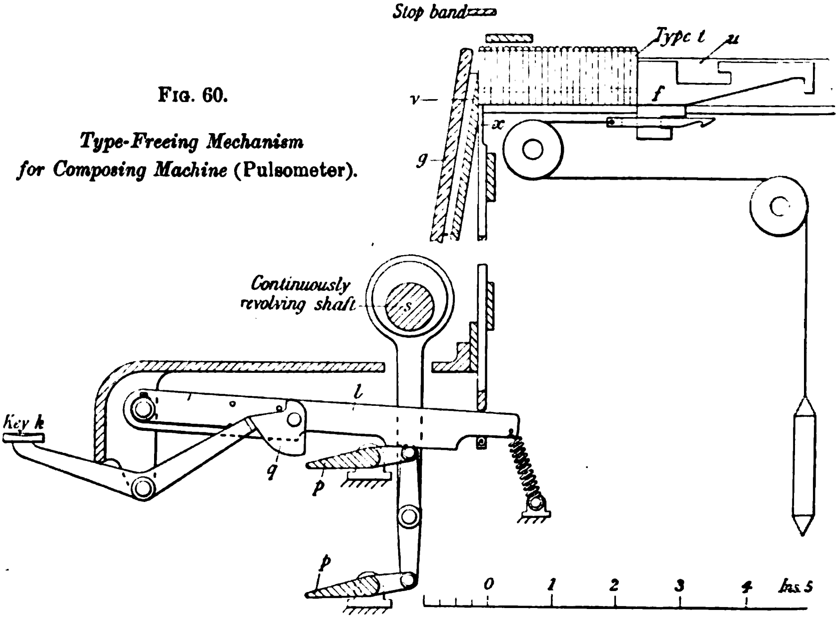


FIG. 60.

Type-Freeing Mechanism for Composing Machine (Pulsometer).

horizontal shaft *s* imparts a vertical reciprocating motion to two steel swing plates *p* placed longitudinally with the machine. Across the direction of these are flat steel levers *l*, one for each character, pivoted at the front end and each carrying a triangular pawl *q* which is normally raised. When a key *k* is depressed the corresponding pawl drops into the range of action of one of the swing plates,* which carries it and the lever upwards; the vertical pusher is driven

* The keys acting in conjunction with the lower swing plate are not shown in Fig. 60.

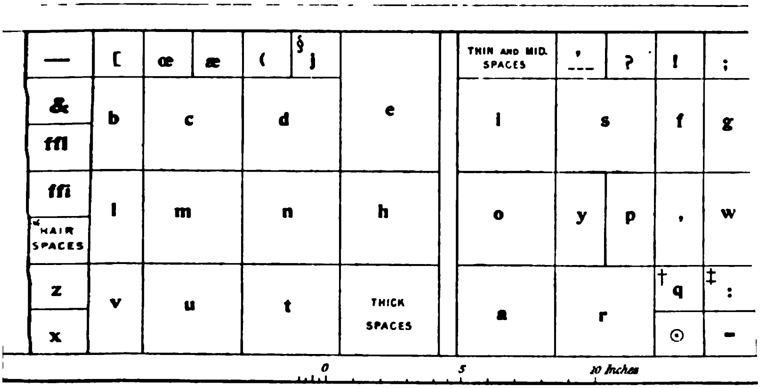
upwards by the lever, and its upper end *x* passing through th side of the U, lifts the corresponding first type up till it cle front plate. There are four rows of keys arranged as sh Fig. 57 (page 1104).

. The power required is stated to be about 0·1 H.P.

Other machines of Class I b are the Hattersley, the Fras the Hooker machines; the latter, which was patented about 3(

FIG. 61.

Lay of Lower-Case (Hand Composition).



* In Hooker's machine the space marked "hair spaces" was occupied b
In the modern lay it is occupied by "q."

† " " " the space marked "q" was occupied by "k."

‡ " " " the "colon" space was occupied by "j."

§ " " " the space marked "j" was occupied by ' (apostrop

since, is interesting as the keyboard was not made of the form in other typesetting machines or in typewriters, but was arr as a series of plates forming a copy of the ordinary lowe Fig. 61, from which the compositor would pick up the ty hand composition; but instead of picking up the character touch freed a type through the intervention of a contact ex an electromagnet corresponding to each plate.

The warning bell which gives notice before the completion line to the operator of typewriting machines is usually fitt typesetting machines.

CLASS IC. LINE-JUSTIFYING MACHINES.

Compressible Spaces.—Many inventors have endeavoured to effect line-justifying by the use of compressible spaces, but the difficulties have not been satisfactorily overcome. The compressible space should be capable of occupying the width of the em quad before compression and of being compressed to the thickness of the thick space. This should be possible without risk of throwing the sides of the adjacent type out of parallel, without lifting the type from their feet and without bending a character occurring singly, such as a or I which may come between two spaces. Moreover the space must not

FIG. 62.
Compressible Space (Mackie).
Twice full size.

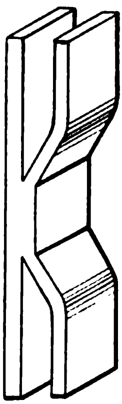


FIG. 63.
Compressible Space (Wicks).
Two and a half times full size.

itself rise so as to interfere with the typographic surface. Two attempts to solve the problem of the compressible space are shown in Figs. 62 and 63.

The Stringer Line-Justifying Machine.—A machine recently invented by Mr. H. Gilbert Stringer has been made in which a line of type as delivered by any typesetting machine of Class I b can be accurately line-justified.

The method adopted is to set em quads throughout the line in place of spaces, and subsequently to reduce these by milling down to the correct width for equally spacing the line. As it is essential that the justified line should contain quads under some conditions (e.g. at the end of a sentence and beginning of a new paragraph) these must not go through the reducing process for line-justification. It is therefore necessary that two kinds of quads be used. Those which are intended to remain quads are of shoulder height while those which are to be reduced may be of stereo height. The former are supplied by the depression of the *quad* key on the type setter and the latter (*space-quads*) by the depression of the *space* key.

Coupled to the *space* key, by tappet action, is a rod which advances a bar step by step below one pair of folding wedges for each *space-quad* set in the line in the automatic line-justifier. The line is composed into a measure longer than the finished line, which allows for the amount to be machined from the *space-quads*. Having composed a line in excess of the length required, the operator depresses a starting key and resumes composition. The line-justifier, while he is so occupied, acting independently first transfers the excess of length of the line to the wedge box, and when those wedges which are above the counting bar are driven home by vertically lifting the bar and with it the long part of each folding wedge, the amount that the lifter rises automatically divides the difference of length by the number of spaces and sets the milling device for reducing the *space-quads*. The machine then operates by pushing the line of characters forward along a race which has an opening at the side provided for a reciprocating feeler. Any character having the requisite height stops the feeler, and is then pushed through by the pusher into the continuation of the race. When a *space-quad* occurs, the feeler passes over it and the *space-quad* is then gripped between narrow jaws on its front and back edges in a slide, carried vertically down past a rapidly-revolving face-mill (the depth of cut being proportional to the lift of the wedges of the measuring device). It is replaced in the line by the automatic release of the jaws and the forward pressure of the next character. The gear which drives the feeler and pushing plunger is thrown out during the milling operation and recommences to operate as soon as the milling operation is completed. When the complete line has been line-justified, it is automatically transferred to a galley.

About 0·5 H.P. is required to run the line-justifying machine.

CLASS ID. DISTRIBUTING MACHINES.

In the earliest distributing machines the type was sliced off the column, the line read by the operator and the type returned to the tubes used on the composing machine, by depressing keys corresponding to each character, the operation being the converse of composing.

The Pulsometer Distributing Machine, Fig. 64, Plate 33.—The galley containing the matter to be distributed is inclined at 45°, and slopes downwards towards the keyboard. The lowest line is raised into the receiving trough, where it is read by the operator and is distributed through shutters on an apron inclined at 45° to the horizontal and at right angles to the galley. There are 24 keys, and each generally corresponds to a group of three type which are selected so as to differ by at least 0·008 inch in *set* width among themselves. The distribution of the three sorts of type is performed automatically by two bridge pieces, arranged at different heights, which divert the character to the mouth of the corresponding tube, Fig. 65 (page 1113). A brass follower is placed in each tube to keep the type upright; the type as they fall are pushed into the tubes by a series of eccentrics, one to each tube, carried on a continuously-rotating shaft. The keyboard of the Pulsometer distributing machine is shown in Fig. 68 (page 1114).

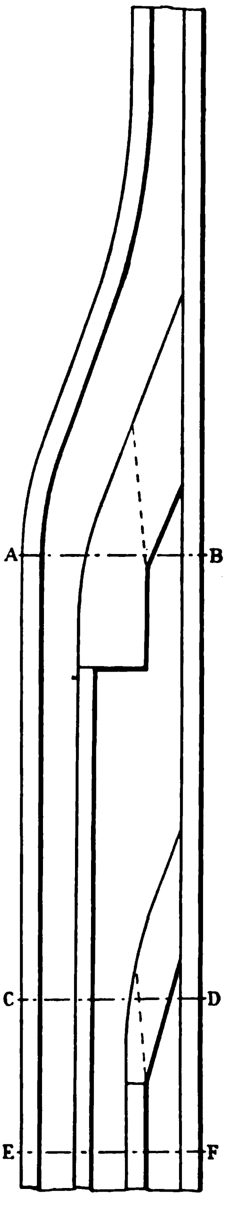
The power required is stated to be about 0·1 H.P.

Automatic Distributing Machines perform the work by means of nicks cut on the back (and occasionally on both back and front) of the type. The type are nicked so that each sort dealt with by the distributor has a different combination.

In the *Empire Automatic Distributing Machine*, which was in use for

FIG. 65.—*Detail of Separating Bridges for Distributing Machine* (Pulsometer).

Full size.



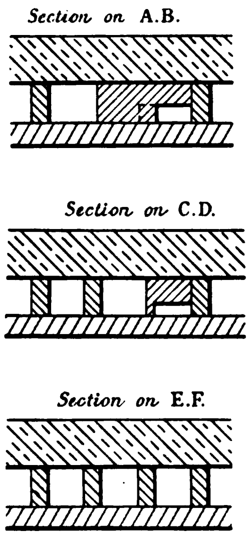


FIG. 66.

Type nicked for Distributing Machine (Empire).

Twice full size.

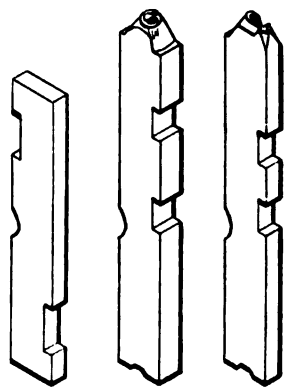
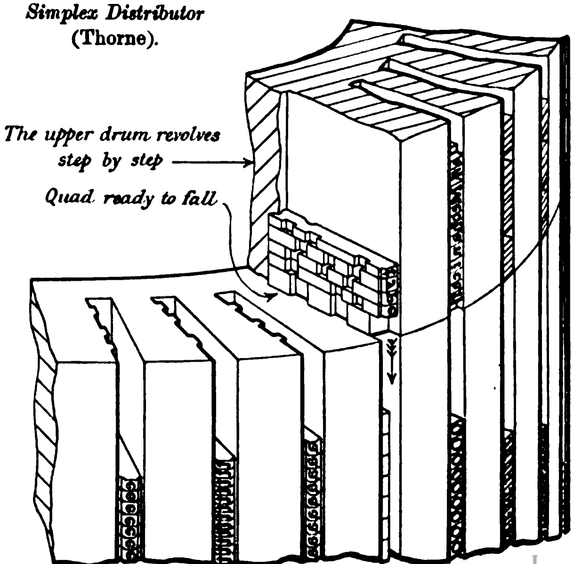


FIG. 67.

Method of Distribution.



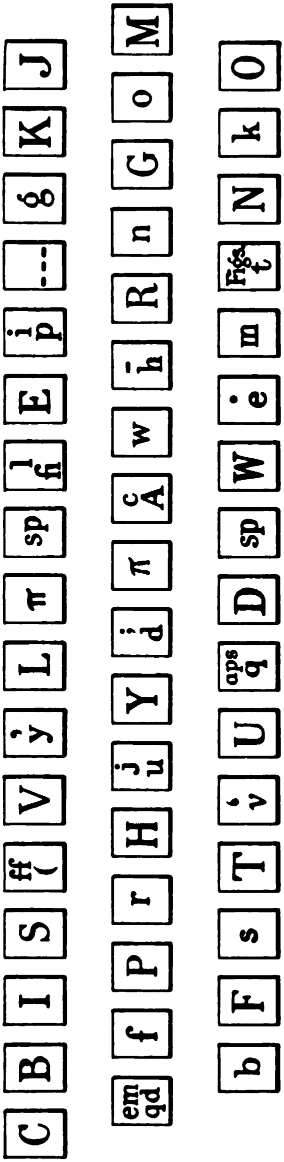


Fig. 68.—Keyboard of Distributing Machine (Pulsometer). Half size.

FIG. 69.

Where two characters appear on the same key, the upper is roman or italic, the lower small caps.
The 30 hatched keys are coloured blue.

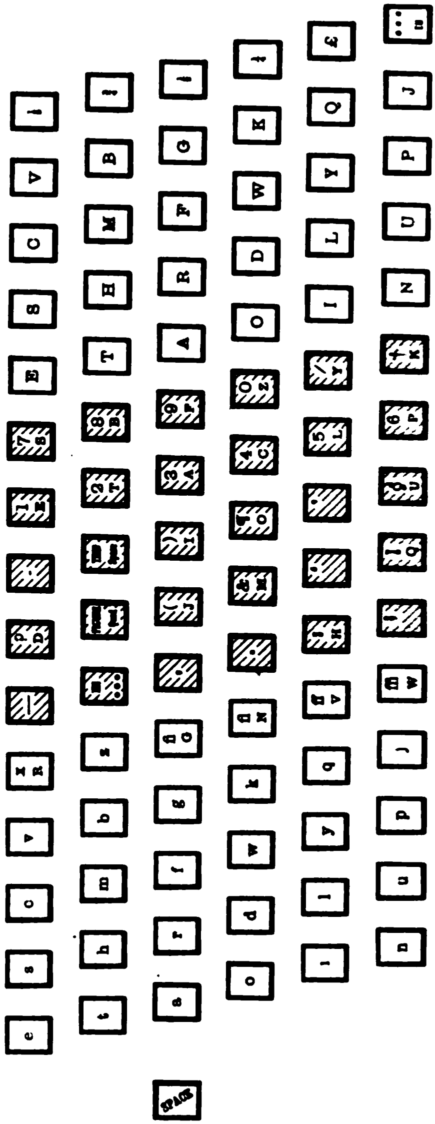


Fig. 69.—Keyboard of Matrix Composing Machine (Linotype). ⅓rd full size.

some years at the Office of *The Times*,* the type were nicked back, Fig. 66 (page 1113), by means of a planing machine wi sliding tool-holders. The setting of the tools could be rapidly by putting dowel pins into numbered holes in each slide. A ta provided with the machine giving the numbers of the holes used on each slide for each character. Actually the combinat the nicking machine were arranged in a somewhat haphazard m The type in the distributing machine was automatically re from the galley in a line and then pushed by a pusher, one ch at a time, into a series of carriers. The carriers had a step-b motion and stopped consecutively in front of feelers whicl formed to the counterpart of the nicks cut in the type. The slides advanced against the type, and when a feeler fitted th combination in the type it could move forward releasing th from the carrier and thereby allowing the type to fall in magazine of tubes. The machine distributed 84 sorts.

CLASS IIA. COMPOSING AND LINE-JUSTIFYING MACHINES.

The Empire Composing and Line-Justifying Machine.- type are contained in three cases, each of about 30 cha which are carried on cradles with glass fronts. The cradles c placed horizontally for receiving the cases and then turned vert with the face of the type to the front so as to be visible th the glass. The arrangement of guide plate, pendulum checl type race is very similar to that of the Kastenbein com Tapered space-bars are used temporarily in composing, and are position by the space key. When the line is nearly completed warns the operator, and he either completes the word or divid The temporary space-bars are then driven home to expand th to the proper measure. The bars are arranged to correspond six different *set* widths of spaces, viz. 0·25, 0·375, 0·5, 0 0·75 and 0·875 of the body. The distance that the spac

* And subsequently in the Office of *The Hereford Times*, to the Prop of which the author is indebted for some of these data.

projects decides the width of space supplied; the machine supplies a space not greater than the setting and at the same time withdraws the space-bar. After each operation of inserting a space, the remaining space-bars are driven home so that the final maximum possible error is 0·125 of the body. This is a considerably larger error than that usually obtained in spacing by hand, in which the limit attainable depends on the L. C. M. of the fractions of the body represented by the thin, middle and thick spaces.

$$\tfrac{1}{5} \times \tfrac{1}{4} \times \tfrac{1}{3} = \tfrac{1}{60} \times \text{body}.$$

The Dow Composing and Line-Justifying Machine is of recent American design. The type are contained in a magazine of vertical tubes and do not fall down a guide plate, but are pushed by carriers from right or left to the centre of the machine where the line is composed *vertically;* the arrangement is said to be somewhat similar to that previously adopted in the Paige machine. Temporary brass spaces are set in the line; and on depressing the *justifying* key the line is transferred to a horizontal position and measured. A space magazine, placed on the left of the machine, supplies the proper spaces from a range of ten different *set* widths. The line-justification therefore can be a much closer approximation than in the case of the other composing and line-justifying machines of this class using fewer *set* widths.

CLASS IIB. COMPOSING AND CASTING MACHINES.

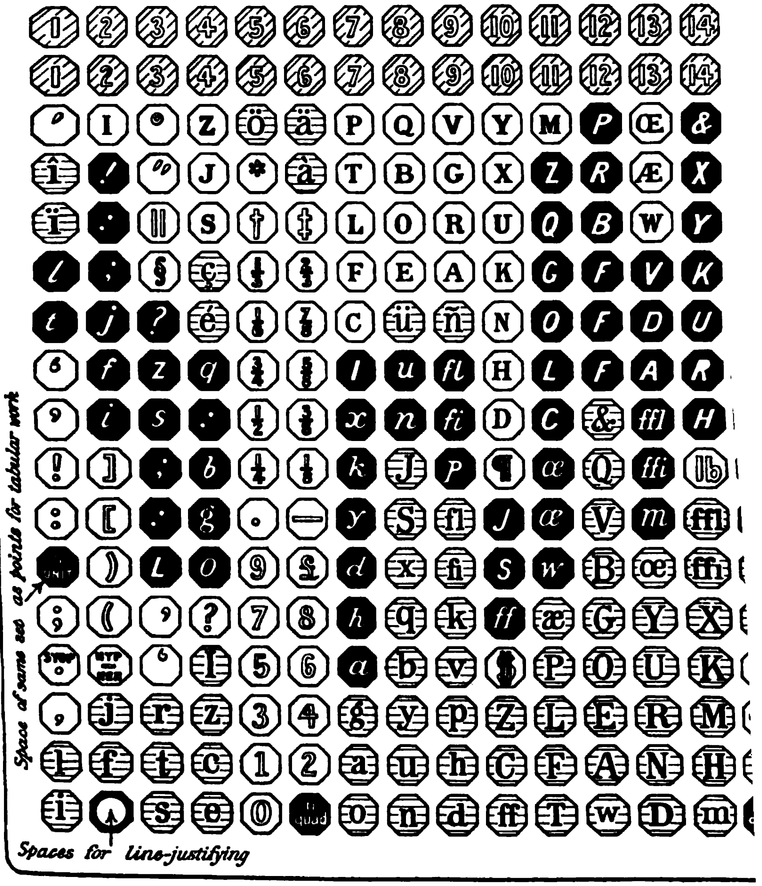
The Lanston Monotype Composing and Casting Machines.—These machines consist of two separate and quite distinct parts; firstly the composing and line-justifying machine, Fig. 70, Plate 34 (frequently called the keyboard); and secondly the casting and setting machine, Fig. 71.

The keyboard of the composing machine is very much like that of a typewriter, but with a larger number of keys, Fig. 72.* A ribbon of paper is fed through the machine, guided, as in the Wheatstone

* The inverted comma and apostrophe are repeated in two *set* widths, some printers preferring more white, and accordingly they can use either.

FIG. 72.

Plan of Keyboard of Composing Machine (Lanston Monotype).
Scale: about ⅓rd full size.



= *Line-justifying keys. (Red)*

= *Italics: lower-case, capital points and quads. (Black*

= *Small capitals, points, peculiars, figures & fractions. (Blue)*

= *Roman: lower-case, capitals and lower-case accents. (W*

Two additional keys on extreme right of keyboard (*Green*).

perforated strip, by side perforations.* The two top rows of (*red*) keys, bearing numbers, fulfil the function of line-justifying described later. The right-hand vertical row of keys and the bottom horizontal row of keys each effect one perforation only in the ribbon. The other keys each effect two perforations. Each key when depressed about $\frac{1}{4}$ inch admits compressed air to the required combination of 31 plungers, equally spaced, which perforate the roll; 14 of these perforations produce variation of the position of the matrix grid in x and 14 in y so that a total of 225 characters, spaces and quads can be produced (the case of $x = o$ and of $y = o$, being provided for by the keys which give one perforation only).

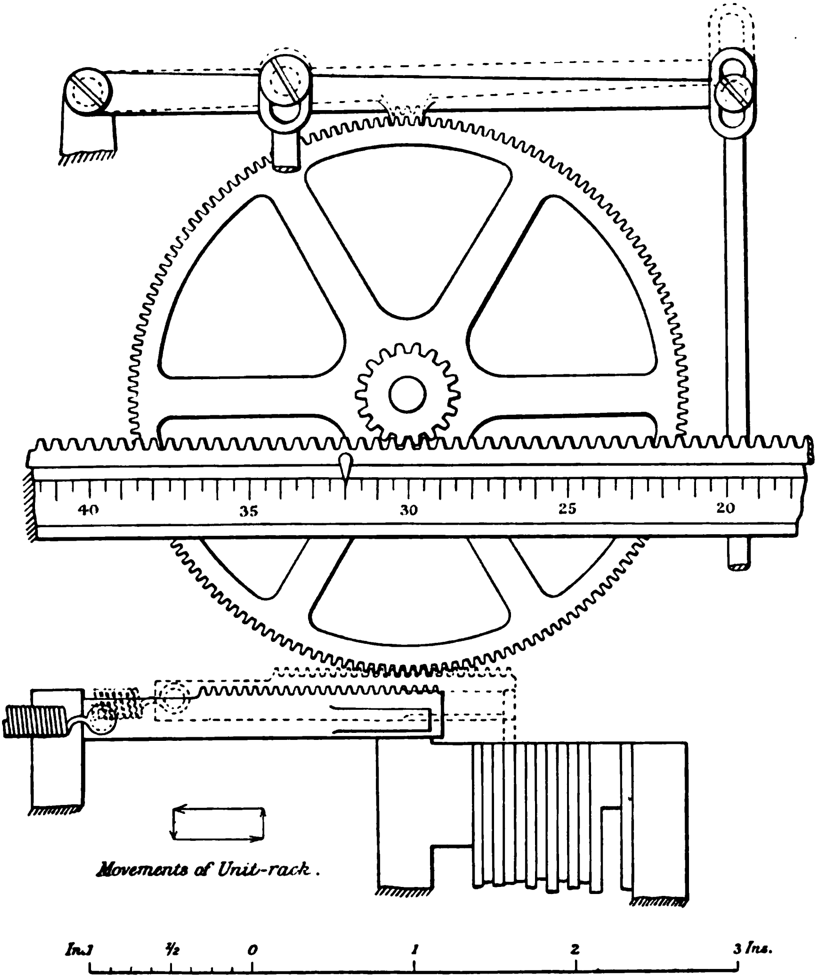
Above the keyboard proper is a pointer which rises step-by-step for each depression of the space key, and a drum (somewhat like the cylinder of a Fuller's slide-rule) on which are figures giving the resulting spacing required for the line. This drum can be rotated up to a movable stop by depressing the upper of the two (*green*) keys on the extreme right of the keyboard. This justifying scale key is depressed when ready to justify, and causes the line-justifying scale to rotate until it stops with the correct number at the end of the pointer. The bell rings 5 ems before the completion of the line; this is sufficient to ensure the acceptance or rejection of the longest indivisible word. The mechanism driving the drum stop, Fig. 73, aggregates the total *set* of the letters on a scale like that of a typewriter, and enables the operator to see whether he will proceed with the space and the next word, or will divide the word, or complete the line at the end of the word. Having completed the setting of the line, he depresses the upper (*green*) key and then refers to the reading shown on the drum which is of the form $\frac{3}{7}$. This reading gives the two (*red*) keys to be depressed in the top row and second row respectively; the reading corresponds to the settings of two differential wedges which divide the surplus space (left on completing the line) over the number of spaces in the line.

---

* The perforated ribbon was employed by Mackie, of Warrington, in 1868 in his composing machine. He used 14 rows of holes in combinations of two at a time, giving $\frac{14 \times 13}{2} = 91$ combinations available.

FIG. 73.

Counting Mechanism for Composing Machine (Lanston Monotype).



All the fifteen characters of a row arranged vertically on the keyboard (or of a row arranged body-wise on the grid) have the same *set* width; this is a most important feature in designing faces to suit the machine. The unit employed is one eighteenth of the quad and the vertical rows of keys give the following *set* widths, one row each 5, 6, 7, and 8 units, three rows 9 units (en quad), two rows 10 units, one row each 11, 12, 13, 14, 15, and 18 units, Fig. 74. The space key operates in a different manner and gives a setting of 4 units only; the keys act by elevating stops which limit the travel of a rack engaging with the counting wheel; one tooth of which equals one unit, and one revolution of which is equal to 9 ems, Fig. 73.

FIG. 74.

Standard lay-out as cast in long-primer modern.
(Lanston Monotype Machine.)

The small figures below the columns show the set-values in eighteenths of an em for the type in each column.

′	I	°	Z	Ö	Ä	P	Q	V	Y	M	*P*	Œ	*&*	✦
î	*!*	″	J	*	à	T	B	G	X	*Z*	*R*	Æ	*X*	a/c
ĩ	*:*	‖	S	†	‡	L	O	R	U	*Q*	*B*	W	*Y*	%
l	*;*	§	ç	⅓	⅔	F	E	A	K	*G*	*F*	*V*	*K*	℔
t	*j*	*?*	é	⅙	⅞	C	ü	ñ	N	*O*	*E*	*D*	*U*	@
‘	*f*	*z*	*q*	¾	⅝	*I*	*u*	*fl*	H	*L*	*T*	*A*	*N*	*Œ*
’	*i*	*s*	*v*	½	⅜	*x*	*n*	*fi*	D	*C*	&	*ffl*	*H*	*Æ*
!	]	*r*	*b*	¼	⅛	*k*	J	*p*	¶	*æ*	Q	*ffi*	℔	*W*
:	[	*c*	*g*	.	–	*y*	S	fl	*J*	*æ*	V	*m*	ffl	*M*
	)	*e*	*o*	9	£	*d*	x	fi	*S*	*w*	B	œ	ffi	Œ
;	(	’	?	7	8	*h*	q	k	*ff*	æ	G	Y	X	Æ
.	-	‘	I	5	6	*a*	b	v	$	P	O	U	K	..
,	j	r	z	3	4	g	y	p	Z	L	E	R	M	—
l	f	t	c	1	2	a	u	h	C	F	A	N	H	W
i		s	e	0		o	n	d	ff	T	w	D	m	
5	6	7	8	9			10		11	12	13	14	15	18

To enable different faces and different bodies to be cast from the same ribbon two difficulties have to be met:—

(1) The difference in *set* widths which exists in certain sorts between old style and modern;

(2) The increased *set* width of the sorts as bodies decrease in series, or when an extended or condensed face is required to be cast.

The first difficulty is got over by designing the old style face of modernized form so that the lower case r, s are wider, the h, k, n, u, etc., narrower, the a and the o much narrower while the e remains unaffected. The resulting face is very legible, though many of the distinctive features of old style are almost absent.*

The second is dealt with by increasing the whole of the *set* widths proportionately; the quads are thus no longer square or half square, though the em is double the en; the spaces must also be proportionately widened, and this involves altering the space-wedges in the casting machine to give the correct measure.†

The actual perforation of the ribbon is effected by means of compressed air from the same supply used for controlling the casting machine.

The lower of the two additional (*green*) keys to the extreme right of the keyboard, Fig. 72 (page 1117), serves for returning the counting gear to zero, ready for commencing a new line.

The appearance of the perforated ribbon is shown in Fig. 75 (page 1122). The ribbon is rolled on a drum as it is perforated, and on completion is removed from the composing machine. The completed ribbon can now be fed into the typecasting machine and is in proper order for this, as it requires to go through in the *opposite* direction; the casting machine begins work at the end of the matter and works back to the beginning. The last operation in composing is the depression of the two keys in the top row; the corresponding perforations are now the first to come into operation, and provide the adjustment for the space-wedges which retain their setting till the casting of the line is completed.

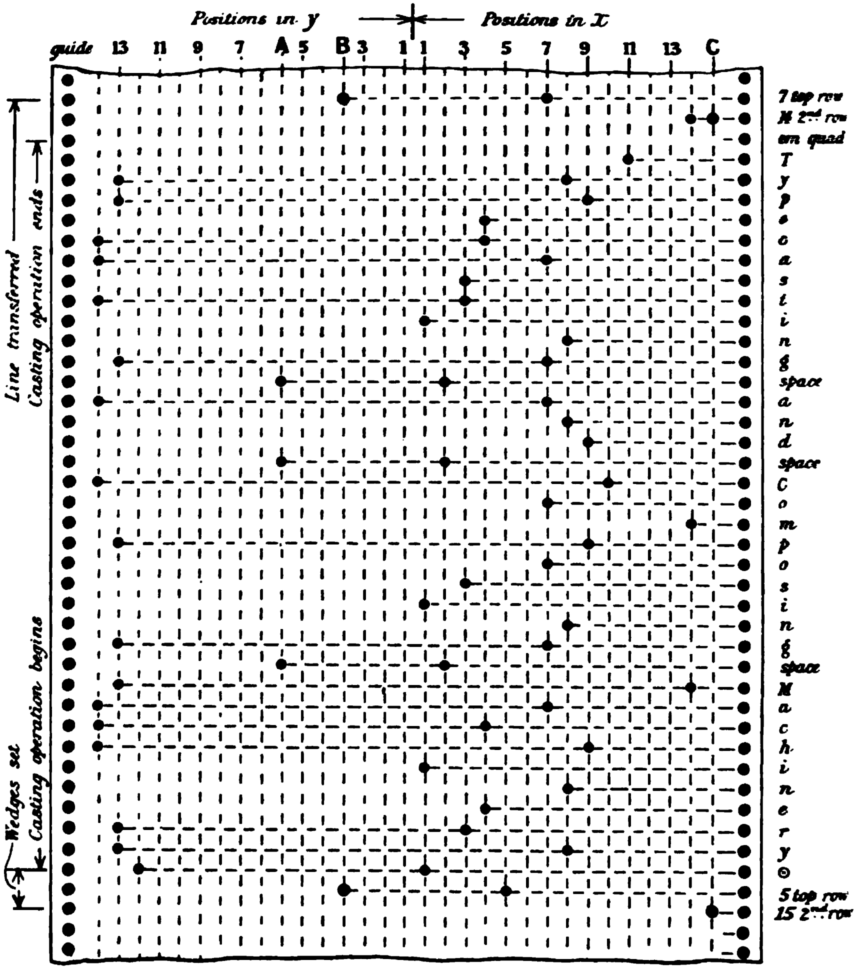
The perforated ribbon passes over the air tower of the caster between a long port and a drilled surface, which communicates by pipes with the cylinders of 31 plungers which correspond to the

* It is however possible by altering the "lay-out" (or arrangement of matrices) and by marking certain keys for a different character to that originally shown on them, to cast an old-style face having the full peculiarities of old style.

† A different drum is used on the keyboard corresponding to the number of points in the *set* width of the special em quad.

FIG. 75.

Perforated Ribbon for Typecaster (Lanston Monotype). Scale: about full size.



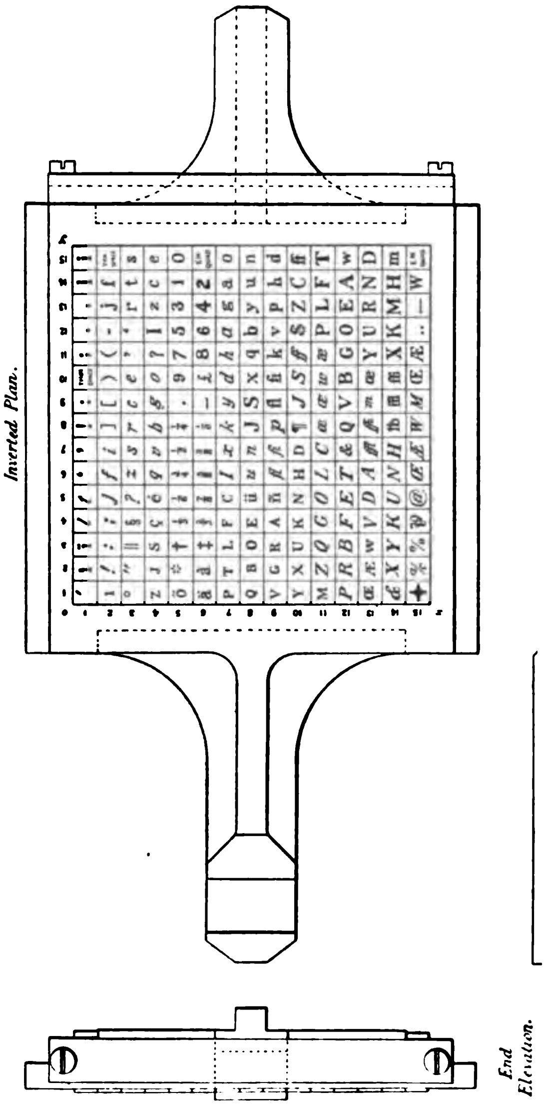
A Space transfer. **B** Coarse wedge. **C** Fine wedge.

When C and B are operated the line is transferred to the galley. The caster can be so set that consecutive strikes of C and B do not transfer the line, enabling double or multiple justification to be performed for tabular work. The final justification is effected by striking the required key of the top row, and then striking Key No. 1 of the top row simultaneously with the required key of the second row.

FIG. 76.

Matrix Grid for Casting Machine (Lanston Monotype).

Scale: about half size.



31 rows of holes which can be punched in the ribbon. The holes in the ribbon act like ports in a valve and admit air only to those cylinders the plungers of which are to be actuated. In the first instance the space-adjusting wedges for controlling the opening of the mould are set, and this setting remains constant till the line is completed and a new setting is given. Then for each character a third wedge comes into operation, determining the *set* width to be given to the mould for that character. The position of this wedge is dependent on the position of the matrix grid in the direction of the *set* width relatively to the mould. The matrices, Fig. 18 (page 1070), are secured in the grid, Fig. 76 (page 1123), by wires passing through the cross holes. They are arranged in 15 rows of 15 each, all the characters of a row body-wise being of the same *set* width. The matrix grid is spring-controlled so that it tends to be driven the maximum distance in both directions; i.e. it tends to travel to the origin in both x and y, and actually travels the full distance in both when there is no perforation in the ribbon (em quad). The movement is checked by 14 plungers, for each direction which rise vertically and stop the travel of the grid horizontally. The plungers are operated by compressed air at a pressure of about 15 lb. per square inch.

The plungers also perform another function; the two justifying keys of the top row on the keyboard (which are last depressed in composing the line) operate the plungers in x and y respectively, the one controls the distance moved by the coarse space-wedge and the other by the fine space-wedge one-fifteenth the taper of the coarse wedge. Once set, these wedges retain their position for the whole of the line; hence all these spaces are equal in *set* width. The whole travel of the fine wedge may correspond to only 0·0075 inch in the mould, the minimum difference of width for each space being 0·0005 inch. The maximum error of line-justification in a line containing ten spaces will then be 0·005 inch and in small pica body it will be nearly double the minimum error obtainable by hand-justification, but probably nearly equal to the error actually obtained in practice. The coarse wedge will move 0·0075 inch for each step and the total range will represent 14 $\times$ 0·0075 inch $\times$ 14 $\times$ 0·0005 inch or 0·1120 inch. In the case of small pica of 11 point the space already represents 4 units (each of about 0·0085 inch) or 0·0338 inch. The limits of width between which the space can be varied are therefore from 0·0338 inch to 0·1458 inch, or from rather less than the middle space up to nearly the em quad.

In the event of a line being cast of wrong length, the machine stops automatically.

The machine presents some very special features. The ribbon, if rolled up, can be used again an indefinite number of times; it can be used for any body size (say pica to nonpareil) provided the *set* widths are proportional to the bodies, and it can be used for either modern or modernized old style. A different drum must be used on the keyboard machine however, and a different ribbon produced if the matter is required to be printed in a style which necessitates variation in the space-wedge settings or in the lay-out. The ribbons can be stored, and represent a much smaller amount of capital locked up than in the case of type or stereotypes.

The speed of the Lanston Monotype can be as great as 180 type per minute for a medium-sized body, and in ordinary work 150 type per minute can be obtained.

The power required to run the keyboard and the casting machine is about 0·5 H.P.

The Tachytype, invented by F. A. Johnson of America, is a very similar machine. The perforated strip is narrow, being about 2 inches wide; the line-justification is effected automatically by the machine, and at the same time that the holes are perforated the character represented is typed on the strip so that the operator or any other person can read the record. The English rights in this machine have been acquired by the Linotype Co.; the machine has not been worked commercially.

Class IIIa. Machines in which Type is Distributed, Composed, and Line-Justified.

The Thorne Machine in its earlier forms did not line-justify the type, but in its latest form an automatic line-justifier is combined.

In the Thorne machine there are two coaxial vertical cylinders having radial grooves to receive the type. The upper cylinder is charged with matter for distributing without special preparation except that, as in the Empire machine, the type are specially nicked in the back with a different combination for each character. The grooves in the top cylinder are plain without any projections, Fig. 67 (page 1113). The grooves in the lower cylinder, on the other hand, bear the combinations of raised beads corresponding to the nicks at the back of each individual character. The lower cylinder remains stationary, and the upper revolves intermittently with a pause when the grooves are in alinement. When the beads in the lower cylinder groove agree with the nicks in a type above it the latter descends, and is available in due course for composition. The composition is effected by ejecting the lowest type (from the groove corresponding to the key depressed) on to a revolving circular disk. The type are brought round by the disk to the point of delivery, where they are received on a belt and thence travel to the receiving race. The *line-justifying* mechanism comprises a summing device which registers the total *set* of the line, and a registering device for the number of spaces. There are four *set* widths of spaces, and the justification takes account of any tendency to under- or over-space the line as in the Empire machine; but owing to the smaller number of sizes available, the result is not even so close an approximation as in the case of the Empire. The Thorne machine patents for England were acquired by the Linotype Co.; the machine has not been worked here commercially.

The Paige Distributing, Composing and Line-Justifying Machine is probably one of the most complicated machines ever devised, and contests the first place with Babbage's original calculating machine. Only two of the Paige machines have been made, and they are preserved in America in the Cornell and Columbia Universities as curiosities.*

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* *See* J. S. Thompson: "History of Composing Machines," pages 23 to 27.

CLASS IIIB. MATRIX COMPOSING MACHINES CASTING SLUGS.

The Linotype Machine, Fig. 77, Plate 35. The Linotype, which was originally produced by the Mergenthaler Linotype Company of New York, has been the subject of so much invention, it has played so important a part in the development and production of a great proportion of the newspapers of the day, and it has involved the sinking of so large a capital sum that it is really worthy of a Paper to itself. It cannot be dealt with so briefly as the preceding machines, and many interesting features must be here omitted for want of space.

At the top of the machine is the distributing bar, Fig. 78 (page 1128), which is formed with seven wards interrupted on the following system. The top ward, which may be styled No. 1, is alternately tooth and space, the length of tooth corresponding to the pitch of the divisions in the magazine mouths immediately below. Ward No. 2 is alternately tooth and space, but the length is double the tooth length of No. 1; similarly No. 3 is alternately tooth and space for four times the tooth length of No. 1, and generally No. n is 2^{n-1} times the pitch of the magazine mouths. Each matrix is formed with 7 teeth on each side of the top V nick, that combination being retained which corresponds to the wards removed from the rack at the point at which it is desired that it should fall. In every case the arrangement on each side of the V is symmetrical. The matrices of the characters which are most used travel the shortest distance, return soonest to the magazine, and the keys releasing them are most conveniently placed together under the operator's left hand. The order of release, detail of the distributing bar, and detail of some of the matrices will be seen in Fig. 78, and the keyboard in Fig. 69 (page 1114). The matrices in the magazine are retained by an escapement w, which is freed on the depression of the key k, Fig. 79. The key does not effect this directly, but releases a cam carrier q, which permits the cam c to be driven by one of two roller shafts S_1, S_2 which are kept revolving one in front of and one behind the lower verge rods v_1, which are raised by the depression of the keys. So long as the key remains depressed, the cam will roll on the roller and cause the upper verge v_2 to reciprocate vertically and

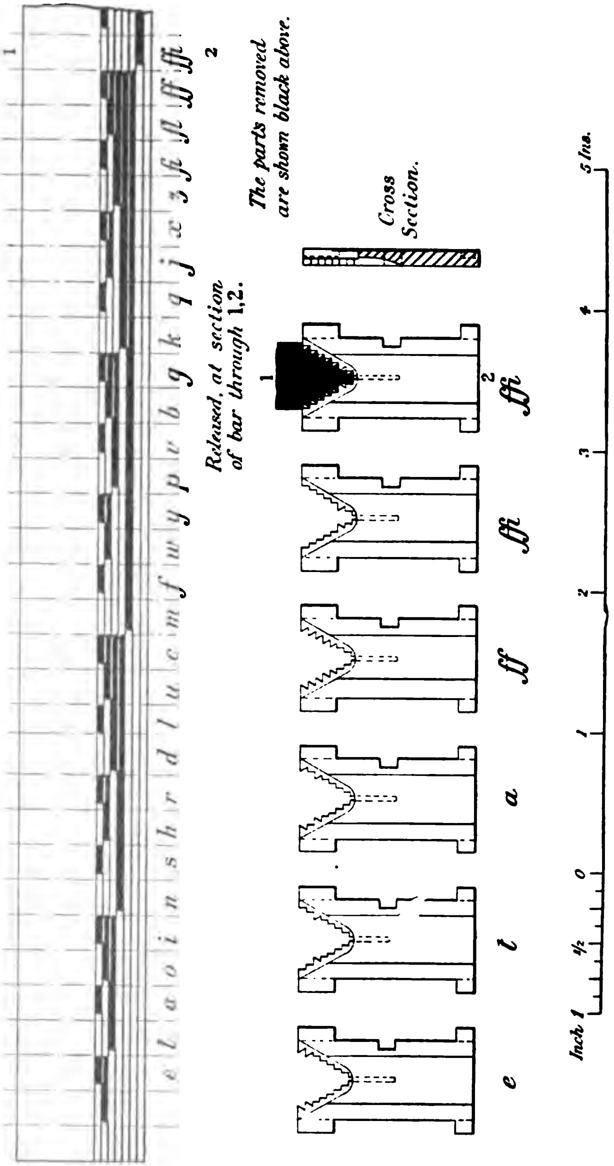
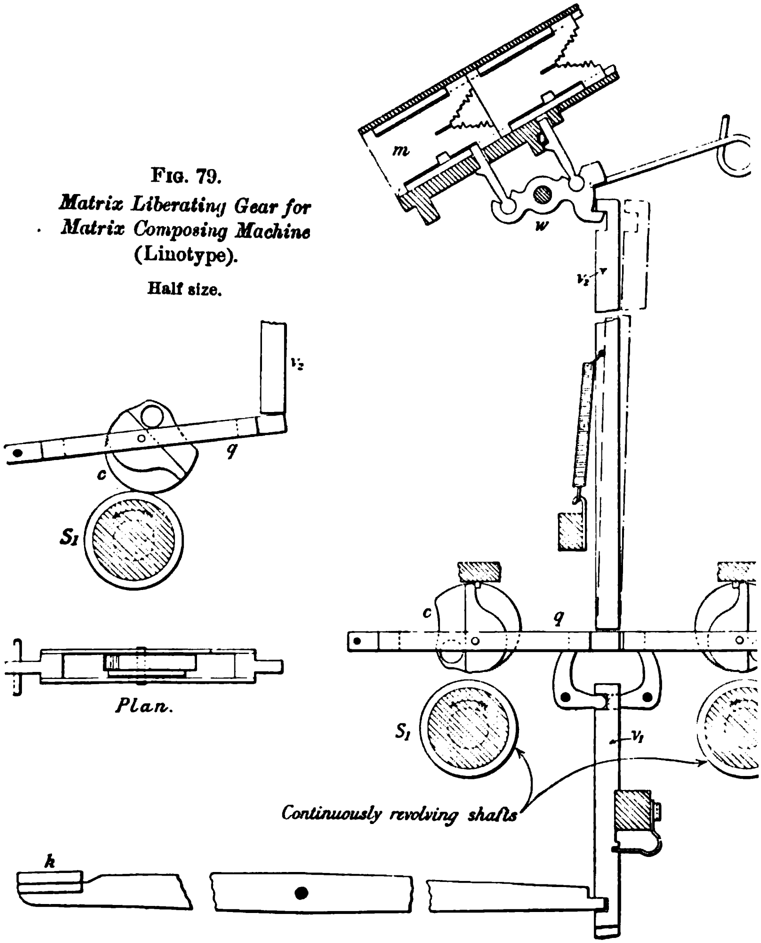


FIG. 78.—*Distributor-bar and Matrices for Matrix-Composing Machine* (Linotype).

release a matrix successively at each stroke. A very light to the key is sufficient, the power drive completing the release. matrices, as they fall, travel in a curved path from the mag which slopes downwards and forwards, into the guide box in

FIG. 79.
Matrix Liberating Gear for Matrix Composing Machine (Linotype).
Half size.



the left-hand grooves are nearly vertical, and the right-hand gro rudimentary, and supplemented by a continuously-running which assists the matrices to the star wheel. The star wheel fibre) pushes the matrices through a set of pawls. In falling past the star wheel the matrix was apt to strike against the last in the line and to damage the sharp edge at the strike. To obviate this, one corner has been cut away, and the life of the matrices has thereby been greatly increased. The completed line of matrices is shown in Fig. 80, Plate 36. Some matrices are now made with two faces; when the second face is used, the lower side-tongues of the matrices travel in a groove at a higher level until the casting has been effected, Fig. 81. The line is measured directly by the total length of the group of matrices. As in other composing machines the operator is warned by a bell, set about five ems before the end, when the line is nearly full; the length set must be *short* to allow for the spaces filling out the line. Between each word a space matrix or space band is dropped; this has no teeth, consequently it is not elevated to the distributor bar at the top of the machine, but goes direct to its own magazine. The space matrix, Fig. 82, consists of two main pieces dovetailed together, yet sliding freely and fitting sufficiently well to avoid trouble from metal getting between the two parts. The line having been set up, the other parts of the machine come into operation when the operator pulls the starting handle.

At the back of the machine is a cam-shaft carrying nine cams; this shaft is belt-driven through the intervention of an internal expanding clutch. The clutch is thrown out of gear in the event of any accident jamming parts of the machine; this renders the machine practically fool proof—a very necessary precaution—not only to avoid risk of damage by a learner, but because the expert operator, once he has composed a line and pulled the lever, immediately begins the composition of the next succeeding line, and does not watch the line which he has set through the successive operations of casting and trimming, nor does he follow the matrices in the elevator and distributor.

The following is the sequence of movements made by the Linotype. A line of matrices having been assembled, it is raised by means of a lever, and passes into the delivery carriage, which

Space Matrices. **Full size.**

Fig. 82.
Linotype.

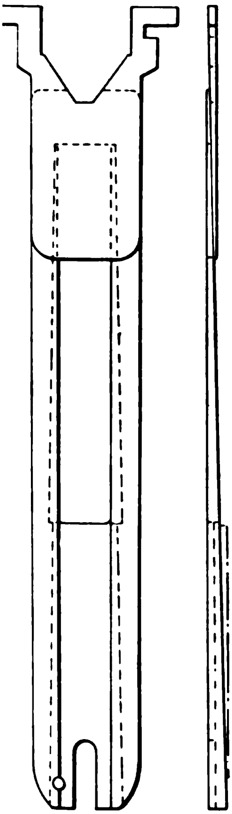


FIG. 83 —*Monoline.*
Three views of the 3 combined sliding pieces A. B. C.

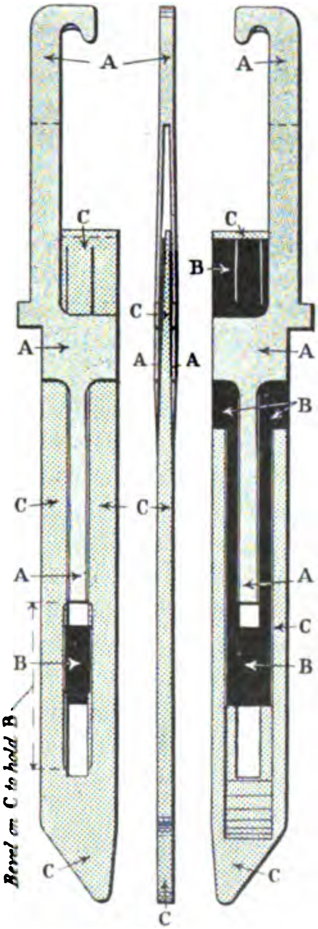
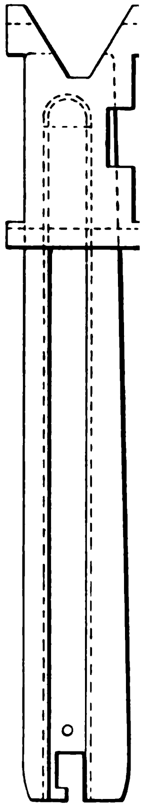


FIG. 84
Stringerty



carries it in to the first elevator. The first elevator descends (1).* Simultaneously the mould-wheel makes a quarter revolution (2) [turning from the ejecting to the casting position]: *see* Fig. 37 (page 1086); the matrices are now in front of the mould. The mould-wheel now comes forward (8) and engages the matrices [the alining lugs of the latter passing under the alining edge of the mould], but does not make *complete* contact. The vice-closing lever rises (3), allowing a spring to seat, which in so doing turns a screw which sets the vice block to the *correct* size of the line. The first line-justification lever (4) rises, pushing up the spaces successively from right to left in an inclined position, Fig. 85, Plate 36. Meanwhile, the delivery carriage has returned to the position of rest (9). The first line-justification lever (4) having descended, pressure is also now removed from the end of line by the vice lever returning to the position of rest (3), the partially-justified line being sufficiently held in position by the pressure of the left vice jaw. The first elevator (1) now slightly rises, causing the matrices to aline along the edge of the mould. The metal-pot (7), Fig. 86, Plate 37, now makes a *temporary* forward movement, the object of which is to press the mould against the matrix line to ensure *face* alinement. The pot having dropped back, the vice lever (3) again rises, allowing the spring-controlled vice block to determine the correct length of line. Both the first (4) and second (3) line-justification levers now rise simultaneously, and push the space bands up *evenly*. The pot (7) again advances, and is tightly pressed against the back of the mould; the plunger (6) descends, forcing the molten metal into the mould and matrices. The plunger having returned, the pressure on the bottom of the matrices caused by the first elevator is withdrawn, the line-justification and vice levers return to the position of rest, and the pot and mould-wheel (8) retreat, leaving the slug in the mould. The mould-wheel now completes its revolution by making a three-quarter turn (2), Fig. 37 (page 1086), during which the back of the mould passes over a knife which trims off the superfluous metal, Fig. 38 (page 1087) [including, of course, the locking bars].

* The figures in parentheses denote the cams actuating the lever or other member, counting from left to right along the cam shaft.

The mould-wheel now advances (8) on to two steady pins, the mould being in front of two parallel trimming knives, through which the line is forced by an ejector blade (8), which pushes the line from the mould, Fig. 38, and thence through the knives into the galley at the front of the machine, Fig. 87, Plate 37 [the ejector lever being returned by (9)]. Meanwhile, the first elevator (1) has carried the line of matrices upwards to the intermediate channel, where it is met by the second elevator (5). The first matrix pusher (9) now transfers the line of matrices from the first elevator to the second. The pusher having temporarily receded, the elevators return to their position of rest. Meanwhile, the first matrix pusher, acting in conjunction with the space shifter (9), again advances and causes the space matrices to be gathered by the space shifter, which returns them to their receptacle at the right-hand end of the intermediate channel. In the meantime, the line of matrices has been pushed by the second matrix pusher (2) from the second elevator into the lift box, where the matrices are lifted, one at a time, so that each successive matrix is engaged by three revolving screws, and passes on to the distributor bar, Fig. 78 (page 1128), along which it travels [by means of revolving screws engaging with the lugs]. The matrices are suspended from the distributor bar by their teeth, and when each arrives at that portion of the bar from which the same combination of teeth has been removed, it falls between guides and passes back into the magazine. The path of the matrices through the machine is shown in Fig. 85, Plate 36.

The Linotype is driven usually by belting; the main shaft carrying the clutch runs at about 72 revolutions per minute and the cam shaft at about 7 revolutions per minute. About 0·3 H.P. is required to run the machine; the maximum torque is required when making the upstroke of the pump.

The mould and the body-trimming knives can be specially arranged, so that when a suitable matrix is used the type can be kerned below the body-size, the kerned portion being entirely formed in the matrix. This is used to form the two-line letter used in newspapers at the commencement of advertisements. The beginning of the succeeding line must be set with two or more quads so as to provide the clearance for the kern, or the exact length may be obtained by using the two-line matrix reversed, Fig. 88.

The two-line and other special matrices are formed *without* nicks, and consequently are not elevated to the distributor bar; they drop into a tray near the space magazine.

The rate of output of the Linotype machine is generally taken at 6,000 ens per hour, this representing the normal rate of an average compositor. Under good conditions however the compositor can average from 7,000 to 8,000 ens. The machine is capable of greatly exceeding this speed.

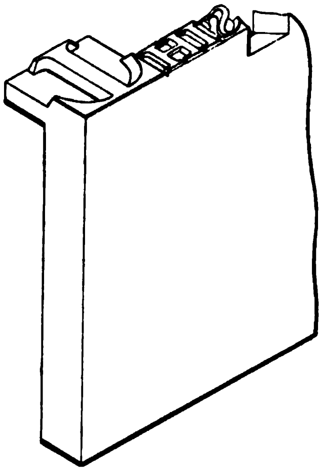


FIG. 88.

Two-line Letter

(Linotype Slug).

Twice full size.

Linotype Duplex Machine.—By a recent improvement the Linotype can be arranged with two interchangeable magazines and two moulds fitted diametrically opposite each other on the mould wheel. This enables the machine to be changed very quickly from one face and body to another.

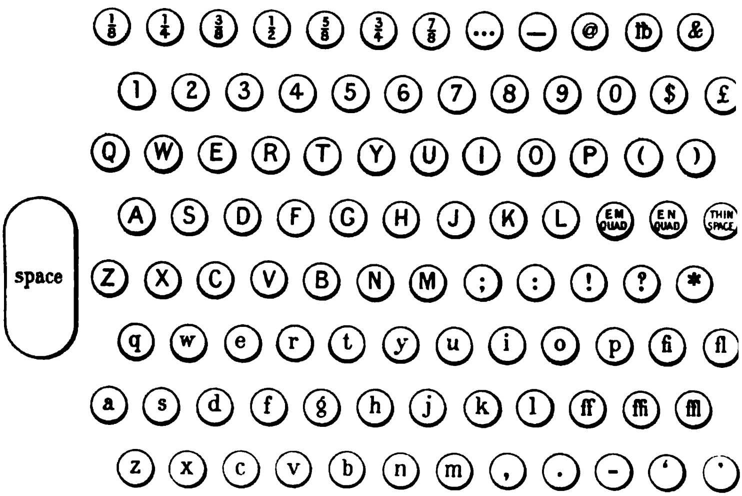
Mergenthaler Linotype.—This is the American Linotype, and in its latest form comprises some further improvements in duplex working.

Monoline.—The Monoline, Fig. 89, Plate 37, is of American origin, though manufactured in other countries, and is remarkable for its great simplicity as compared with the other slug-casting machines. Reduction in the number of parts has been carried consistently through the design, with the result that a very compact

FIG. 90.

Keyboard for Matrix Composing Machine (Monoline).

Scale: about ⅓rd full size.



a much lighter and much less costly machine has been evolved. (The actual cost is less than half that of the Linotype machine.)

The keyboard, Fig. 90, comprises ninety-six keys (and a space key) which are arranged in eight rows of twelve, the arrangement being very similar to the keyboard of the Bar-Lock or Yōst typewriters. There are, apart from space matrices for line-justification, eight different kinds of matrix, Fig. 19 (page 1070), each kind carrying twelve strikes. The characters of a group are, of course, chosen so that they come on the same *set* width, Fig. 91 (page 1136).

FIG. 91.

Arrangement of Strikes on Matrices (Monoline).

	Kind of Matrices.							
	1	2	3	4	5	6	7	8
bottom 1	7	⅞	q	!	;	Z	@	&
2	6	¾	b	)	‘	p	...	Y
3	en quad	½	g	?	thin space	L	em quad	U
4	5	¼	a	e	i	T	m	R
5	8	y	o	t	,	O	H	w
6	0	fi	n	s	l	D	W	A
7	1	ff	h	r	f	F	M	G
8	2	x	d	c	.	B	—	E
9	3	fl	u	I	-	S	ffi	N
10	4	⅛	p	z	j	C	ffl	X
11	9	⅜	v	*	’	J	K	V
top* 12	$	⅝	k	(	:	Q	℔	£

* Since in composing the matrices are added to the right, with their faces *from* the operator, it is necessary that the strikes should be inverted.

According to the particular key depressed, a matrix is released from the magazine compartment for the kind of matrix containing that sort, and is received on a stop, set by the key, so that it is at the proper level to bring the required character in line when it passes into the assembler. The space matrix, Fig. 83 (page 1131), consists of a long steel wedge sliding between two short steel wedges, and is operated in a similar manner to the Linotype space matrix, Fig. 82. The long wedge has a projection on the back against which the justifier pushes, lifting the wedges until the line is filled.

The casting, trimming, and ejection of the slug from the mould are effected in a very similar way to the same operations on the

Linotype, but the distribution of the matrices after the line has been cast is effected in a much more simple manner. The hooks at the top of the matrices are arranged in a series of nine different lengths corresponding to the eight kinds of type matrices and the space matrix. The selection to the nine magazine compartments is effected by sliding the matrices on their lower ends so that the hooks engage on a series of distributor rails, which are then lifted and bring all those of each kind of matrix (which have been used in the line) opposite their respective channels in the magazine into which each kind is pushed laterally, off the distributor rails, by a pusher.

The Monoline slugs are delivered into a galley in column.

The Monoline machine occupies a space of about 3 feet 6 inches by 4 feet 6 inches, it weighs about 800 lb. and requires about $\frac{1}{6}$ H.P. to drive it.

The adoption of a rational keyboard in which the keys most used are placed close together is, in the author's opinion, preferable to the methods adopted on some of the other machines described, in which the arrangement of keys is dependent on the *set* width of the character or on some constructional peculiarity of the machine.

Class IVa. Four-Operation Machines.

The operations of composing and line-justifying, casting a justified line and setting it, which are usually divided between two machines, are combined in the *Stringertype Machine.*

The Stringertype Machine, Fig. 92, Plate 38.—In this machine a line of matrices is composed, and the operations of line-justifying, casting a justified line, and setting are performed automatically. The Stringertype matrix, Fig. 21 (page 1070), differs from the Linotype matrix, Fig. 20 (page 1070), the strike being on the flat. The matrix is notched at the side, and this notch serves to set the mould to the correct width for the character, the dimension from the bottom of the notch across the flat being the *set* width plus a constant. The matrices are assembled as in the Linotype and measured in a vice together with space matrices, Fig. 84 (page 1131), the measurement being made on the aggregate thickness of all the matrices.

When the line has been composed, the spaces are driven up to fill the vice. The *set* width of the spaces is obtained in just the same way as with the type matrices; the Stringertype space matrix is tapered in side elevation, and the width at any point is equal to the *set* desired plus the same constant as in the type matrix. It is not essential that the thickness of the matrix should be the same as the *set* width of the type cast from it, but all the matrices of a fount may be a constant multiple of the *set* width in thickness. The space matrices must then be arranged with different tapers in front and side elevation. If θ_1 is the inclination of the wedge surface to the vertical in front elevation and θ_2 in side elevation, and C is the constant multiple in the case of the type matrices, then

$$\tan \theta_1 = C \tan \theta_2.$$

It is thus possible to set the vice and its details to the dimensions of any convenient body-size, such as pica, and the difficulty of obtaining a sufficient thickness for the matrices of the thin sorts is overcome.

The platform by which the space matrices are pushed up is L shaped in plan, and maintains the lower ends of the space matrices at the same height while passing before the mould.

The matrices having been measured are presented one by one in front of the mould, which closes to the *set* width given by the notch; the pump injects metal into the mould, which then opens, and one part acting as an elevator vertically raises the type with its tang to the receiving race, into which it is pushed by a horizontal pusher. By an ingenious arrangement of the mould the tang is carried up above the feet, two V notches being left one at each side, Fig. 42 (page 1087); the tang can thus be readily broken off, and the rough fractured part is clear above the feet. This is done automatically by the machine before delivery, the tangs falling clear down a shoot.

The type during the casting and composing operations is horizontal; when the line is completed it is automatically turned through 90° to the vertical position and placed in the receiving galley.

The matrices travel from the vice to the left of the machine after the measuring operation; they are then pushed successively one at a time into the cross race and travel from the operator in front of the mould; the last matrix cast from remains in the slide until the first of the next line comes along, when this matrix is pushed along the cross race. After the matrix has been cast from, it passes along the cross race by the pressure of the next succeeding matrix, and when it has travelled its own width past the casting point a plunger pushes it into the elevator race. On the completion of the line the elevator lifts the matrices then in the race to the slide where the space matrices are transferred to their magazine, and the type matrices elevated to the distributor bar, which operates in the same way as in the Linotype machine.

Safety cut-outs are provided, which operate under any circumstances which would involve damage to the machine, and in the event of a line being cast of incorrect length the machine is also stopped.

The advantages of casting separate type are many: corrections can be made by hand and away from the machine if necessary, whereas in the slug machines it is necessary to recast the whole of the line, even when the correction consists only of two transposed letters or a point omitted; the depth of the strike can be deeper, and therefore a clearer impression obtained, and the breakaway tang permits a hard metal to be used (similar to that employed in ordinary type for hand composition), whereas the metal used in the slug machines, and in those similar to the Monotype, must necessarily be soft.

The normal speed of the Stringertype mould is 160 characters per minute; as stated above, this does not represent the limit of output of a single mould; the total output possible of nearly 10,000 ens per hour is greater than that of any operator at work.

The machine requires about one half horse-power.

It is not generally intended to distribute the type but to remelt it; when, however, it is desired, a matrix can be left at rest in the machine and type cast from it continuously, so that sorts can be obtained from the machine for hand composition, if both machine and hand work are used.

The same degree of accuracy is required in type cast by these machines as in type cast on the simple typecaster. The test usually applied to check accuracy is that known as the "lock up," which consists of repeating the same characters for a whole page. A page thus set up is shown in Fig. 93, Plate 39; the type for this were cast at the rate of 160 per minute.

It does not appear probable to the author that the old method of casting single type and composing by hand can ever be entirely superseded by machine composition, as the bulk of display work and a large portion of scientific works cannot be so treated. In the case of most daily newspapers the whole of the ordinary matter, with much of the small type advertising, is set either in the form of slugs, or in the case of some of the more expensively-produced papers by means of other composing machines.

A very large amount of high-class work for the better weekly periodicals, for magazines, for novels and for text-books is still being performed by hand, but it is probable that this work also will be performed by machines in the near future, owing to the greater degree of perfection regularly obtainable in the product.

One word of caution is offered by the author to those who think of competing in the field covered by these machines. The detail is so complex and the difficulties met with in working out the machines are so numerous, that the time for which a patent is granted may easily be in greater part absorbed in experimenting before a commercial result is obtained.

In conclusion the author wishes to express his thanks to Mr. W. H. Maw, Past-President, for his kind assistance and for help in obtaining particulars, to his son Mr. R. L. Maw, Associate Member,

for his aid in preparing diagrams, to Mr. J. F. Gilmore of the British Stringertype Syndicate, who has been connected with the Linotype and several of the principal machines, for much valuable information, and to his staff for their assistance in the preparation of many of the diagrams with which this Paper is illustrated.

The Paper is illustrated by Plates 32 to 39 and 78 Figs. in the letterpress and is accompanied by 6 Appendices with 15 Figs. and Plates 40 to 45.

APPENDIX I.

French Type.

The French very early adopted a point system, known as the Fournier system, in which the unit or point was 0·34875 mm. This system has now been almost entirely superseded by the Didot system, and the Fournier point is now in use only in Belgium and the North of France.

The Didot system now generally adopted has as basis the point of 0·376 mm.* It is to this (Didot) unit that typecasting and composing machines are designed.

The bodies in use are named according to the number of points; the sizes most generally in use are 5, 6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22, 24, 28, etc. The 11 point (*corps onze*) corresponds very nearly to the English pica.

The height-to-paper of French type is 23·50 mm. and is 23·545 mm. for very fat black faces. The height of quads and spaces is from 19·18 mm. to 19·50 mm. The height of rules and furniture is about the same, the minimum being 18·05 mm.

The supplementary nick, used for distinguishing the small capitals o s v w x z and i in old style, is also employed in France.

There are certain differences between some of the characters as usually cut in France and those cut in England; for example, the Cap. C has "cats-ears" at top and bottom (C) while in England they occur at the top only; also a French fount comprises a sign for inverted commas « le guillemet » not used in England. The triple logotypes ffi and ffl are now scarcely ever used (*see* Appendix III on Logotypes).

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* The English point is 0·35145 mm.

The following short vocabulary gives the names o parts or dimensions of type, *see* Figs. 1 and 2 (page 10

The face	la face	Depth of strike	pr
The shoulder	le talus	Serif	po
The nick	le cran	Body	fo
The heel-nick	la gouttière au pied	Line-to-front	di
The feet	les pieds de la lettre	Height-to-paper	he
The pin-mark	la marque	Set	ép
The counter	l'œil	A space	un
Kerned letter	lettre crénée	A quad	un
To distribute pie	distribuer un pâté	A galley	un
An em-quad	un cadratin	Furniture	ga
An en-quad	un demi-cadratin	A lead (1 to 4 pt.)	un
The line	la ligne	Leaded	in
Side wall	l'approche	A rule (metal)	un
Supplementary nick	le cran supplémentaire	A rule (1 to 12 pt.)	un
The tang	le jet	A rule (wood)	un
The slope (of italic)	la pente	A fount	un

The nick in French type is placed at the back instead of i English founts.

The bill of fount for French type gives very differe to those of the English bill. The bill shown in the fo (based on that of M. Rignoux) will probably be found not usual to include italic unless specified; when ital it is usually in the ratio to roman of about 1 to 6. T taken 15 per cent. The quantities, for a fount of ron be obtained by summing those given for roman and ital

The superiors are used for abbreviations, such as

M^{gr} = Monseigneur, C^{ie} = Compagnie, N^{os} = Num

It is the custom of the trade to supply only É Ê I small capitals, and italic capitals, but in this bill th included the other accented capitals which may be calle

TABLE 9 (*continued on opposite page*).

French bill of fount for 100,000 *characters, exclusive of spaces and quads.* (*Police pour* 100,000 *caractères, les espaces et cadratins non compris.*)

Bas de casse.

a	4,220
b	845
c	2,110
ç	90
d	2,510
e	9,250
f	845
g	845
h	845
i	4,630
j	420
k	80
l	3,820
m	2,110
n	4,220
o	3,820
p	1,720
q	1,010
r	4,630
s	5.540
t	4,630
u	4,220
v	845
x	420
y	260
z	260
æ	40
œ	80
w	40
ff	160
fi	300
fl	210
32	65,025

Ponctuations.

.	1,500
,	1,800
;	250
:	170
?	170
!	170
6	4,060

Signes.

-	950
'	950
»	300
*	40
†	40
(	130
[	40
§	40
—	260
9	2,750

Bas de casse accents.

à	380
â	210
ä	40
é	1,250
è	380
ê	260
ë	40
î	125
ï	40
ô	125
ö	40
ù	210
û	125
ü	40
14	3,265

Capitales. / Petites capitales.

Capitales.		Petites capitales.	
A	260	A	170
B	125	B	80
C	210	C	125
Ç	20	Ç	20
D	210	D	170
E	380	E	300
F	125	F	80
G	125	G	80
H	125	H	80
I	260	I	210
J	80	J	80
K	20	K	20
L	260	L	170
M	170	M	125
N	210	N	170
O	260	O	170
P	170	P	125
Q	125	Q	80
R	260	R	170
S	260	S	170
T	260	T	170
U	210	U	150
V	170	V	110
X	65	X	65
Y	40	Y	40
Z	40	Z	40
Æ	20	Æ	20
Œ	20	Œ	20
W	20	W	20
&	125	&	80
30	4,625	30	3,310

Capitales accents.

À	65
Â	35
É	80
È	65
Ê	20
Î	15
Ô	15
Ù	35
Û	15
9	345

Petites capitales accents.

À	40
Â	20
É	65
È	50
Ê	25
Î	10
Ô	10
Ù	20
Û	10
9	250

Ital. capitales accents.

À	15
Â	10
É	20
È	15
Ê	10
Î	5
Ô	5
Ù	10
Û	5
9	95

Total number of sorts 259.

(*concluded from opposite page*

French bill of fount for 100,000 *characters, exclusive of quads.* (*Police pour* 100,000 *caractères, les esp et cadratins non compris.*)

Supérieures.	
d	100
e	200
g	100
i	100
l	150
m	100
n	100
o	200
r	150
s	100
t	100
11	1,400

Chiffres.	
1	400
2	300
3	250
4	250
5	400
6	250
7	250
8	250
9	250
0	400
10	3,000

Ital. bas de casse.		Ital. capitales.	
a	650	*A*	40
b	125	*B*	20
c	325	*C*	35
ç	20	*Ç*	5
d	380	*D*	35
e	1,400	*E*	60
f	125	*F*	20
g	125	*G*	20
h	125	*H*	20
i	715	*I*	40
j	65	*J*	15
k	15	*K*	5
l	575	*L*	40
m	325	*M*	25
n	650	*N*	35
o	575	*O*	40
p	260	*P*	25
q	150	*Q*	20
r	715	*R*	40
s	840	*S*	40
t	715	*T*	40
u	650	*U*	35
v	125	*V*	25
x	65	*X*	10
y	40	*Y*	10
z	40	*Z*	10
æ	10	*Æ*	5
œ	15	*Œ*	5
w	10	*W*	5
ff	25	*&*	20
fi	45		
fl	35		
32	9,935	30	745

APPENDIX II.

Characters and Signs required in Scientific and Other Works.

MATHEMATICAL.

$>$	is greater than	○	circle	$\therefore$	therefore
$<$	is less than	△	triangle	$\because$	because
$\propto$	varies as	□	square	$^{\circ}$	degree
∞	infinite	▭	rectangle	$'$	minute
$\angle$	angle	$\surd$	square root *	$''$	second
∟	right angle	$^{123\ldots n}$	exponents or powers †	$\equiv$	identical with
$\perp$	perpendicular to	$_{123\ldots n}$	suffixes †	$\backsim$	difference
$\parallel$	parallel	$\int$	integral	∂	used for partial differential coefficients.
$\pm$	plus or minus	$\underline{\lvert n}$	factorial ‡		

And those characters of the Greek lower case and capitals which differ from the Roman. α, β, γ, δ, ϵ, ζ, η, θ, λ, μ, ν, ξ, π, ρ, σ, τ, ϕ, χ, ψ, ω, Γ, Δ, Θ, Λ, Ξ, Σ Φ, Ψ, Ω.

MEDICINE.

℞ recipe ℥ ounce ʒ drachm ℈ scruple ♏ drop

ASTRONOMICAL.

Ꝝ right ascension ☊ ascending node ☌ conjunction ☍ opposition

---

* The radix must in some instances be made of ⌐┘ section to receive the figure or sign thus $\sqrt[3]{(A+B)^2}$. Owing to the great difficulty to the compositor involved by this sign it should when possible be replaced by the fractional index thus $(A + B)^{\frac{2}{3}}$. The solidus or diagonal stroke (/) is now frequently used to save work in composing, thus we read $(D - 1)/D$ instead of $\frac{D-1}{D}$. The author suggests that greater legibility would be obtained by the use of the diagonal stroke in fractional indices, e.g. $(A + B)^{2/3}$.

† Known in printing as superiors and inferiors.

‡ The factorial sign ($\underline{\lvert\ \ }$), which also gave great trouble, has now been superseded by the exclamation (!), thus we now read $\frac{n!}{m!(n-m)!}$ instead of $\frac{\underline{\lvert n}}{\underline{\lvert m}\,\underline{\lvert n-m}}$.

SIGNS OF THE ZODIAC.

♈ Aries	♌ Leo	♐ Sagittarius
♉ Taurus	♍ Virgo	♑ Capricornus
♊ Gemini	♎ Libra	♒ Aquarius
♋ Cancer	♏ Scorpio	♓ Pisces

SOLAR SYSTEM.

☉ Sun	○ Full Moon	⚶ Vesta
☿ Mercury	☾ Last quarter	♃ Jupiter
♀ Venus	♂ Mars	♄ Saturn
⊕ Earth	⚳ Ceres	♅ Uranus
● New Moon	⚴ Pallas	♆ Neptune
☽ First quarter	⚵ Juno	

MISCELLANEOUS.

HP Horsepower	℣ versicle	X St. Andrew's Cross
℟ response	† Latin Cross	
✠ Maltese Cross	☞ ☜ fists	

APPENDIX III.

Logotypes.

The subject of logotypes, or combinations of characters cast together, has not yet, so far as the author is aware, been studied in its bearing on typesetting. The very early patent (1782) of Henry Johnson was bought by John Walter, the founder of *The Times* newspaper, and was probably the only extensive application which the system has met with.

The advantage of the use of logotypes in the case of hand (or machine) composition lies in the reduction of movements to be made by the hand of the operator; thus a combination of three letters, e.g. "the," will save two lifts or key depressions, and a combination of four letters, e.g. "tion," will save three lifts or key depressions. It appears obvious that if a certain combination occurs so frequently that it is commoner than any individual letters of the alphabet, a saving of labour would result from the adoption of logotypes for such combinations without additional strain on the memory of the operator. On the other hand, where hand-composition is concerned, the number of case divisions would increase for each added combination, and consequently the size of the cases would be increased also. Moreover the number of compartments or keys to be memorized by the compositor would increase, as also would the distance to be travelled by the hand of the operator.

A further objection to the use of logotypes in hand work is that, owing to the larger mass of the combination, the face of any of the characters is more easily damaged, and damage to any one character necessitates replacement of the whole logotype.

In view of the absence of statistics on the subject of the recurrence of the commonest combinations of characters, and with the further view of testing the accuracy of the proportions in the ordinary bill of fount, the author, after some preliminary trials, has examined 100,000 characters (exclusive of spaces), occupying rather more than two pages of matter from *The Times* of 30 April 1907, selected from: Leading Articles, Foreign Intelligence and Parliamentary Debate (this latter amounting to nearly 60 per cent.

TABLE 10.

Number of Logotypes in 100,000 *Characters.*

the	1933	ther	132	who	85	car	44
and	800	pro	176	able	63	ple	43
of	910	ess	171	der	82	eve	43
tion	428	us	244	he	122	ert	42
in	843	all	160	oun	81	age	40
er	806	wh	236	ance	59	rec	39
ing	536	ate	155	out	78	very	29
ed	776	ere	147	will	55	ng	58
to	716	ter	140	his	73	He	58
re	667	ill	136	int	72	tor	38
that	314	not	135	so	107	miss	26
it	546	ion	134	end	71	ble	34
on	522	had	134	one	71	if	48
al	519	est	134	por	70	It	44
is	450	ly	201	aid	69	col	27
ould	220	com	125	per	69	Con	27
be	433	our	119	qu	103	than	19
for	285	ist	117	some	49	—	—
was	282	by	169	are	63	—	—
or	404	pos	111	man	63	—	—
ar	380	ted	106	art	62	—	—
at	366	igh	102	ough	44	—	—
ment	182	sh	153	ade	57	—	—
as	364	un	151	but	54	—	—
an	355	ence	75	Com	54	—	—
th	344	have	73	day	54	—	—
ch	336	pre	97	ever	40	—	—
ent	220	ant	97	act	49	—	—
en	311	ver	97	has	48	—	—
st	310	from	71	ace	46	—	—
The	202	ect	93	cha	46	—	—
con	196	ear	89	him	46	—	—
with	140	ish	86	its	45	—	—

of the whole). The following method was adopted in counting the combinations: first the matter was gone over and all the four-letter combinations (chosen from the preliminary trials) counted; then the three-letter combinations were taken, and to avoid overlapping treated in order of precedence, thus in the word "expressed" the combination "pre" was counted but "ess" was not counted; then on the remainder the two-letter combinations were similarly eliminated.

The number of each of the combinations counted in the 100,000 characters is shown in Table 10 (page 1149), in which the combinations are arranged in order of importance according to the total number of separate characters employed.

From this Table the total number of times any combination occurred can be obtained by adding together the figures opposite the different combinations in which it occurs. Thus the combination "th" occurs in "the," "that," "th," "with," "ther," "than," or in all 2,882 times, while "Th" occurs in "The" 202 times.

By summarizing the totals successively it will be found that the first combination "the" accounts for over 6 per cent. of the whole matter; the first three combinations for over 10·4 per cent.; the first eight for over 20·2 per cent.; the first fifteen for over 30·3 per cent.; the first twenty-six for over 40·5 per cent., and the first fifty for 50·1 per cent.

Logotypes are actually in use for the seven combinations æ, œ, ff, fi, fl, ffi and ffl; they are also used for the italics of these, and for the caps Æ, Œ, roman, italic and small capitals. In all twenty different logotypes are actually supplied with every complete fount. All these combinations are rare, and, for the bulk of printed matter, could be abolished without seriously offending the eye, or orthography; in France the ffi and ffl are no longer generally used, ffi and ffl being substituted.* Why should not the seven commonest

* These combinations were originally necessary owing to the f being made to kern in the earlier type; the combined letters had to be cut specially to avoid fouling. With machine-cast characters (which usually do not kern) the necessity for the special combinations ceases to exist, and combinations such as ff and fl do not offend the eye.

logotypes be substituted for these, and while performing the composition of nearly 20 per cent. of ordinary reading matter, at the same time save lifting type (or depressing keys) to the extent of nearly 12 per cent. of the total work? The answer is probably to be found in the conservatism of the printing trade, and in the fact that the tendency is to abolish rather than adopt these combinations. The long s (ſ) with all its combinations, ſi ſl ſſ ſt, still found in German, to the illegibility of which language it largely contributes, the ct and qu with several others have been generally dropped in this country, the ct alone being still occasionally supplied with some old style faces. It is difficult to understand why the logotype "qu" should have gone out of use, for with the exception of algebraical expressions (and occasional quotations involving the occurrence of a very few foreign words) the "q" practically never occurs except in the combination "qu."

The Table of frequency of logotypes given (page 1149) would have proved of considerable utility in the design of the Wicks Composing Machine, the keyboard of which is shown in Fig. 56 (page 1104). In this machine the inventor attached special importance to the possibility of obtaining many frequently occurring combinations just as chords are struck on the piano. With the keyboard shown in the figure, chords can be struck for 34 of the logotypes given in the Table accounting for nearly 33 per cent. of ordinary reading matter. With the following arrangement b t w p c h e a i o u r s n g d l y , . sp. qd. for the front row, chords could be struck accounting for 51 of the logotypes given in the Table, and for over 44 per cent. of the ordinary reading matter.

It may be asked how far does the above Table show the true proportion of logotypes in general, or how far may they have been affected by the particular character of the matter selected for the statistics. In the Leading Articles and Foreign Intelligence (40·8 per cent. of the whole) and in the Parliamentary Debate (59·2 per cent. of the 100,000 type), the first eight combinations as given in the Table occurred in the following numbers (reduced to per 100,000).

Logotypes per 100,000 Characters Roman Lower Case, Capitals, and Points.

	On 40·8 per cent. Per 100,000.	On 59·2 per cent. Per 100,000.	On 100 per cent. Per 100,000.		On 40·8 per cent. Per 100,000.	On 59·2 per cent. Per 100,000.	On 100 per cent. Per 100,000.
the	1,958	1,915	1,933	in	897	806	843
and	635	914	800	er	981	684	806
of	1,040	821	910	ing	549	527	536
tion	532	356	428	ed	816	748	776

The counting of the single letters gave the result shown in the following Table, in which the actual number found is compared with that calculated from the bill of fount. (In Table 11 the figures for the individual letters are reduced in the ratio of 100,000 to the total Roman lower case, Capitals and points = 812,540.)*

TABLE 11.

Comparison of Observed and Calculated frequency of Occurrence of Individual Characters per 100,000.

	Observed.	Calculated.	Per cent.		Observed.	Calculated.	Per cent.
e	11,520	9,638	119·5	s	5,442	5,502	98·9
t	8,832	6,885	128·3	r	5,880	4,819	122·0
a	7,078	6,195	114·3	h	4,990	4,130	120·8
i	6,225	6,195	100·5	d	3,524	3,441	102·4
o	7,161	5,502	130·2	l	3,407	3,441	99·0
n	6,231	5,502	113·2	u	2,483	3,098	80·2

* In computing the number of points, it must be remembered that in the bill of fount about 10 per cent. of the quantities of full point and comma respectively belong to the italic fount.

It will be seen that there was a considerable variation between the observed and calculated frequency of occurrence, and the total observed characters in the Table exceeded the total calculated by some 13 per cent. This is in a great measure due to the matter selected consisting of long sentences. It is probable that if a much larger number of characters were taken and a greater diversity of printed matter selected the result would agree more closely with the fount bill.

Modification of the Alphabet.—There are in the English language several sounds which are represented in writing and printing by combinations of consonants and in shorthand by single signs. The author has investigated the frequency of occurrence of these, and has found that in the 100,000 characters counted above the following combinations occurred which could be represented by single characters if the alphabet were modified.

TABLE 12.

Sounds represented by Two-letter Combinations per 100,000 *Characters.*

th	2,882	wh	321	sh	239
Th or TH	259	Wh	27	Sh or SH	8
ng	594	st	490	ch	382
NG	5	St or ST	34	Ch or CH	50

The author suggests that a saving of about 3½ per cent. in writing, typewriting, printing, and reading would be effected by adopting two new letters for "th" and "ng" respectively. The early English thorn ð could be used for "th," or, if considered more legible, the Greek θ could be adopted; for "ng" a hybrid letter could be easily designed resembling both its components (like the Greek $\dot{\eta}$). It would also be very easy to design simple longhand letters to replace the two separate letters now used; this saving does not only apply to the printer and compositor, but affects equally all who write and read the English language, and, moreover, it is a change which could be introduced first in the daily press and become gradually universal.* The author does not consider that it would be easy to carry his proposal further than the two new letters mentioned, which would increase the alphabet by two characters. The "th" (θ) would rank eleventh in order of demand and the "ng" (η) twenty-third in this new alphabet of twenty-eight letters, the "ng" being in greater demand than k, q, x, j and z. The adoption of the two new characters named could moreover be effected readily on nearly all composing machines by the elimination of some of the existing unnecessary logotypes, such as ffi, ffl, æ and œ.

* This change has been already predicted by Mr. H. G. Wells in his novel "When the Sleeper Wakes.

APPENDIX IV.

On the Methods employed in correcting the Division Plates for producing the Wicks Machine.

The division plates used were of the form of a circular disk with a central boss scraped to fit a central column. The divisions were 100 in number and cut in the periphery of the disk with the ordinary dividing gear supplied with one of the best makes of milling machine. The form of division was such that the working face of each was radial and the other face inclined to the tangent, Fig. 94 (page 1156); the locking bolt was accurately ground and lapped to fit in a slide on the base of the division plate. At an early stage in the manufacture of the Wicks machine it was found that the division plates were not sufficiently accurate for the grinding processes on the segments to be carried out so far that segments could be manufactured to stock as components. The *maximum* error permissible, so that the segments could be prepared up to the stage at which lapping would begin, was found to be about equal to an error of 0·0007 inch at the periphery of a circle 20 inches in diameter or less than 15 seconds of arc. This corresponds to about 4½ inches at a distance of one mile; to ensure the result it was considered necessary to make the measurements to less than one-fourth of this amount.

(1) In the first method employed the author used a theodolite with two micrometer microscopes reading to 10 *seconds centesimal.* One side of the plain end of a lightning conductor on a distant chimney was used as the distant object, and the angle moved through from one setting of the division plate to the next obtained by direct reading on the graduated circle of the theodolite with the micrometer microscope, the reading obtained being of the form:

$$4 \cdot 000 \text{ grades} \pm \text{difference.}$$

After taking the reading the theodolite was reset to zero, set on the distant object, and the plate moved another tooth; the second angle was then measured. By this means the total of the readings

Fig. 94.—*First Method of Correcting Division Plate.*

Each division is compared with the arc $0^g - 4^g$ of the theodolite circle by aid of a distant object **X**.

Scale ⅕th.

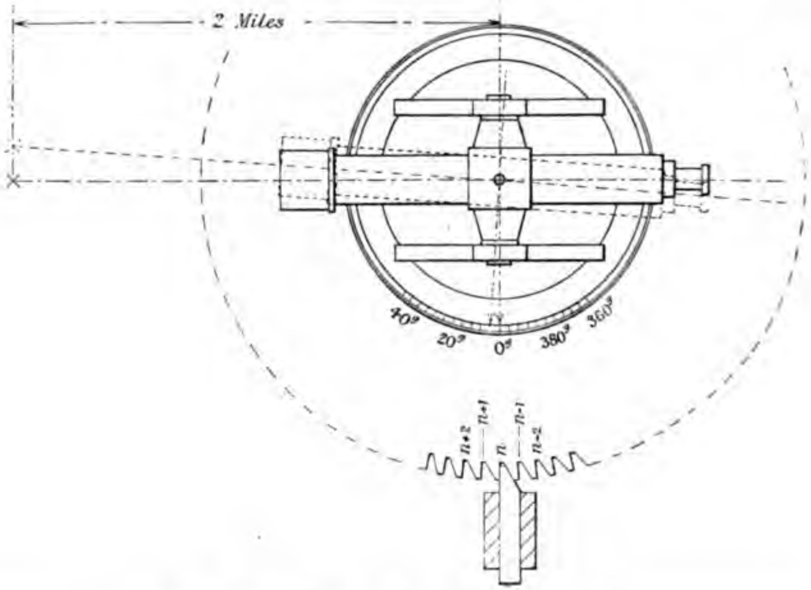
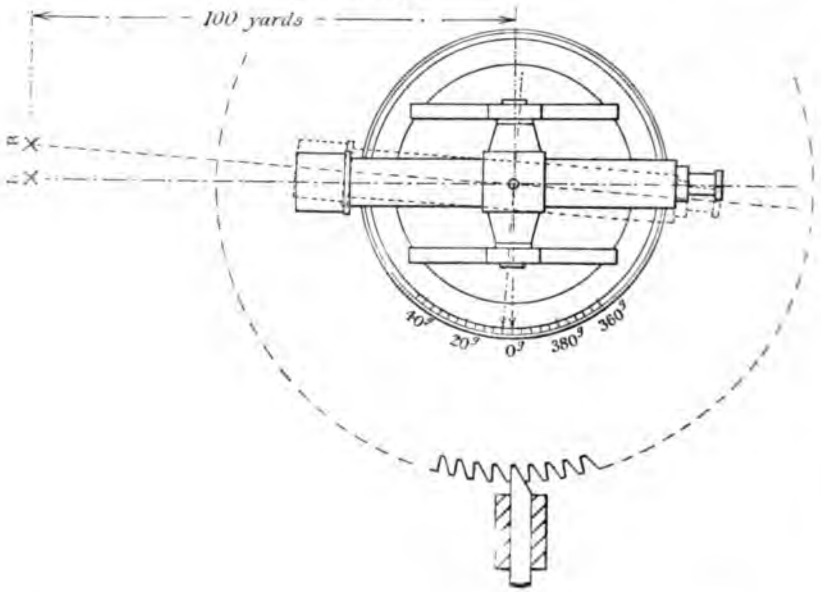


Fig. 95.—*Second Method of Correcting Division Plate.*

Each division is compared with the angle subtended by the two fixed wires L and R at the centre O.

Scale ⅕th.



should have equalled 400 grades, but the errors of personal equation and of the standand arc of the theodolite were found to be equal to say 0·00045 grade (4·5 seconds centesimal).

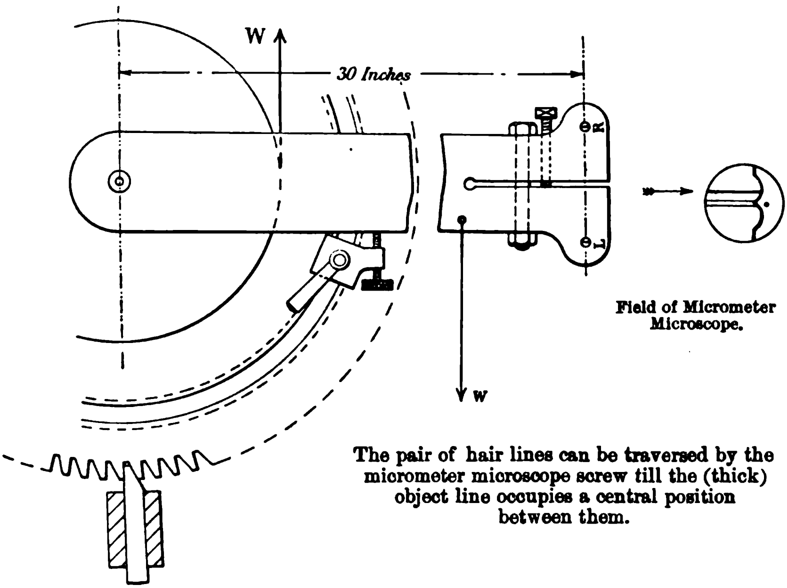
It was then possible to determine the actual difference from the standard angle for each angle moved through by the division plate

FIG. 96.

Third Method of Correcting Division Plate.

Each division is compared with the standard angle LOR by the micrometer microscope.

Scale $\frac{1}{8}$th.



and, by continuously summing the differences, the maximum positive error (or from the workshop point of view, the lowest tooth) could be determined. The excess of the maximum positive error above the sum of errors at any particular tooth gave the cut to be removed from that tooth.

The method adopted for performing this work was devised by Mr. Colebrook; it consisted in mounting the division plate on a horizontal spindle between centres on a milling machine and applying a constant torque by means of a wire fastened to the periphery of the boss, passing over a pulley and loaded with a weight.

A micrometer screw was fitted so that it could be engaged with the flat radial surface of any tooth in succession. An angle mill mounted on the spindle of the milling machine could be fed across the face of the tooth to be reduced. This micrometer screw was set in contact with a different tooth of the plate, so that the cutter came inside the gap corresponding to the tooth to be reduced; the micrometer screw was then slacked back till this tooth, following it under the action of the weight, just touched the revolving mill. The mill was then traversed to one side and the micrometer screw turned through the amount desired to be removed plus a constant. This constant was $\frac{1}{1000}$ inch which represented the least amount that could be removed with certainty by a cutter without risk of refusal and glazing of the surface.

The single distant-object method of measurement did not require any particular accuracy in centering the theodolite on the division plate. It proved however a very troublesome method in practice owing to the rapid and frequent variations in light and atmosphere near London, and further owing to the yielding of the clay strata under the passage of trains on adjacent railways.

(2) As several plates were required, the author next tried a different method, Fig. 95 (page 1156), in which the chief troubles noted above were diminished. The same centesimal theodolite was used. Two pieces of fine piano wire were stretched by suspended weights from a slide and slide-rest some 200 yards from the instrument. The wires were blackened, a clean white paper background placed behind them, and the suspended weights were immersed in water to damp out any vibration. The screw of the slide-rest was worked till the readings obtained, using the side of each of the two wires, gave a close approximation to the desired angle of the division plate (4·000 grades).

In this case it was necessary to set the theodolite more nearly central with the division plate, an eccentricity of $\frac{1}{16}$ inch only being permissible.

The mode of operation was as follows:—

(i) The bolt being inserted in the space *n* of the division plate of the theodolite, the telescope was first set on the left wire L and the reading L_n noted.

(ii) The telescope was then turned on the right wire and the reading R_n noted; thus by difference the angle LOR was obtained $R_n - L_n$).

(iii) The plate was turned till the bolt engaged in space $(n + 1)$ and the reading of the left wire L_{n+1} was taken.

(iv) The telescope was turned and another reading of the right wire R_{n+1} was obtained; from these again the angle LOR was obtained as $(R_{n+1} - L_{n+1})$.

Thus the angle LOR was measured 100 times and from these measurements its error was obtained. (For example $d = 0 \cdot 000031$ grade.)

If d and e are the differences from the angle of $4 \cdot 000$ grades in the readings of the left and right wires respectively, then the readings are of this form (where n is the starting point):—

$$
\begin{aligned}
L_n &= (n) \quad 4 \cdot 000^g + d_n & R_n &= (n+1)\, 4 \cdot 000^g + e_{n+1} \\
L_{n+1} &= (n+1)\, 4 \cdot 000^g + d_{n+1} & R_{n+1} &= (n+2)\, 4 \cdot 000^g + e_{n+2} \\
L_{n+2} &= (n+2)\, 4 \cdot 000^g + d_{n+2} & R_{n+2} &= (n+3)\, 4 \cdot 000^g + e_{n+3}
\end{aligned}
$$

and $\qquad R_n - L_n = 4 \cdot 000^g + e_{n+1} - d_n = 4 \cdot 000^g + \delta - \eta_{n+1}$
where δ is the mean error of standard angle and η_{n+1} is the error in the theodolite arc over the portion used from space n to space $(n + 1)$.

Now taking the alternate readings,

$$
\begin{aligned}
L_{n+1} &= (n+1)\, 4 \cdot 000^g + d_{n+1} \\
R_n &= (n+1)\, 4 \cdot 000^g + e_{n+1}
\end{aligned}
$$

and subtracting we get $L_{n+1} - R_n = d_{n+1} - e_{n+1}$ where η, the error of the theodolite arc, is eliminated, and if a represents the actual error of the angle from space n to space $n + 1$,

$$a = d_{n+1} - (e_{n+1} - \delta).$$

4 I

The actual arithmetical work can be reduced to about six columns of figures and the corrections obtained without difficulty.

The degree of accuracy attained can be judged by the following result after three series of corrections had been applied.

Errors at periphery of wheel 10 inches radius expressed in millionths of an inch:—

Errors.	0 to 70	70 to 140	140 to 210	210 to 280	280 to 350	350 to 420	420 to 490	490 to 560	560 to 630	630 to 700	700 to 770
Number of divisions	10	21	15	19	7	7	7	6	4	0	4

It will be seen that the errors had only just been reduced to the desired amount after the division plate had been corrected three successive times.

(3) The next method devised, Fig. 96 (page 1157), gave far better results, and did not involve the necessity for making so many observations continuously.

The column of the division plate was fitted with centres and a long bar of mild steel suspended between these. This lever was forked at its outer end some 30 inches from the centre. A bolt and set screw were provided for springing open the forked part or closing it. Each arm of the fork was drilled and a plug of silver wire inserted in each. A very fine radial line was drawn on each silver plug with a diamond. A micrometer microscope was arranged on a fixed support fast to the base of the division plate so that the horizontal lever could swing under it. A stop was fitted on the division plate with an adjusting screw with long stem to enable the horizontal lever to be set so that either the left or right wire could be brought to zero; the lever was kept under a constant pressure against the screw end by means of a weight and fine cord. Further means was arranged for enabling the stop to be moved through approximately 4 grades after the reading had been taken. The gear was boxed in so that variations in temperature, and radiation from the operator, did not affect the readings appreciably.

The method adopted was as follows: in the plan of th R is the right hand radial line and L the left. The lin brought under the micrometer microscope and set to zero, plate was moved one tooth and the reading on the line L ta reading being the difference between the angle LOR and tl moved through by the plate. After the reading had been ta stop and lever were moved so as to again bring R to zero; t was then moved another tooth and the next reading of L take

The readings of R were always zero. The readings of the differences $d_1, d_2, d_3 \ldots$ from the standard angle.

Moreover, since the plate moves through 400 grades completes its revolution,

$$\Sigma\, d_1 + d_2 + d_3 + \ldots d_{100} \text{ should} = 0.$$

Actually it was found to equal Δ, and $\frac{\Delta}{100} = \delta$ was the the standard angle between the lines on the silver plugs.

The corrected differences $d_1 - \delta$, $d_2 - \delta$, $d_3 - \delta \ldots$ we tabulated as $D_1, D_2, D_3 \ldots D_{100}$ and summated conti thus:—

$$D_1,\ D_1 + D_2,\ D_1 + D_2 + D_3, \ldots D_1 + \ldots D_{100},$$

the calculation being of a form which makes checkin easy.

These totals were then each multiplied by a constant s reduce them to the scale of the micrometer adjustment for r The new values being $\sigma_1, \sigma_2, \sigma_3, \sigma_4 \ldots \sigma_{100}$, of which the ma value σ_m corresponded to the lowest tooth; adding $0{\cdot}001$ this and subtracting $(\sigma_m + 0{\cdot}001)$ from each term in succ the negative value obtained gave directly the amount of cu taken.

The results obtained can be seen from the following Ta which the error in millionths of an inch at the circumferen wheel 10-inch radius is given in the top line, and the num teeth falling between the limits is given in the succeeding as shown by measurement after the first, second and third cu been taken.

Measured error.	0 to 100	100 to 200	200 to 300	300 to 400	400 to 500	500 to 600	600 to 700	700 to 800	800 to 900	900 to 1000	1000 to 1100	1100 to 1200	1200 to 1300
After 1st cut .	15	18	22	16	10	7	4	0	2	3	1	0	2
After 2nd cut .	10	20	17	14	13	10	4	4	3	2	1		
After 3rd cut .	16	26	30	16	9	2	1						

The methods adopted may appear troublesome and complicated, but actually the calculation was merely of a simple arithmetical character. These division plates, it should be remembered, were not light measuring apparatus, but had to serve for carrying numerous drilling and other jigs, and required sufficient surface to bear setting hundreds of times each day in continuous regular work.

APPENDIX V.

Machines Not Described in the Body of this Paper.
(The same classification is adhered to as in the Paper.)

Class Ia (page 1092).

The Bhisotype.—Since this Paper was written the author has received particulars of a multiple mould typecasting machine known as the Bhisotype (Prof. S. A. Bhisey). This machine is stated to be arranged to cast from thirty to sixty different characters per revolution, and to run at 40 revolutions per minute. The speed claimed for it is, therefore, even greater than that of the Wicks machine, being 2,400 type per minute in the larger size machine. The type are stated to be turned out with the full depth of strike and with nicks and groove finished.

It is intended to work this machine in conjunction with a composing machine, the characters cast on the casting machine being conveyed by chains to a group of from eight to ten composing machines.

The Bhisotype machines are not at present in general use.

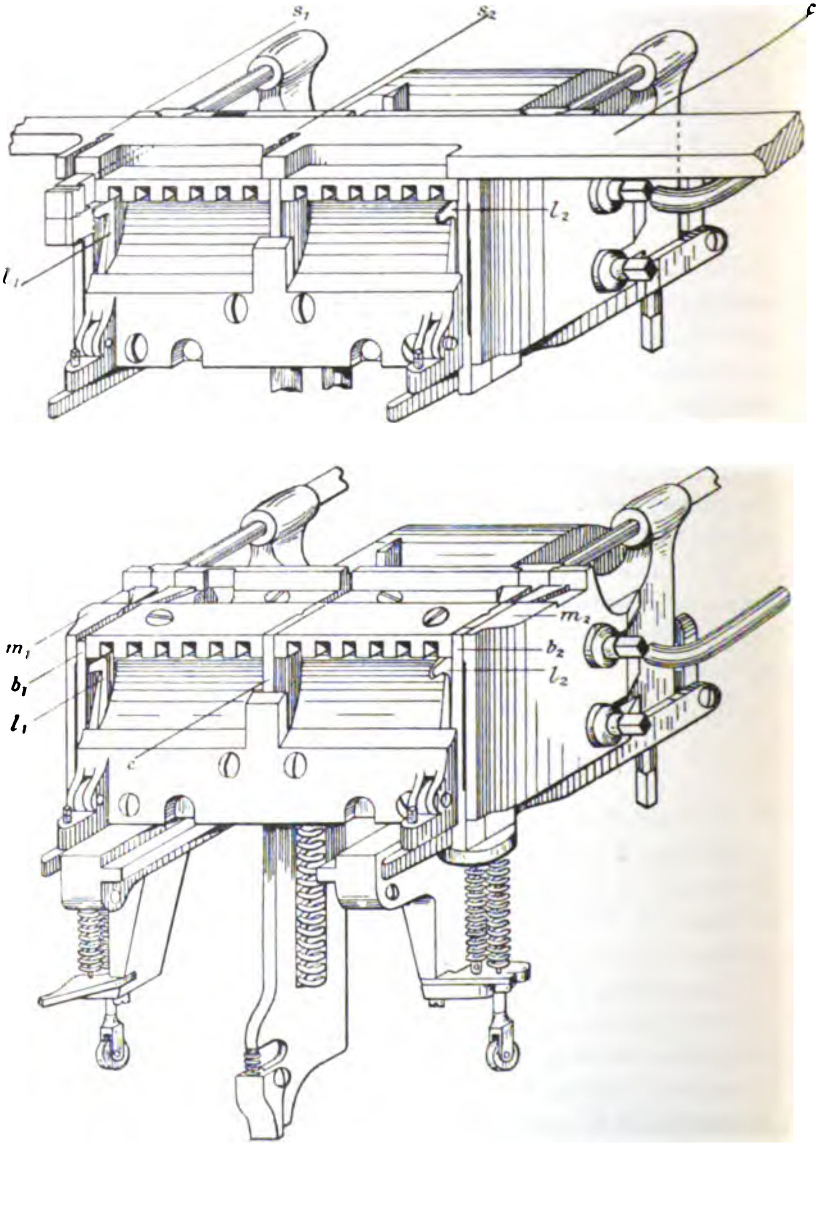
Class IIb (page 1092).

The Pinel Dyotype.—Since the Paper was written the author has received from Mons. R. H. de la Colombe particulars of a new machine, the Dyotype (J. Pinel). This machine has recently been constructed in Paris, and differs in several respects from the other machines described of this class.

The matrices, Fig. 97, Plate 40, are of trapezoidal shape, and a number of them are built up into a wheel, Fig. 98, having solid longitudinal dividing bars of the same section as the matrices. These solid dividing bars serve for casting spaces of the various thicknesses and for quads. The matrices are secured in the matrix-

Fig. 99.

Arrangement of Moulds for Typecaster (Pinel Dyotype). About ½ size.



wheels by cylindrical pins which lock them to each other, to the dividing bars formed on the solid portion of the matrix-wheel, and to the ends of the matrix-wheels.

Each matrix is provided with a small steel plate at one side; the upper end of the bellcrank levers l_1 l_2 takes against this, when the matrix-wheel is presented to the mould, and the other end of the lever depresses the body-slide against the pressure of a spring, so as to give the characters a proportional *set* width to the distance moved by the upper end of the bellcrank, Fig. 99.

Each matrix-wheel contains twelve solid dividing bars with four rows of matrices arranged circumferentially between each pair of dividing bars. There are six circumferential rows of matrices, each of which contains 48 matrices arranged thus: the first row for lower-case roman; the second row roman capitals; the third row lower-case italic; the fourth row italic capitals; the fifth row small capitals; and the sixth row the various signs and figures. Thus each matrix-wheel contains 288 matrices for characters, apart from the twelve solid dividing bars upon which spaces can be cast. There are two matrix-wheels on each casting machine.

The moulds on the Pinel Dyotype casting machine are, in construction, somewhat similar to those already described in the Lanston Monotype and the Stringertype machines, in so much as each comprises a movable body-slide which takes up a position corresponding to the *set* width of each character to be cast.

There are two moulds m_1 m_2, Fig. 99, in the casting machine, and a collector-slide c which has a to-and-fro movement over them. This collector-slide forms one side of the mould; it also contains two slots s_1 s_2, of the same section as the type, into which the type is received when the collector-slide has moved (after the casting has been effected), so as to bring one of these slots over a body-slide b_1 b_2. Each slot is in turn then brought over the elevator-slide e placed centrally between the two moulds, and this moves the type successively out of the collector into the guide clip, from which it passes to the composing stick.

The body-slide is made in two portions which move together, with their upper surfaces at the same level when type are to be cast, but when a space is to be cast the portion nearest the face does not move, but acts as the matrix end of the mould, so that spaces are cast of trade height instead of shoulder height as in other machines of this class.

The two moulds are closed simultaneously by the collector, and the two type are cast at the same moment. At the end of its movement to the left the collector-slide pauses and receives the type cast in the left hand mould m_1; it pauses again when it has brought this type over the elevator e; the type received from the left mould is now ejected into the guide clip and the type from the right mould m_2 is received in the right slot s_2 of the collector, to be removed by the elevator e when the next successive type is being received in the left groove of the collector-slide.

It appears that the idea of the inventor of this machine is to be able to cast up to double the speed obtainable in a single mould, but of course there is some attendant complication in arriving at this result owing to the doubling of a large number of parts essential for each mould. Unlike the Lanston Monotype in which compressed air is employed, or the Graphotype, in which electro-magnets are used, the selecting needles are caused to enter the perforations by means of spring blades.

The perforated ribbon is very similar to that prepared in the Graphotype perforator. There are, however two lines of guide perforations, one on each side of the strip, Fig. 100, Plate 40, which are made by the keyboard itself. The strip may receive perforations on thirteen longitudinal lines, of which the perforations on lines 1, 2, 10, 11 and 12 indicate the kind of type fount (and consequently the lateral position of the matrix-wheel), while perforations on lines 4, 5, 6, 7, 8 and 9 indicate the different characters, letters, or signs and control the rotational movement of the matrix-wheel. Perforations on line 3 control the casting of spaces, giving a middle space when there is a perforation on line 3 alone, and a justifying space when the perforation on line 3 occurs in combination with another perforation. The perforation on line 13 is of larger diameter than the others and sets in operation the trip gear for transferring the line to the galley.

A very important feature of the Pinel Dyotype is that it avoids the disadvantages of requiring the use of unit systems or self-spacing type. The keyboard is arranged to effect the summation of any widths of characters, this being performed by a metal piece which is changed for each fount used. The wheel, which is used for the summation, is a toothless ratchet, driven and held by friction. This arrangement allows the matrices to be struck from existing punches, and therefore permits the work to conform to the faces already in use by the printer, a matter of considerable importance.

The line-justification of the line when composed is the same for all bodies and permits any shortness of length from one point up to twenty-four points to be made up. This is performed by an arrangement connected with the keyboard.

At the end of the line, the operator presses the line-justifying lever, and the machine modifies the space perforations already made, the strip being held in readiness for the purpose, without the further intervention of the operator.

Unlike the other two machines of this class described,* the justifying perforations occur at the beginning of the line and the strip is put into the machine so as to start at the beginning of the matter. In order to obtain the requisite total of combinations, the number of perforations varies for different characters, some characters being formed by one perforation and others by two, three, four or five perforations respectively.

The first Pinel Dyotype casting machine is shown in Fig. 101, Plate 40.

CLASS IIIB (page 1093).

The Double Magazine Linotype (Fig. 102, Plate 41).—Machines of this pattern are now in use both in America and England. As stated in the Paper (page 1134) there are two magazines which are placed one above the other; the lower magazine has its escapement below as shown in Fig. 103, Plate 42. The upper magazine has its escapement

* The *Goodson Graphotype* is described by Mr. P. W. Davis in the Discussion (page 1203).

above with separate upper verge rods. By means of a lever on the right of the keyboard either series of verge rods can be thrown into gear, the lever performing a similar function to the shift key on typewriters; thus any portion or portions of a line may be set in matrices from the upper magazine and the remainder from the lower magazine. Each magazine may contain two-letter matrices so that, with a keyboard of 90 keys, a total of 360 characters can be obtained. The return of the matrices to their respective magazines is effected by means of a central notch in the bottom of those matrices which belong to the upper magazine, Fig. 104, Plate 42. The matrices after leaving the arm or second elevator are received on a short rail and those without notches engage with the lower distributor bar, whereas the notched matrices straddle this short rail, travel between guides below the top ears and drop sufficiently to clear below the lower distributor bar; they then fall into an elevating device which transfers them to their own distributor box above the other. The return of the matrix to its proper place in its own magazine is therefore perfectly automatic. The magazines can be thrown backwards and raised clear of the escapements at the front end by means of an arrangement of levers; in this position they can be changed very quickly.

The American machine has the same difference in the matrices, but the notched matrix in this case falls down a shoot to its distributor box and enters the *lower* magazine. The escapement of the upper magazine is below and that of the lower magazine is above. Thus in the American machine the additional magazine has been added below, and in the English machine above, the original position. With the American arrangement the lower magazine can be changed while the machine is being operated with the upper magazine in use.

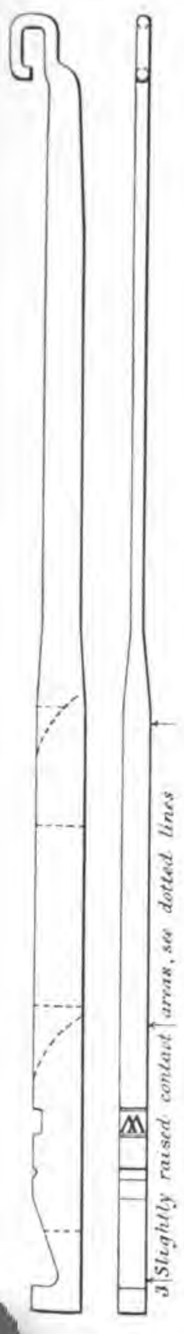
The new machines comprise a number of improvements for facilitating, in particular, the access to the mould wheel and to the trimming knives.

CLASS IIIB (page 1093).

The Typograph (Fig. 105, Plate 43).—This machine was originally produced in America. It was bought up so far as that country was concerned by the Mergenthaler Linotype in order to acquire the rights of the wedge space invented by J. W. Schuckers. The Typograph continued to be made in Canada and Germany, and since this Paper was written has been introduced into this country.

Matrices.—The Typograph matrices are struck in one face of a bar of rectangular section; this bar has let in, and silver soldered to it, an eye of steel by which it is suspended from a steel wire throughout the operations of composing, line-justifying, casting, and distributing. As the matrix never leaves the wire, distribution is a very simple matter; the whole of the upper portion of the machine rocks on an axis and is balanced by a spring so that a very small force only is required to tilt the top of the machine comprising the magazine, escapement, and keyboard until the magazine is at so low a level that the matrices slide back into place along the polished steel wires from which they are suspended, Fig. 106. The matrices may be of two kinds; in the single-letter machines they have a rigid eye at the upper end and are cut away to a hooked form at the lower end, Fig. 108 (page 1170), and in the two-letter machines, they have two notches at the lower end on the same side as the strike and two parallel notches on the opposite side above the strike, Fig. 109. In the former case the matrices are pulled down to justify for alinement, the upper surface of the hooked end being used for this purpose. In the case of the two-letter matrices, Fig. 107, Plate 43, these slide along the upper surface of one or other of the back parallel notches, and the justification for alinement is obtained by the gripper pressing the matrices upwards by means of one or the other of the front notches so that the lower face of one of the parallel rear notches bears against the setting bar which has been clear in the groove during the period of composition. The matrices do not bear against the faces used for alinement either during composition or distribution, consequently the tendency to wear and so produce irregularity of alinement is a minimum.

Matrix Composing and Slug-casting Machine (Typograph).



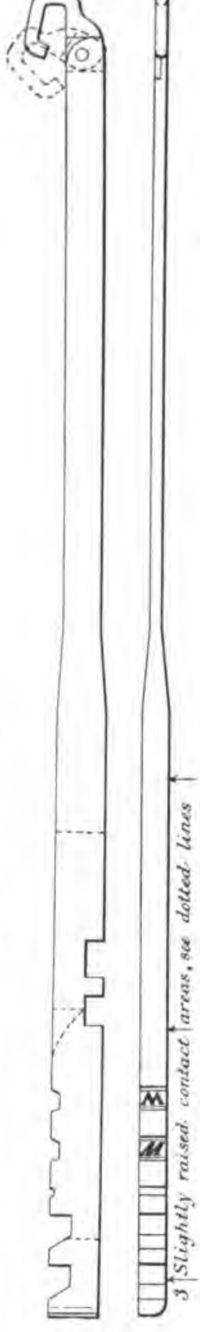
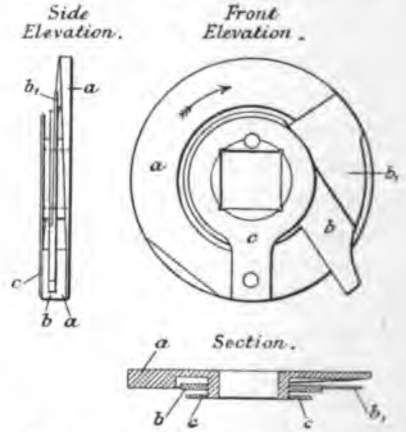


Fig. 108.—*Single-letter Matrix.* Full size.

Fig. 109.—*Double-letter Matrix.* Full size.

Fig. 110.—*Space-disk.* Full size.



The space-disk, Fig. 110, is of circular form made up of three pieces; the main piece a is plane on one side and on the other is formed with a helical face and a cylindrical boss; a loose plate b with a projecting arm turns freely on this boss; the portion of this plate b_1 which acts in making up the variable space is also made helical on the face next to the main part so that the outer face is parallel to the back of the main part when both helical surfaces are in contact; the plate is retained on the boss by a cover-plate c riveted to the main portion.

Assembly Channel of Matrix Composing and Slug-casting Machine.

(See also Plates 44 and 45.)

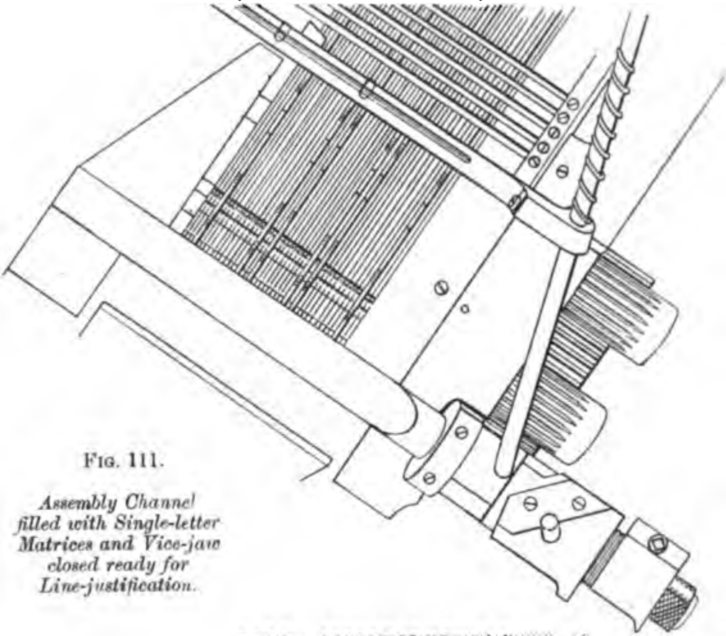


Fig. 111.

Assembly Channel filled with Single-letter Matrices and Vice-jaw closed ready for Line-justification.

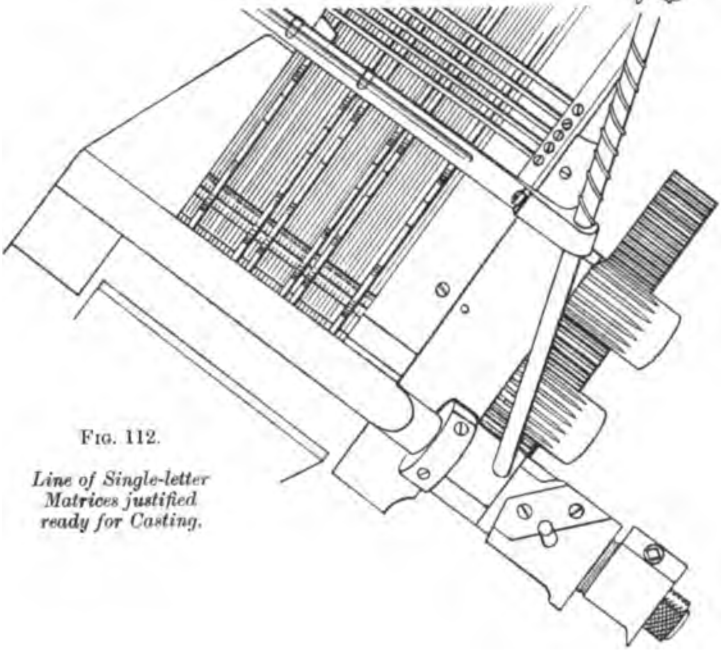


Fig. 112.

Line of Single-letter Matrices justified ready for Casting.

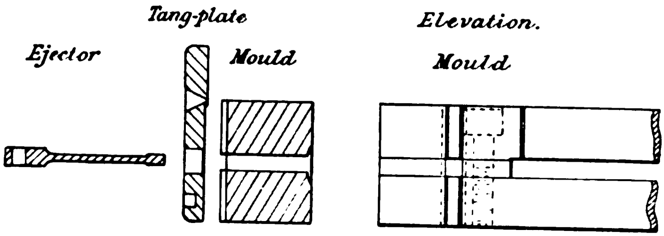
The space-disks, Fig. 110 (page 1170), are used in pairs one above the other, and are rotated equally so that the long stems of the letter matrices are kept parallel. Two steel bars of square section form the magazines for the space-disks; each of these bars is separate from, but forms the continuation of, the end of one of the square steel line-justifying shafts. In the normal position of these shafts relatively to the bars the space-disks can be made to slide freely from the one to the other in either direction. The hole through the centre of the main part of the space-disks is square, which enables this piece to be rotated relatively to the plate *b*, the arm of which is held in a groove in a brass guide. The letter matrices on each side of a pair of space-disks are thus wedged apart by the action of the helical surfaces; equal rotation of the two square shafts is effected by spur gears on the overhung ends of the shafts engaging with a rack which is spring-propelled on the line-justifying stroke.

Fig. 111 (page 1171) shows a line of single-letter matrices ready for line-justification and Fig. 112 shows the line after the shafts have been partially rotated to the requisite extent to fill the line.

Mould.—Owing to the form of the space-disk the Typograph mould, Fig. 113, is concave where it comes in contact with the space-disks which project slightly in front of the letter matrices. The hole formed by the various portions of the mould for the body of the slug is plain and rectangular, there being no beads, grooves or projections in this portion; the back is however recessed to a small depth, but only over a part of the length and width, so that the tang joins the slug below the level of the surrounding portion, Fig. 114. The tang is formed by a separate tang-plate interposed between the mould and the pump mouth. The tang-plate moves upwards after the slug is cast, and the metal pot has receded, shearing off the tang. The shearing is actually effected by the steel tang-plate against the typemetal of the recess in the slug and thus wear is avoided. The slug is then ejected towards the matrices by an ejector acting through a hole in the tang-plate; this takes place in two stages, at the end of the first the fins on the shoulder of the slug, Fig. 114, are removed by a pair of trimming knives which travel in the direction of the length of the slug and towards the back of the machine. The

Matrix Composing and Slug-casting Machine (Typograph).

Fig. 113.—*Mould, Tang-plate, and Ejector.* Half size.



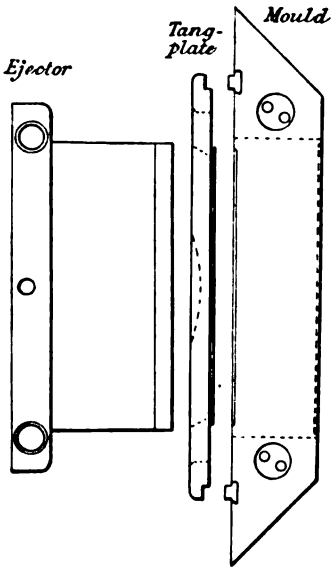


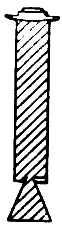
Fig. 114.

Type-slug as cast. Section through a space.

Fig. 115.

Type-slug trimmed and tang cleared off. (*section*)

Full size.



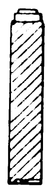
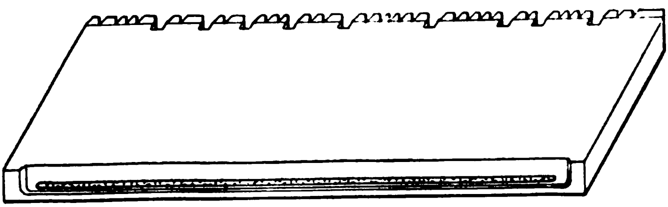


Fig. 116.—*Type-slug finished.* Full size.



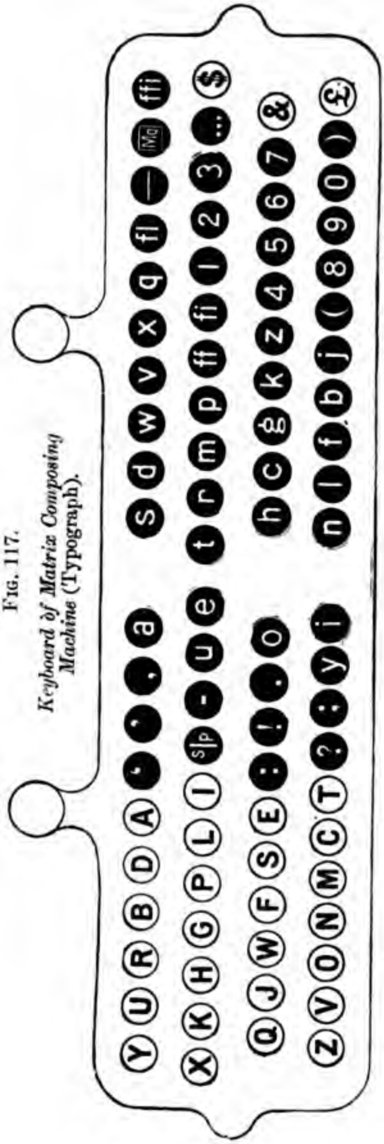


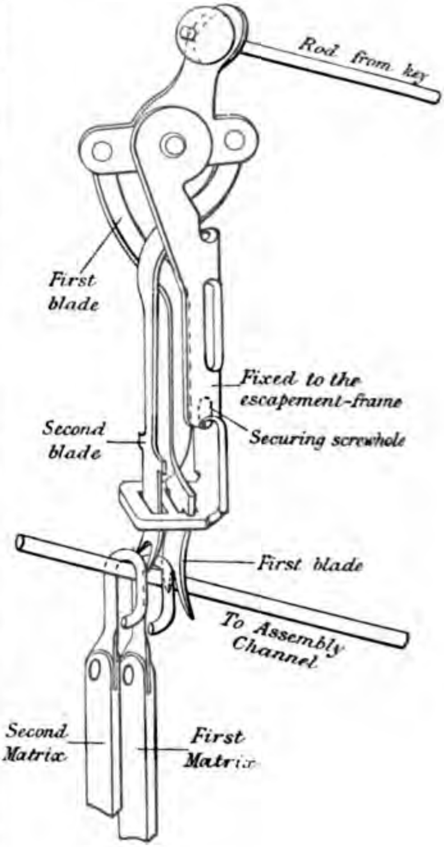
Fig. 117.

Keyboard of Matrix Composing Machine (Typograph).

Fig. 118.

Escapement for Matrix Composing Machine (Typograph).

Full size.



second movement finally ejects the finished slug Fig. 116 and in section in Fig. 115. A second removes the tang from the tang-plate and it falls finished slug is delivered into a galley.

The pump plunger is spring-propelled on the a pause on completion of the cast to allow th This process is assisted by the circulation of water-jacket which surrounds the mould and kee

The Typograph Machine.—At the top of the Plate 43, is the keyboard together with the escape: The keyboard comprises eighty-four keys, the arra the English language is shown in Fig. 117; s not leave the wires it is possible to adapt the r language without either the necessity for spe faces to any particular system of *set* width modification of the magazine, escapements, etc easy to adapt the machine to use other character a typewriter. The escapement, Fig. 118, is from the key; it is of the shears variety, the pu the first blade and releasing the first matr matrix has been checked by the second bl On the return of the key, the second matrix forward to the place occupied by the first matrix has descended far enough to check its further m upper frame of the machine is tilted back the es carried on a separate frame, are raised clear of having an eccentric movement, so that the matri to the ends of their respective wires. The esc back into position on commencing the return r escapements are in place before the wires re position.

The operation of tilting the upper portion also ensures the return of the two sets of respective places on their magazine-bars, this cam on the magazine shaft operating a rack, wh a vertical shaft carrying two levers; these act two space-disk shafts upon which the former are threaded. These space-disks are released by a key button just above the keyboard proper.

The operations of assembling and line-justifying are shown in the four Figs. 119–122, Plates 44 and 45, the reference numbers in each of these being the same.

In Fig. 119 the machine is shown at rest, neither the matrices, nor the space-disks being in the assembling place which is open ready to receive them; the vice-jaw 1 is in the open position and the square shaft 2 is empty. The part 3 is a removable stop piece which can be changed when the mould is altered for varying the length of line. The two bars 4, 4 serve as a bearing to carry the matrices while being assembled, and to support them against the pressure of the metal pot when the cast is being made. The alinement bar 5 provides the bearing surface for the feet of the matrix-bars to rest on during line-justification. The vice-jaw 1 connected to this bar closes the assembling place when the composition of the line has been completed, and keeps the line of matrices in position during the casting operation. There is an adjustable mark 6 above these parts which shows the width of line to which the machine has been set to correspond to the mould in use. This mark warns the operator when he must finish the line and start the casting operation. The part 7 shown below the alining bar is called the gripper; it is mounted on the shaft carrying the mould arm and bears against one of the notches in the matrix-bars pressing them up so that one of the back notches bears against the alining rib. This operation takes place at the same time that the space-disks revolve and spread the line,* the final justification of the line being performed after alinement has been effected.

Fig. 120 shows the assembling block with a line of two-letter matrices composed but free; the space-disks, nine of which are shown

* The operations described here relate to the two-letter matrix. It will be seen from the description of the single-letter matrix how the position and action of the alining bars must differ in the single-letter machine. In the two-letter machine the gripper moves up to aline the matrices; in the single-letter it moves down.

between the ten words composed, are barely visible as they occupy that position which presents the narrowest face towards the mould.

Fig. 121, Plate 45, shows the vice-jaw in its erect position ready for closing in to the proper length of line indicated by the mark 6. This closing is effected automatically on moving the starting handle. When the vice-jaw 1 has reached the position corresponding to the proper length of line the space-disks, which have up to this time remained stationary, rotate by the action of the rack on the two pinions. The space-disks can assume any width from two to nine points.

Fig. 122 shows the arrangement of the matrices after line-justification has been completed. The increased width occupied by the space-disks, as compared with that shown in Fig. 121, is easily seen. The gripper 7 holds the matrices in position for alinement. The mould is then brought up and held against the matrices pressing them against the back bars 4, 4. The metal pot with its mouthpiece is then brought to face the tang-plate of the mould making the whole space to be filled with metal airtight, except for the small air ways ground in on the face of the mould. The pump now operates and the slug is cast. After a slight pause, the pump and mould return to their original position and the line of matrices is then unlocked.

While the above operations are taking place the compositor is reading his copy, and so soon as the casting has taken place he can tilt the top of the machine back distributing the line of matrices. This done, he can commence the composition of the succeeding line. The upper portion of the machine is locked from the moment of moving the starting handle until the casting has taken place.

After the matrices have been unlocked the tang-plate rises, cutting the tang clear from the slug; when the tang-plate has reached its upper position the slug-ejector comes into operation partially ejecting the slug ready for the trimming knives to operate. After the knives have completed their stroke the slug is ejected and travels down a shoot to the galley; the tang is ejected from the tang-plate by the small ejector, and the various parts return to their positions of rest in readiness for the next casting operation.

The time occupied in performing the cycle is three seconds, during half of which time the magazine is locked while the casting takes place. Immediately this is released, the operator, who in the meantime has been reading his copy, distributes the line of matrices just cast from and proceeds with the next, simultaneously with the operation of trimming and ejecting the slug. It is stated that it is found in practice that the time occupied by the casting operation is that required by the operator for reading his copy and that consequently no time is actually lost; the copy holder remains fixed in its place while the upper portion of the machine is tilted.

Where repetitions of a line are required, it is merely necessary to leave the line of matrices standing and move the starting handle as soon as each slug is turned out, which is done at the rate of 20 lines per minute, being more than double the speed of the other slug casting machines.

The output of the Typograph is stated to average from 6,000 to 12,000 ens per hour.

The metal pot is stated to hold about 40 lb. of metal; it is heated by town-gas, the quantity required being about 11 cubic feet per hour.

The machine weighs about 9 cwt. It occupies a floor space about 2 ft. by 2 ft. and stands about 5 ft. high, the space required for machine and operator being about 6 ft. by 6 ft.

The power required to run the Typograph is about 0·25 H.P.

APPENDIX VI.

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See also the life of Sir Henry Bessemer for interesting information on early typefounding and setting machines; it is entitled "Sir Henry Bessemer, F.R.S, An Autobiography." Published by "Engineering," London, 1905.

Discussion.

The PRESIDENT, in moving a vote of thanks to the author, said the Institution owed him a deep debt of gratitude for a most interesting, voluminous and clear Paper. Many of the members believed that the Institution of Mechanical Engineers should be the receptacle of all classes of information connected with Engineering, and heartily welcomed a Paper on typographical work, because it certainly was very instructive and could not fail to be of interest and use to the Institution, both to the present members and to those who would join the Institution in the future.

The resolution was carried with acclamation.

The PRESIDENT had pleasure in calling upon a gentleman to open the discussion who had been to a considerable degree connected with the Institution for many years. He referred to Mr. Maurice Clowes, whose firm had been concerned with the Institution printing and had produced the Proceedings not only with credit to themselves but with credit to the Institution.

Mr. MAURICE CLOWES (of Messrs. William Clowes and Sons) said that one of the great problems in typecasting machines was the cost of the metal to the printer. Some machines needed a more expensive metal than others, and he thought attention should be turned to the subject of cheapening the price of metal in connection with mechanical composing. In many of the machines the metal could not be made to run, unless of an expensive character. A cheap metal would neither run nor cast solid, and therefore it was a serious question to the printer. As he saw several gentlemen present who had studied the question, perhaps they might be able to throw some light upon it.

Mr. J. F. GILMORE (British Stringertype Syndicate) said a large number of people hardly realised how serious the question of the metal was, and he quite agreed with what Mr. Clowes had said, as to typecasting machines, that the ordinary metal without a good flux would not flow. The great question was to know how to mix the metal. There was no real secret as to what was generally used, but there was some difficulty in mixing it and using it afterwards. The old type-founders used to test the temperature of the metal in the pot by putting in a piece of paper and seeing how it burned, and the man who was engaged in looking after the typecasting in this crude way judged whether the metal in the pot was too hot or too cold. Even now this old method was adopted by some type-founders. Engineers, however, who measured to a ten-thousandth of an inch knew the necessity of being correct in typecasting and composing machinery, as an error in the casting of single type as to body by the multiplication of such error would at the end of a page of printed matter throw everything out. A type-founder had to deal with very minute divisions of an inch, and mechanical engineers knew the necessity of keeping the metal at an even temperature. If they were casting at one time at a temperature between 600° F. and 800° F. and at another at over 1,000° F., there would be a marked difference in the resultant product. It was absolutely necessary to know the exact conditions they were working under to obtain the best results. It was also essential that the metal should be kept properly mixed and should flow freely. Phosphor-bronze (phosphorus, copper and tin) was now used as a flux. This made the metal much cheaper and tougher than that used by the old-fashioned type-founders. A man might, however, experiment with this for months before he was able to obtain thoroughly satisfactory results.

Mr. W. Worby Beaumont said he wished to record his very high appreciation of what he considered a remarkable Paper, a splendid monograph on a subject that was interesting to a very large number of those who enjoyed the products of the inventions the author had described. It showed what might be done in the future, not only towards the production of type of characters most pleasing, and produced in a way to assist in the cheapening—even if that were necessary—of literature, but also the directions in which improvements might be looked for.

(Mr. W. Worby Beaumont.)

In the first place, he wished to remark that the Paper, from the mechanical engineering point of view, showed the immense diversity of the knowledge of materials and mechanics that had to be possessed by a mechanical engineer who, as in the case of the author, took up different fields of occupation at different times. He had worked with the author in connection with tramway construction, in connection with gas-engine construction, and in connection with motor vehicle construction, and he was glad to be able to say that he passed through the mill of exaction by the machinery he had been describing that evening, and had not only come out unharmed, but was able after all that to produce one of the best designs of English motor vehicles.

He himself had had some experience with printing machinery and with printing, but not with type-making. When visiting the author at the Wicks works he was very much surprised to find him occupied in making a sort of trigonometrical survey. He knew that he was engaged on some kind of mechanism for the making of type, but as he had not then inspected the machinery, the trigonometrical survey was somewhat surprising to him. At the end of the Paper would be found the reason for that use of the theodolite that he had found the author using to set out accurately the circumference of a 20-inch disk. He had, in fact, brought into play a method which would have delighted Bugge or Roemer, Hooke, Airy, or Rosse, and some of the others who in early days found very great difficulty in setting out certain divided circles required for astronomical purposes. When engaged in considering certain questions of printing he had often found himself gently warned off when he asked the printers to make this or that modification of methods or practices commonly adopted, and he could therefore sympathise with the remarks of the author with regard to some of the old forms of type and certain of the things that had been felt to be necessary, simply because of the romance of the survivals of what probably were the wishes of the great penmen with regard to forms and shapes of letters. The Paper, for example, referred to kerns and various other details in the forms of letters, hair lines, and so on, and the author advocated the selection by the reading public of types that would be an improvement so far as eyesight was concerned, and an improvement so far as the casting of the type itself was concerned, and would lessen the difficulties in making the different kinds of punches and tools for milling the punches. It was not that the author made in any part of his Paper any objection to the difficulties that had been experienced; otherwise there would have been mentioned some of the objections to the extreme minuteness, almost objectionable minuteness, which had become necessary in order to make the moulds of the types for the speeds mentioned. But the author did say that although there were improvements still desirable, the engineer had broken down a great many of the old reverences or arguments of the type-founder of the "always-has-been-so-and-therefore-should-be-so-in-future" kind. Until the author read the Paper, it was probable that very few even of the members of the Institution realised the degree of absolute accuracy necessary to the production of type to produce that printing which everybody saw every day and thought nothing of. One of the remarks made by the author with regard to the matter was quite noteworthy. He pointed out that practice with readers, just as practice with artists or handicraftsmen in any particular craft, brought about a wonderful power of detecting inaccuracies, and mentioned as a proof the manner in which the eye could instantaneously and without conscious effort detect any inaccuracy in the alinement of a line of type or any other imperfection. He showed how necessary it was to provide for the acuteness of that observation by purposely producing an accurate inaccuracy. He stated, for instance, that it was necessary to make type not of certain sizes with regard to each other, but so that the relative depths should appear to be so, so that not only had a type-founder to make things accurately, but he had also to judge of the amount of inaccuracy as to form which the public might demand as a means of pleasing the observant eye.

With regard to many of the requirements arising from the form of type being simply the survival of the demands of old penmanship, it would be noticed that on pages 1047 and 1048 the author referred to another phase of that important question where he spoke of type

(Mr. W. Worby Beaumont.)

faces, and gave excellent examples of different forms of type, those which were the product of the expert in type-designing in modern times, those that were of the older form made before type with very fine hair lines was possible, and also an example of type which was very easily readable, but perhaps not considered by the type-designer as having the same perfection. He would especially draw attention to that particular type, given as an example of "fancy faces," in connection with the importance of the statement made by the author in the sentence printed with the type face marked (*c*) (page 1048).

With regard to the constitution of the metal, there was evidence in the Paper of one of the difficulties that had been met with not only in typefounding but in various other kinds of founding, and there again could be seen the importance of the extreme accuracy which had been the aim of the author and others, that the type metal which would flow into the finest possible line should not be able to make fins by flowing along the edges of the mould into which the metal was driven at the necessarily somewhat high temperature in making the type. The difficulties were enhanced by the necessity for getting the cooling to take place, as the author put it, in three hundredths of a second with metal hot enough to run into the corners. He had touched on a few of the points in the Paper, and would only repeat his very high appreciation of the book which the author had written on a subject about which very few knew much.

Mr. A. E. GIBBS (of Harrison and Sons) wished first of all to thank the Institution for their invitation to printers to be present that evening. Though he was not familiar with mechanical engineering himself, he knew something of printing and about one well-known type-setting and casting machine. Something had been said with regard to cost of metal, but as far as his experience went that did not enter into the question very largely. When the firm with which he was connected was taking up machine composition six years ago the metal was a trouble, the reason being that the general run of printers knew very little of the type-founder's art. There was difficulty in getting the metal to run freely in the mould ;

sometimes the metal was too hard and at other tir sluggish. The trouble arose partially from the prc ingredients being scarcely suitable and partially fron mixing. It was thought at first, at any rate by anybody could mix metal, and it was relegated to a took little interest in his work, with the conseq mixing was neglected and the heavier metals got to the lighter to the top, and the metal varied very endless trouble on the casting section of the machi the firm had taken up typecasting largely, and t knowledge and practical men to deal with the m trouble was now experienced.

With regard to the actual cost of the metal, h the exact figure, but he had made a rough calculatio to the conclusion that in the firm to which he ref exceed 3*d*. per lb., a cost which certainly woul handicap machine composition as compared with ha remarks referred to the Monotype, working all type up to small pica, and, with the larger types predom no alteration was made in the metal used. The peculiar thing about the majority of his work; the r short, and in consequence very hard type was not ne

There were three things that most appealed to t must be absolutely certain of his height-to-pape experience endless trouble on the printing machin equally assured of the correctness of his alinement, to get into trouble with his customer; and, thirdly, l solidly cast, true to body and *set*, and with a clean-c face. Alinement on the Monotype machine, and he any other single-letter machine, was dependent o details, and a very sharp look out had to be kept to not go wrong. On all single-letter machines the many advantages, the principal being that it was easily with authors' corrections, the bugbear of the a single-letter machine the corrections could be mad apart from the machine, and consequently that t

(Mr. A. E. Gibbs.)
appeared to have immense advantages for the general printer. He did not however decry the slug machine; that also had its advantages, and undoubtedly one was the ease with which the solid lines could be handled for newspaper work.

With regard to the effect of high quads and spaces, if high quads and spaces could be got rid of, half the printer's trouble would be over. They were a serious objection in the composing room, and a still worse trouble in the machining department, and the printer would value any aid which mechanical engineers could render in the direction of reducing the height of these very necessary types. There was always a difficulty, however much care was taken over the locking up of the formes, in keeping the quads down and more particularly where blocks were included in the make up of the pages. With very open table work, which of course it was policy to run on the machines, the only thing to do was to lift the quadrats out bodily and substitute metal furniture or something of that sort. In connection with a table job he was running that day, with the first column very open and fairly wide, he had come to the conclusion that the best thing to do was to run the three or four remaining rather solid columns on the machine, leaving the composition of the first column entirely to the men making up the work. In that way he saved time in the operating room and time in the casting room, the hand-compositors' work became more remunerative, and blacking of quads when machining was avoided. If only the mechanical engineer could invent a means of securing low quads and spaces it would add largely to the commercial utility of the machine, and would prove an immense advantage to the printer.

Mr. W. H. LOCK said the Paper, in his view, represented a tremendous amount of work, and he had been very much interested in it, but it was not a Paper—he was sure the author would appreciate the spirit in which this was said—that justified the title. The author laid himself open to this criticism when, for this Paper, he selected the title "Typecasting and Composing Machinery." Reading it as a specialist, it appeared to him that it was not a Paper that *covered* the subject. It seemed to be a Paper written by an engineer who had come in contact with typecasting and type-composing machinery as one of the incidents of his profession, a Paper by an engineer who had thoroughly understood the subject just where he happened to have touched it, but not a Paper which would justify its title. He mentioned that because he was rather proud of the subject, with which he was most intimately associated, and he should not like the mechanical engineer, on whom typecasting and composing machine men depended so much, to think that the whole subject was exhausted by this Paper. He would have liked to see the author dealing with something of the history of typecasting and composing machinery, with the mechanical problems that commercial men had from time to time put to engineers, and with the different attempts that engineers had made to solve these problems. He would also have liked the author to put before the Institution some idea of the mass of patents existing on the subject.

However, coming to the Paper as it stood, there were one or two things he wished to correct. He was associated with the Linotype machine, which came under the heading in the Paper of slug casting machines. Engineers had attempted in many ways to solve the problem of producing a printing surface by mechanical means as opposed to the old hand-setting of type. There were two classes of machines which stood out from the rest: one, producing a line of type made up of separate types, a separate piece for each letter, and the other producing a line of type made of a solid block. As a believer in the latter class of machine, he wished to say a word or two to mechanical engineers who were not necessarily composing machine men or users of type composing machines. On page 1072 the author spoke of the depth of the strike, and said that the depth of the strike in ordinary matrices was usually 0·045 to 0·050 inch, according to the particular type-founder producing it; and then went on to say that it reached its minimum of depth in the Linotype and Monoline machines where the depth of the strike—the distance the punch pentrated into the copper or brass piece into which it was struck—had a minimum of 0·02 inch. The author had overlooked the fact that in the Linotype matrix the punching, which was 0·025 inch deep, was struck on the edge of a piece of brass in a

(Mr. W. H. Lock.)

routing of 0·050 inch deep, so that the routing and strike together gave a depth of seventy-five thousandths. It was necessary to point this out as, as the statement appeared in the Paper, it would give the idea that Linotype type was much shallower than ordinary type.

Another point was that the author said the Linotype mould was so constructed as to cast a line of type having an overhang at the back. There again he wished to put him right on a detail of construction. The mould itself was perfectly plain, and the overhang was cast in the pot mouthpiece that came up against the mould. Those were points that the author might possibly put right in the Paper.

On page 1134 the author spoke about the output of the Linotype machine as being generally taken at 6,000 ens per hour, or, under good conditions, 7,000 to 8,000 letters per hour. Under good conditions, however, the actual working output of the Linotype machine would be, roughly, 75 per cent. greater than the figures given; that is to say, 13,000 to 14,000 letters per hour.

On page 1139 the author summed up apparently in favour of single type machines, and, in addition to claiming a greater depth of strike, a point which he (Mr. Lock) had already dealt with—stated that corrections could be made by hand and away from the machine in the case of single type machine, whereas in slug machines it was necessary to recast the whole line even where the corrections consisted only of two transposed letters or a point omitted, thus conveying the idea that corrections on the slug machine were more difficult than on the single type machine. That idea was all very well in theory, and might, unless corrected, appeal to mechanical engineers, because mechanical engineers understood the mechanics of the machine, but did not, he apprehended, understand much about the practical typesetting part. Therefore, he would say that, while these advantages claimed for the single type machine were all right in theory, they in practice proved otherwise, and corrections could be made quicker on the Linotype and other slug machines than with the older method of separate types.

Lastly, the speaker referred to the end of the Paper, where the author offered a word of caution to those who think of competing in the field covered by composing machines. Here the author had said the detail is so complex, and the difficulties met with in working out the machines were so numerous, that the time for which a patent was granted might easily be in greater part absorbed in experiment before a commercial result was obtained. He (Mr. Lock) thought that a truer statement than this had never been made.

Mr. H. A. Longhurst drew attention to the fact that the author mentioned (page 1090) that Sir Henry Bessemer created a vacuum in the mould of his typecasting machine immediately before casting, and went on to say that "although this method appears to have been successful in his case, it has no practical application at the present time so far as the author is aware." It seemed to him that the question of creating a vacuum in a mould was a very important one, and if it could be applied in a practical way to the machines in use today it would be a very great advantage. Perhaps the author would explain how that vacuum was produced, and why it had gone out of use if it was really a success.

The author described a method of engraving matrices instead of cutting punches (page 1074). Probably the real reason why matrices were not engraved, instead of going to the extent of cutting punches, was because such a good result was not obtained from engraved matrices as was obtained from the punch and the driven matrix. On that subject he would also like to have the author's opinion.

On page 1139 the author, referring to machines in which the tang of the cast was broken away instead of being trimmed by a cutter, stated that "...... the breakaway tang permits a hard metal to be used (similar to that employed in ordinary type for hand composition), whereas the metal used in the slug machines, and in those similar to the Monotype, must necessarily be soft." The Typograph Composing and Slug Casting Machine was apparently unknown to the author at the time of writing this Paper, as the system of casting and breaking away the tang, employed in this machine, was practically identical with the system he described. The tang was broken away from the base of the slug and the rough fractured part was left in a recess, clear of the feet. This system not only enabled a harder metal to be used,

(Mr. H. A. Longhurst.)

but it also ensured dead accuracy with regard to height-to-paper. The importance of this latter fact could not be overestimated, and was fully appreciated by the high-class book printer, whose requirements in this direction were of the most exacting nature, for he thus obtained all the advantages of the slug, in ease of handling, etc., combined with the highest degree of accuracy that could be obtained in movable type. In establishments where Typographs were in use, matter might be set on one machine and corrected on another with the absolute certainty that the slugs from each machine would be exactly the same height. The mouthpiece of the metal pot in this machine was also specially designed with a view of enabling hard metal to be used, being in the shape of a wide slot instead of a line of small holes, which rendered it far less liable to "freeze" or become corroded.

The slugs cast in the Typograph, again, differed from those cast in other machines, from the fact that no trimming ribs were provided on the side. The mould being encased in a water-jacket ensured perfect uniformity of body and rendered trimming unnecessary, with the exception of removing the slight beard formed by the junction of the mould with the matrices. The slugs being smooth on both sides, lines of single type were readily used alongside of the former.

Referring to Appendix III (page 1148), in which the author considered the adoption of logotypes of frequently recurring combinations such as "the," "tion," "ance," etc., the adoption of such a system in mechanical composition no doubt offered many advantages at first sight, but had its limits. One serious drawback to such a system was that the keyboard would have to be enlarged, as, with the exception of the combined characters such as ff, fi, fl, ffi, ffl, which might well be replaced by some more useful combinations (since the necessity for these ceased to exist upon the abolition of the "kerned" sorts), additional keys would have to be provided for the logotypes, as, obviously, all the single characters comprised in the latter would still be required. Any great addition to the number of keys already necessary was detrimental to speed as it increased the distance that the operator's hands had to travel.

The advantage to be derived from the use of logotypes was therefore offset to a certain extent, that is to say, the gain in minimising the number of key depressions for certain words was discounted by the fact that the hands of the operator would have to cover a greater distance to touch the keys corresponding to the logotypes than would be necessary in the case of the keys carrying the single characters. It seemed, therefore, that unless limited to the present number of keys, or thereabouts, the use of logotypes in composing machines offered very little advantage. The logotypes ff, fi, fl, ffi, ffl, however, might well be replaced by such combinations as "the," "and," "in," etc., and there was no doubt that, but for the conservatism of the printer, this would have been done long ago by the composing-machine manufacturers. Any innovation of this sort was not looked upon with favour by the printer, who, as a rule, preferred to stick to the old ideas and retain the ancient usages of the craft.

The proposal advocated by the author of adding two new characters for "th" and "ng" respectively to the English alphabet did not lead to any difficulty of the kind mentioned, since it merely involved the use of two capital and two lower-case letters which could replace four of the practically useless f combinations, and could be adopted on such a machine as the Typograph without altering the keyboard; the whole extent of the change, in fact, would amount to the substitution of four new key buttons and of four kinds of matrices for the new characters, the total cost of the change amounting to only a trivial sum on existing machines, while it could be made without any expense whatever on new machines. So large a saving as three-and-a-half per cent. in length of matter as well as in the labour of composing, conclusively shown by the author to be obtainable, was well worth the careful consideration of the printing trade.

It was possible that this suggestion had applications in other languages, and it would be of interest to know whether in French or German the author had found any parallel case.

The average reader of books, newspapers, etc., would be none the wiser if the ffi were produced by single matrices instead of a

(Mr. H. A. Longhurst.)
logotype; it was only the printer who would detect it. Composing machines have had to be made to conform to these long-established customs of the printing trade, which in many cases had ceased to be a necessity, whereas, with a freer hand, their designers could increase the efficiency of the machines, without in any way detracting from the appearance of the composition produced by them.

The designing and construction of typecasting and composing machines has presented the mechanical engineer with some of the most complicated and interesting problems he had ever been called upon to solve, and it was an undoubted fact that once a man had taken up this subject he became so engrossed in it that he could not relinquish it, and it became a life study with him.

There was no doubt that hand composition so far as solid work was concerned, even for the very highest class books, was rapidly becoming a thing of the past. The results obtained in this class of work on the Typograph compared most favourably with the best hand setting.

Mr. FREDERICK WICKS thought the best contribution he could make to the subject of the evening would be not in the form of criticisms of minute details in the Paper, which was very comprehensive and excellent in all its departments, but in the form of adding something which would give a more clear idea of the difficulties surrounding the processes of construction of any machine designed to record written speech by typography. When the subject first came under his consideration some thirty-five years ago as a journalist and parliamentary reporter and later as a newspaper proprietor and printer, matrix composing machines had no existence. The only mechanical contrivance for producing a printing surface available in 1870 was the Kastenbein composing machine which was being experimented with in *The Times* office and was supplied by hand distribution, a slow and costly process. He watched the machine composing some of his own copy, and by later calculation found that the difference in time between composing by picking types from a case and by the manipulation of keys was a saving of 83 per cent. in favour of the latter. This 83 per cent. was at that time almost wholly absorbed by the cost of dividing up into lines, known as justification, and by the cost of distribution and arranging the letters in line for the tubes of the machine. It was obvious that the value of the loose-type composing machine was small unless a more speedy and cheaper service of type could be provided. The result was the Rotary Typecasting Machine after some five and twenty years of experimental work in the region of mechanical engineering. Distribution by hand could be realised at a speed of 5,000 per hour. Boy labour could arrange distributed letter in line at some 10,000 per hour, type was cast in *The Times* office prior to 1900 at an average of 4,000 per hour in the hope that new type could be supplied to the composing machine. Mr. J. C. MacDonald, then manager of *The Times*, who conducted these earlier experiments in the endeavour to cast a new fount of type for each day's paper, concluded his efforts by the reflection that the more he pursued the inquiry the more he was struck with "the glorious simplicity of the compositor and a pair of cases." In the Paris Exhibition of 1878 was exhibited the invention of Delcambre, whose machine was really the foundation of all the loose-type composing machines subsequently devised, and was used in composing the first number of the *Family Herald* in 1842 (page 1103). A visit to that exhibition and a conversation with Mons. Delcambre in company with Mr. MacDonald started the series of ideas which resulted in the Wicks composing machine, which set many combinations and several short words with a single touch, and afterwards in the Rotary Typecasting Machine, which put in line 60,000 finished types per hour. The realisation of the rotary scheme solved the question of supplying loose type to a composing machine, seeing that it produced the finished letter from molten metal at a speed twelve times faster than the hand or mechanical distribution of the manufactured type.

In the course of the mechanical development of the rotary machine it was found that the chief difficulty in the way of casting type rapidly arose from an imperfect knowledge of the thermal problem involved as distinguished from the mechanical. The mechanical difficulties had been described in the Paper, but these were aggravated by the fact that while the machine was being

(Mr. Frederick Wicks.)

constructed in a shop temperature of, say, 60° F., it had to deal with molten metal at a temperature of about 700° F. and a point of congelation of about 500° F. As the product had to be delivered with a limit of error of 0·002 it was necessary not only that the mechanical construction should be precise and accurate, but that it should withstand the expansion and contraction involved in the reception and cooling of these thousands of castings, and allowance had to be made for contraction on cooling. The problem was sufficiently novel to excite the eager interest of Lord Kelvin who was present on the occasion of some of the early experiments, and particularly at one, when, in demonstrating the pump force, it was shown that the metal jet of one-tenth of an inch in diameter penetrated a sheet of copper one-eighth of an inch in thickness in twenty seconds—the resultant orifice being a third of an inch in diameter. The proposition, as submitted in this conversation with Lord Kelvin, was this:—How to project a jet of molten metal the distance of an inch in a space of time less than 200° F. could be given up to a cold mould. The casting machines originally in use had been worked on the theory that the mould must be hot. A hot mould, he believed, that is a mould of a temperature above blood heat, was required in all casting processes dealing with results in which fine lines and sharp surfaces were required.

In typefounding for three or four hundred years, ever since Gutenberg invented separate types, the practice had been to cast "dummies" until the heat of the mould had reached about 400° F., and then satisfactory casts began. After a few hundred had been cast the mould became too hot, and the operator had to refrain from casting for a time until the mould had cooled down. Later machines introduced concurrent automatic cooling by a wind blast or water channels, but none of these was equal to the cooling down of castings produced at the rate of a thousand per minute, and a uniformly cold mould became a necessity. The problem resolved itself into the simple question as to how the metal could be injected with sufficient rapidity, and that was a pump question. The pumps in common use had been and were now intermittent in their operation and practically exact in their delivery. The temptation to synchronise the stroke of the pump with the presentation of the moulds in the rotary was considered and abandoned. It would have involved 100 strokes in ten seconds, and the moulds being only a half inch apart, more or less according to the width of the letter to be cast, the mechanical scheme of synchronisation would have been difficult. A continuous and equal projection of metal was resolved on as the simplest solution of the difficulty, and the result has given statistics of unusual interest respecting the passage of heat through metals. The metal being at 700° F. and the point of congelation 500° F., it was projected at a speed of 28 miles per hour through a tenth of an inch orifice under a pressure of 250 lb. on the square inch, and resulted in the passage of 80 lb. weight or 240 cubic inches per minute. The moulds in this way were filled each and all in the 530th part of a second and cooled in something less than the 300th part of a second. How much less, the apparatus was not suited to disclose. There was in any case the 130th part of a second to spare, and the casts were ejected in four seconds at a temperature of 80° F. showing that 620° F. had been removed in four seconds.

The foregoing results were shown in a machine that had been running for two years uninterruptedly, and had cast 250 million types which had been used in the production of *The Times* or *The Morning Post.* These figures would be of interest not only as an exposition of the solution of the thermal problem in connection with this process of rapid typecasting, but of general interest in supplement to what is found in the books on the subject of the conduction of heat.

It was somewhat a matter of regret that a machine which in the course of its construction had resulted in so many interesting mechanical excursions should have become practically obsolete by natural development on the lines of the principles it had demonstrated. The very perfection of the machine made improvements necessary. The great cost of building it obliged a revision of the scheme of construction and it was not probable that any more rotary casting-machines would be built. The time had not arrived for describing the newer form of machine now under construction, beyond stating

(Mr. Frederick Wicks).
that the disk with all its attendant difficulties in the formation of the moulds and the process of cooling was abandoned, and the casting would be proceeded with in a straight line. The machine would also be capable of adjustment so as to cast all sizes and widths of type at will from a single machine. In addition to this the new method of casting would be applied to the Linotype machine, so that the line instead of being cast in a solid slug would be produced in separate words or groups of words or single letters at the operator's will, thus disposing of the criticism that the Linotype line could not be corrected apart from the machine, and giving to the Linotype, which now held the ground, all the qualities claimed by its competitors without detracting from its own.

Much more might be said upon the subject of typefounding, which had hitherto been a secret industry confined for some four hundred years in the hands of some half dozen firms who had jealously guarded what they believed to be their secrets. Probably the Paper was the first comprehensive description of the practical working of the art, and yet it was mainly composed of descriptions of machinery produced within the last thirty years. The metallurgy of typefounding would form material for a Paper by itself. The information contained in the text books was meagre to a degree, and quite insufficient as a record of present-day practice. It would be impossible and inappropriate adequately to deal with it in the course of a discussion on the mechanism of the subject, but it was a matter well worthy the attention of members of the Institution, because it involved consideration of that important question of the evaporation and oxidisation of metals, which entered so largely into the question of the strength and density of castings.

Mr. LEGROS, after thanking the Institution for the kind manner in which the Paper had been received, referred first to Mr. Clowes who had touched upon a very important point, the cost of the metal. Mr. Gilmore had pointed out that there was something to be done in the way of increasing fluidity by the use of phosphorus. It was certainly important that the metal should flow readily, but not too readily; if it flowed too readily a fin was developed, and yet it must flow readily enough to fill a hair-line; therefore it was necessary to keep between reasonable limits.

Mr. Worby Beaumont had alluded to the methods employed for correcting the division plates (page 1182); at the present day there was probably little necessity for originating graduations, but, if the author were required to originate a graduated circle of say 360 main divisions, he would prefer the last method he had described (modified if necessary to suit any special conditions) to that of obtaining 256 equal divisions by continual bisection and the subsequent elimination of errors described by Troughton.

He had also mentioned the question of necessary inaccuracy, and the author did not think this had been alluded to before in anything that had been written on the subject. He had tried to make it clear that it was necessary that the face of the type should be made inaccurate, and if it was desired to produce type pleasing to the eye the inaccuracies had to be standardized as well as the accuracies.

A feature in modern printing which was very bad for the eyesight was the use of high-surface paper for the text in magazines, in periodicals, and even in books. It would be far better for the reading public if the process blocks were printed on calendered paper, interleaved, and the whole of the text on a rougher paper.

It was of interest to note that Mr. Gibbs, as a practical user of one of the machines described, did not appear to lay very much stress on the question of the metal, and had found that this could be managed very cheaply on the Monotype, a single-type machine, but he had also pointed out that there were various things liable to occur if there was the least carelessness (page 1185). If the height-to-paper was not looked after there was trouble with the machine, and if the matrices were not well kept up, or were loose in the frames, the customers objected to the product. Mr. Gibbs had also pointed out a matter mentioned in the Paper, authors' corrections, to which Mr. Lock took exception. He thought their different points of view were due to the use of different machines. He had not attempted to exhaust the subject in the Paper, having endeavoured only to point out a few important facts. Not much had been written on the subject

(Mr. Legros.)

and there was plenty of opportunity for Mr. Lock and other people to read other Papers. In the Paper he had already stated that there was enough in the Linotype to make a very good Paper by itself, and probably no one would be better able to do this than Mr. Lock himself.

With regard to the depth of strike, Mr. Lock had rather criticised that portion of the Paper, but the counter in the Linotype matrix was no deeper than the depth given in the Paper, and it was the counter that sometimes took the ink. Of course there was no difficulty with high spaces or quads on the Linotype or other slug machines, since the depth of routing, alluded to by Mr. Lock, left the spaces low; this was shown clearly in Figs. 39, 40 (1087), Fig. 88 (page 1134), and Fig. 116 (page 1173). In regard to his remarks as to the mould casting a line with an overhang at the foot, this overhung portion was actually formed in the metal-pot mouth, which at the time of casting, and until the metal had set, formed a portion of the mould, though probably Mr. Lock was terminologically correct in not considering this piece a part of the mould. The author could not, however, agree as to the mould being perfectly plain; in the first place there were internal projections at the foot to prevent backward movement, and in the second place there were the raised ribs for trimming to body-size. The slug cast on another line-casting machine, Fig. 116, was cast in a mould free from either of these kinds of projections and one which could more properly be called plain.

Mr. Lock had also called him to account with regard to speed, and probably Mr. Lock knew the speed of the Linotype very much better than the author, who had not worked one practically; he had taken the ordinary figures given to him, figures which he believed to be correct.

Mr. Lock did not mention one reason, which tended to minimise the disadvantage of having to reset the lines for corrections; this was the ease with which the complete slugs could be handled. Recently some inventive effort (A. W. Hanigan) had been expended in the direction of securing loose type when composed and line-justified so as to form it into a bar.

Mr. Longhurst asked a very interesting question about vacuum in the mould. He did not know what Bessemer di because it was only alluded to very briefly in his life, bu that it was re-invented subsequently by somebody else, alt did not believe that it was actually put to practical use. the mould was a constant trouble, and there was usually so provision made for getting rid of it. In the Typograph m very fine depressions could be found, ground in just deep let the air escape, and grooves for the same purpose were the foot of a Linotype slug before trimming. Mr. Longl raised a very interesting point with reference to engraving When a matrix was engraved the actual depression corresp the strike of the punch had the same appearance as the su over by an end-mill; it looked like the engine turning o of a watch, and therefore the same polished appearance obtained that could be obtained with any struck or electro- matrix.

The author wished to express his appreciation of Mr. Lo remarks on logotypes (page 1191). The author was not i of carrying the idea beyond the strictly practical limit. language comprised certain well recognised sounds repres two or more characters in that language and by a single in some allied language, it would generally, the author bel a problem worthy of careful investigation.

Mr. Wicks had alluded to the cold mould as a ve invention. He did not think many people used it before M It had been used in one of the slug machines, the Typog the slugs cast in the Typograph and in the Linotype were c it would be seen that the cold mould produced a con difference in the appearance of the slug, though he would greater accuracy, except in height-to-paper. Water-cooling used on a number of other machines, in particular on the Monotype.

The author shared the regret of Mr. Wicks that the utility of the Wicks machine had been so limited. If these m

(Mr. Legros.)

had been put to the task of supplying only the commoner sorts of character, say the first twelve in order of demand, over 50 per cent. of the total production would be so dealt with; or, if the whole of the lower case were taken, together with the two commonest punctuation marks, about 72 per cent. of the total could be dealt with by a Wicks rotary caster, using only thirty-two kinds of matrices. The stock could be kept balanced by other and slower machines, but machines in which there was not the same loss on stoppage or due to over-production of some sorts. It was to be hoped that the new machine, of which Mr. Wicks had spoken, would prove as interesting as the various machines of his invention, which the author had described in the Paper.

Communications.

Mr. A. S. CAPEHART (Monoline), of Paris, wrote that he had made numerous experiments, extending over a period of several years, in the attempt to produce a type-metal which should have greater stability of composition than that generally employed. These experiments had demonstrated that from 1·8 to 2 per cent. of copper was the maximum which it was possible to alloy with type-founders' metal.

Line-casting machine type-metal underwent a wastage or depreciation; he had found from trials and observations, made during a period of two years, that this depreciation amounted to an average of 2 per cent. each time the metal passed through one complete cycle of making and using. The metal was mixed and melted in large quantities so as to ensure uniformity, it was then cast into ingots, then passed once through the line-casting machine and stereotyped from; after this it was returned direct to the mixing pot when it was found to have depreciated to the extent of 2 per cent.

There are advantages in manufacturing matrix-bars or matrix-plates by electro-deposition. The writer had invent electro-deposition which had the advantage that (corresponding to the strike in a punch-struck m placed in the bars or plates *after* these had been m necessary degree of accuracy for the machine requir in the ordinary process used in typefoundries the ma required to be machined, or justified to shape, after been formed or put in place. By the writer's sys intaglios required for each matrix-bar, in a line-c like the Monoline, were electro-deposited in the e after this had been machined to the requirements machine. It was found in use that the thin copper stand the machine-handling and contracted, giving between the letters. With compound matrix-plates, surfaces to the mould, this would not occur, nor wo in the case of individual intaglios under conditions edges of the intaglio were protected by the mechani matrix in position.

The German method of depositing nickel, ins might make this or some similar system of pro commercially advantageous to those engaged in typ the construction of typecasting machinery, as it obvi of manufacturing and maintaining steel punches.

Mr. E. J. Crosier forwarded a communication fr de la Colombe giving a description of the Dyotype has been added to the Paper in Appendix V (page 11

Mr. George Davis wrote that it might be of inte means employed by practical mould makers and type- last 150 years to ensure the requisite degree of a without the use of the, then unknown, micrometer. used for this purpose was known in the trade as the and was shown in Fig. 124 (page 1202). The u gauge was fixed to the stem by screws and the lower made a good sliding fit on the stem by grinding an be secured in any desired position by the thumb-s

(Mr. George Davis.)

were made with a small amount of taper, the inclination being usually 1 in 300, but finer if required. The sides of the jaws had lines engraved $\frac{1}{8}$-inch apart; each division ordinarily, therefore, equalled 0·0005-inch. To use the gauge the type were rubbed free from grease and gently pushed into the taper-opening of the jaws, the position of the type being as shown in Fig. 124; the type was

FIG. 123.

Height-to-Paper Gauge. Full size

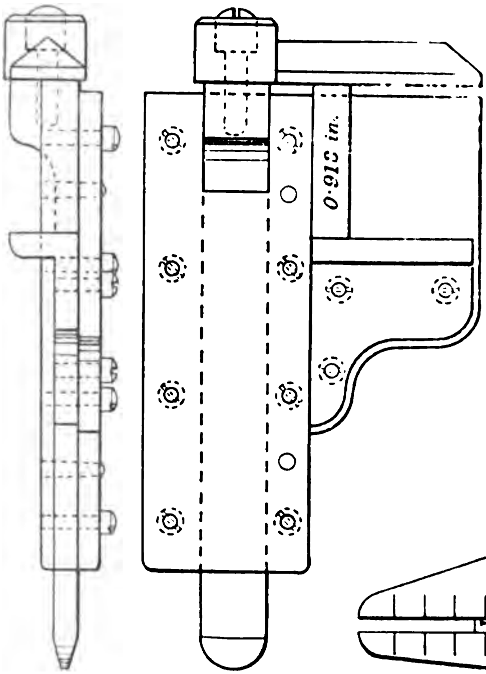
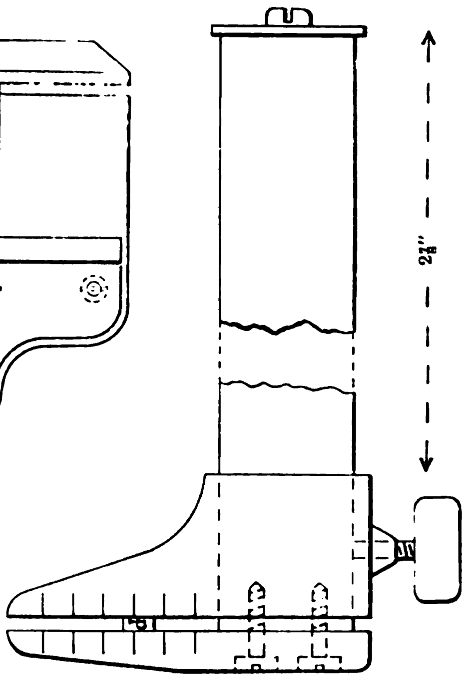


FIG. 124.

Turning Gauge. Full size.



turned end for end to compare the sizes at head and foot; a variation of 0·0001 inch could be as easily detected by feel as variation in the size of a shaft when compared with a Whitworth gauge by means of calipers. The gauge was also used for checking parallelism in *set* as well as the definite *set* width produced by the type-founder. Still greater delicacy of comparison could be made by using three or four type together in the turning gauge. This was actually the usual practice in typefoundries. Commercially perfect type should fulfil the following conditions:—

(1) The face must be true for flatness, i.e. its plane must be normal to the four sides of the body; the degree of accuracy was governed by condition (4).

(2) The face must be true for position, i.e. in plan the vertical main-strokes must be parallel to the *set* and the line parallel to the body; the degree of accuracy was governed by condition (3).

(3) It must also be true for alinement; i.e. within a total of 0·0003 inch the dimension line-to-back must be correct to gauge.

(4) The height-to-paper must be correct to within 0·0003 inch.

(5) The body must be parallel within a total of 0·0001 inch at head and foot.

(6) The *set* must give the correct side-wall on both sides.

The height-to-paper gauge in ordinary use by the type-founder was shown in Fig. 123. This gauge was generally employed for testing flatness of face for compliance with condition (1) above, and, unlike the turning gauge, the jaws were made parallel. The type was placed in the gauge and sighted against the light in two directions in the plane of the face of the upper jaw at right angles to each other and inclined each at 45° to the faces of the body. The ordinary lining-gauge was somewhat similar to that shown by the author of the Paper, but was less elaborate.

Mr. Percy W. Davis wrote that he had been connected in the past with the Goodson Graphotype, and that he considered this machine to be in many respects superior to other machines which the author had referred to in his Class II b (page 1092).

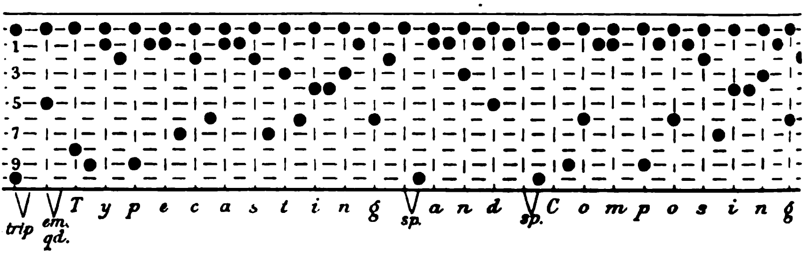
In the *Goodson Graphotype* the keyboard was similar to that of the typewriter and comprised 100 keys; these operated a typewriter which gave a written record of the work of composition as it proceeded, and, in addition, made certain electrical contacts by

(Mr. Percy W. Davis.)

which any one or any pair selected by the key from two sets of ten perforating punches could be operated by electro-magnets. The perforated strip was narrow and had guide perforations on one side only, Fig. 125; the perforations corresponding to any character or space occupied two consecutive transverse units of its length. The typewriter had connected to it a dial scale to show the amount of line to be made up by increasing *or decreasing* the spaces. The face of type employed was of the self-spacing kind having six units to the em-quad, described by the author on pages 1044 and 1045. Five different *set* widths were used comprising two to six units. Corrections, should any be required, could therefore be very easily made by hand.

Fig. 125.

Perforated Ribbon for Typecaster (Goodson Graphotype). Nearly full size.



The line-justification was effected by pairs of perforations similar to those used for the characters; a single hole at the left of the ribbon (as composed) and in the upper of the two possible positions formed the space, while another single perforated hole, in the lower position, formed the trip for the end of the line. As in the other ribbon machine described, the ribbon must be put into the machine in reverse order. The increase or decrease in *set* of the spaces was controlled by an electrically operated escapement.

The matrices were all combined in a square matrix block which differed from that described by the author, inasmuch as it was produced by electro-deposition. The counterpart of the matrix block was set up in type and accurately justified, so that all the characters were correctly placed both for body and *set*. The matrix block, after removal of the type from it, was finished and secured to a steel back with conical holes for setting the respective matrices truly in position; the moving parts were much lighter than in the machine described by the author. The stop mechanism for the grid was somewhat similar, but the perforations in this case enabled certain electrical connections to be made which brought electro-magnets into play, and these operated the stops. The matrix grid comprised ten rows each of ten matrices, but some of these were used for quads. There were one row 2-unit, two rows 3-unit, three rows 4-unit, two rows 5-unit, and two rows 6-unit. The arrangement of matrices in

Fig. 126.

Typecasting Machine: Graphotype.

Arrangement of Matrix Block.

	sp.	Q	P	(	[	0	qd.	⅞	qd.	q
	W	R	O	)	I	9	‘	⅛	S	p
	ffi	T	N	]	?	8	’	½	J	k
	—	U	L	£	!	7	l	¼	u	ff
	M	V	G	*	:	6	f	¾	g	o
	em qd.	Y	F	en qd.	;	5	j	⅓	fl	d
	H	&	E	.	z	4	i	⅔	fi	b
	ffl	X	D	$	t	3	-	⅝	x	n
	w	Z	B	s	c	2	.	⅜	v	h
	m	C	A	e	r	1	,	K	y	a
Units	6	5	5	3	3	4	2	6	4	4

the block was shown in Fig. 126. The matrix block being in one solid piece enabled the characters to be placed very close together. This saved weight as well as saving distance for the matrix block to travel.

The mould was adjustable for *set* width according to the position occupied by the grid demanding one of the *set* widths enumerated (or occasionally in the case of spaces the single unit width). The mould was water-cooled, and special precautions, peculiar to this machine, were taken to keep the temperature down. The pump was placed at some distance (about 15 inches) from the mould, and the metal tube connecting it to the nozzle was heated by means of a

(Mr. Percy W. Davis.)

low-tension electric current; this arrangement had been found to work very well in practice, enabling the metal temperature to be kept very accurately within the desired limits; while the removal of the metal pot to a distance permitted adjustments of the mould and adjacent parts to be made with ease and comfort.

The above brief description related to the small machine, constructed under the writer's supervision in England; as originally made it ran at 140 revolutions per minute, and was capable of casting up to pica. By modifying the shape of the cams it was enabled to cast type at the rate of 170 per minute, which it effected with but little noise and without evidence of undue wear. The writer had since been informed that, in America, a larger class of machine had been built with 225 characters and designed to run at the same speed. The alteration had, however, necessitated dispensing with the typewriter portion of the machine, which, in the writer's opinion, was of considerable value, particularly when corrections had to be made.

Mr. J. Cameron Grant wrote asking the author for his opinion upon the following points:—

(1) Upon the troublesome fringes that one got between the matrices in slug machines, the Linotype, for example, when the matrices became worn or when dirt, oil and waste, etc. were squeezed up between the matrices when being locked by the pressure of the wedge spaces. Was there any way, apart from renewals, of modifying this disadvantage, with its resultant disfigurement to the printed page; or had the Linotype user, so far as the mechanical engineer was concerned, to put up with it?

(2) The writer heard it stated by one speaker, who seemed particularly interested in the Linotype, that corrections were practically as easily made on a mass of slugs from a slug machine as upon a page of loose type, and nearly as quickly. Surely this could hardly be the case; and passing over simple corrections within the line, could it be meant that this applied to overrunning? At times the greater part of a column might have to be re-cast to make a correction. He would like the author's opinion upon this point.

(3) While on the subject of corrections in slug cas if these corrections came back to the compositor a re-cast slugs under different condition of mould tempe variation in height-to-paper ensue and spoil the app column owing to the different condition under which parts were cast?

(4) Was it not the case that the use of compo using loose type had been so limited, because none h with a satisfactory justifying apparatus? All o justifying machines described by the author seemingly rougher approximation to the length of the line than obtained in general hand work.

(5) He would like the author's views upon the di to by one of the speakers who asked for low sp composing machine. The trouble with high spaces, w with those machines casting separate type—the Lans for example—consisted in the spaces rising; this less liable to occur with spaces of trade height tha of shoulder height. The difficulty was particularly n type with no heel-nick, as cast on some casting a machines, for example, the one already mentioned.

(6) Had the author considered the disadvantage over and over again, when it practically always mea mixture of worn and new characters which produce appearance. Ought there not to be some escape fro things?

(7) It was true that the author had in the course o pointed out the desirability of using fresh type every d it not be a matter of great practical difficulty to equ typefoundry owing to the very large stock of punches, moulds which would require to be provided? Mou only wanted on account of the various body sizes, but a of the difference in nicks required for distinguishing di

(8) The last matter to which he would like to was to Mr. Legros' original work upon Logotypes. He this was appreciated at its right value by any of those

(Mr. J. Cameron Grant.)
in the discussion. The conclusion to be drawn was very simple, namely, that one did a great deal of unnecessary work both in writing and printing. The saving that would result from the mere introduction of two new letters into the English alphabet was very remarkable. It was a change that could be made gradually, both old and new characters being used in the same papers and periodicals at the commencement, and a gradual introduction thus taking place through all printing. These new letters could be introduced later on in typewriting, and still later in handwriting, in which the tendency in the case of the "ng," the less common of the two proposed letters, was visible already in the handwriting of many people. The other letter whose introduction was proposed, was "th." The use of these two logotypes alone would mean a saving of at least from three to four per cent.—more than ten days' work to every daily paper in the year. The value of this saved space would at once appeal to everyone who had anything to do with the advertisement departments of any of the great daily newspapers. The saving in time in the composing room alone would be considerably over a quarter of an hour in the eight-hour day. The same saving which alike applied to fast and slow operators would occur also in the case of typewriters, though in their case the saving in space would be of no account. Some saving to the reader, when not reading aloud, would also be produced; the eye, when once accustomed to the novelty, taking in words composed with the combined letters faster than those printed with the present characters. He would suggest that the author in his reply should give a few lines or a paragraph set up in type using the ordinary characters, and the same amount of matter set up in a fount embodying his proposed new characters, as an example to demonstrate its feasibility and to show the saving effected by his proposal.

Mr. ROLLS P. LINK wrote that to cover the points in typecasting and composing machinery which were in need of improvement, and to deal with the suggestions received from the operators of the present class of machines and the printers who have used and have discarded every existing composing machine owing to its lack of efficiency and who set the whole of their work by hand, would mean the drafting of a Paper of even greater extent than that of the author. The systems he so ably cited and illustrated were those which were most universally known, and probably represented the limit of present-day inventive capacity, except perhaps such knowledge as it was the privilege of experimentalists to possess. Anyhow, so far as the public understanding went, the latest machine generally represented that which was the most fully developed. It was evident when one took into consideration the number of machines, together with the many thousands of improvements that had been made, that the line the inventors' ability had taken had not been that of originality and initiative, such as was the case with the first discoverers of new methods and principles. The whole trend of present-day thought in connection with typecasting machinery seemed to have been applied to either the modification or elaboration of existing parts, whereby the number of movements to effect a given result had, in the majority of instances, been greatly increased, but with little improvement occurring so far as the type itself was concerned, which was the vital principle involved. The development of the mechanical compositor had been very rapid, and the strides it had made went without question. But real and progressive invention in this particular branch of mechanics seemed for the moment to have ceased, the stream of inventive effort dividing itself into the two main channels of single type and solid slug casting, neither of which represented the ideal form of composing machine.

What was demanded by the modern typographer was merely a printing surface perfect in all respects and which might be easily and quickly produced and, after production, rearranged with equal convenience for proof correction. The machine to give the required result must be light in design, of the simplest mechanical construction consistent with mechanical efficiency, and moderate in price.

The surface produced, as well as the justifying of the type, was the main and, practically, the only consideration in connection with it; whether it were a sixteenth, an eighth or a quarter of an inch in thickness and whatever the manner of its support might be, were

(Mr. Rolls P. Link.)

matters of indifference so long as it performed the required functions. But inventors had drifted with the current into the two channels he had named, and were now painfully comparing merits and demerits of machines which produced "type high" single types with those of machines producing "type high" solid slugs, to the abandonment of true creative effort. With their productions they turned what was originally solely a composing room into a combined composing room, foundry, and machinery hall filled with machines of huge proportions providing (in the case of single typecasting machines, such as the Monotype and Stringertype) a mass of machinery weighing over a ton to produce something weighing less than an ounce.

Mr. Albert Pidgen wrote forwarding two photographs of the latest development of the Thorne machine, Fig. 127, Plate 46, in which the type was delivered positively, and not on to the revolving disk and belt as mentioned in the Paper. The Thorne machine was not an experimental thing in so far as being an automatic distributor and setter (leaving out the line-justifier), which latter was an addition. The machine, taken simply as a distributor and setter, packing up into line (in a galley), had been manufactured for many years, and was the oldest machine of its kind on the market; it was in use in many cities in the United States for small country newspapers. This new machine was designed in order to make the delivery of type positive, so that a justifying machine could be attached. The construction of the machine was roughly as follows: There were two cylinders "upper and lower" with ninety-six longitudinal grooves or channels. The upper cylinder channels were plain, while the lower cylinder channels were warded, to correspond with each character. The upper cylinder was known as the distributor and the lower cylinder as the stationary cylinder. The distributor was kept turning by a worm which allowed a rest every time the channels in the two cylinders came over one another, long enough for the bottom characters in the distributor channels to drop into the stationary cylinder (when the ward in the channel corresponded with the character). At the same time, when the distributor channel indicated empty, a whole line of characters was pushed in to be sorted out as it went around.

In this way the distributor was kept working continuously sorting out the characters into their respective channels, so that columns were obtained of a, b, c, etc., all around the ninety-six channels of the machine in the lower cylinder.

The distributor together with the lower cylinder and the cone attached to the latter were mounted on a stationary shaft in the centre of the machine. Around this shaft a cam was revolved at 300 revolutions per minute (inside the cone); the function of this cam was to carry up and down a plunger, as follows: When a character was called by the key, a catch was released which allowed the plunger to engage into the revolving cam. The plunger going up caused the bottom character in the stationary cylinder to be pushed off, the character falling by gravity down the surface of the cone in a groove; while this character was dropping, the plunger came down much faster (viz. $\frac{1}{10}$ of a second) and pushed the character that had been waiting at the bottom of the cone (from a former operation) into a circular channel or raceway, positively; by this means the time that it took a character to fall down the surface of the cone was saved. A revolving sweep cleared the channel or raceway, and picked up any character that might be there. This sweep was met by a packer which in turn picked the character from the sweep and pushed towards the galley, Fig. 128, Plate 46. The keyboard was so arranged that combinations could be played, such as "and," "of," "tion"; this was effected by arranging the characters so that they fell into the channel in their correct position (relatively), the sweep and packer picking up the combination instead of a single character. The sweep revolved at 300 revolutions per minute, so that it was impossible to play the keys quicker than the machine could deliver, that is, one-fifth second for each character; and a speed of 10,000 ens per hour had been recorded quite easily. The playing of combinations or chords was not however liked, practically, for the reason that the time consumed in playing "the," for instance, by playing each character singly was so very small compared with what

(Mr. Albert Pidgen.)

might be lost in fixing or rectifying an error; and for this reason it was very seldom used by operators.

Thorne Machine and Line-Justifier.—The principle of line-justifying, described on pages 1125–1126, never got beyond the experimental stage. However, the writer believed that line-justifying by using four spaces, namely, 0·024 inch, 0·030 inch, 0·036 inch, and 0·042 inch, for 8 point type, by selecting any combination, was accurate enough. It has been possible by this system to get the length of the line to within a possible error of 0·006 inch, which was close enough in practice; in fact, the spring of a line of type when measuring was at least twice this amount, more or less, according to the number of characters in the line, and the author's remarks on the greater accuracy to be got by using ten brass spaces, as in the Dow machine (page 1116), might be true, but the greater complexity more than vitiated the usefulness of a larger variety to choose from.

When the writer last saw this machine Mr. Johnson was applying his line-justifier, which acted on a better principle than that of selecting by means of brass spaces. It was as follows: a space of the required width was cut off from a timber or slug of type metal by a straight saw arranged vertically, one stroke of which would cut off the space with very little burr. This saw was controlled (for position) by a screw which was actuated by the measuring mechanism. If the space broke during the operation of pushing it into the line, a second similar space would be cut off and pushed up. The advantage of type-metal spaces was the fact that they could be melted up after use, which was an important item from a distributing point of view.

One serious difficulty with the Thorne machine or any other machine that set up and line-justified individual lines of type was the fact that thin characters, such as "i" or "t," broke very easily in hard type metal, and this breakage was likely to occur in the distribution, in the typesetter, or in line-justifying. When this breakage occurred, so much time was wasted in getting the machine started again that the efficiency of this kind of machine was greatly impaired.

The compressible space, shown in Fig. 62 (page 1110), was tried thoroughly on a Thorne machine, and the chief reason why it was abandoned was the impossibility of sorting it out when distributing automatically. The writer did not know exactly what success the Thorne machine had had with the automatic justifier attachment, commercially, although it was perfect, experimentally. It was manufactured by the Unitype Co., of Brooklyn, New York, and the few remarks that he had made were from the experience gained as a designer for the Unitype Co. about five years ago.

Mr. H. Sell sent the following remarks from the operator's point of view. He wrote that the Lanston Monotype did the work of five men, and it would cast a galley full of 10 point, 24 ems wide, in one hour and a quarter; the average of a week's working could be put down at about 5,500 to 5,750 ens per hour, as there were a good many set-backs with trouble on the caster, such as a pin sticking, a splash, face pulling off, a broken latch in the loose wall, etc. It was a very handy machine to the small jobbing printer, as he could become his own typefounder, and cast all his sorts, ornaments, fancy borders, etc.

One disadvantage with the Monotype was that it cast spaces and quads nearly as high as the letters, and in working balance sheets, or any job where there were many whites (or quads), the quads printed as well, causing a waste of time in cutting and smashing the quads down. When printing the quads rose and rolled, causing the sheet to flick the face of the quads which were inked, thus leaving their impression on the paper. Machine minders did not like the sight of Monotype matter, especially on rush jobs. It was more suitable for the jobbing printer than was the Linotype, because it cast each type separately, and all corrections were done in the usual way by hand, away from the machine itself; there was no waste of metal, because the formes were broken up and melted into small square ingots and used again and again for other jobs. There was now an appliance for making quads lower, but it was rather a complicated affair. The machine always required watching, keeping very clean, overhauling once every week, and the speed should be kept even, for if the machine were forced, there was trouble with the metal pump at once. The writer did not find the machine he worked to be very accurate in justifying the lines of type, as there was a slight

(Mr. H. Sell.)
variation in the length of the lines which, in high-class work, made re-justification by hand a necessity.

Mr. LEGROS wrote, in reply to Mr. Capehart, that the author considered the data given as to wastage of metal would help to give information in reply to some of the questions raised. The process described for preparing matrix bars was one of great interest to those who had to deal with this class of work; a matrix comprising several strikes in one small piece of metal, all of which must be in position to the requisite degree of accuracy, presented a much more difficult problem to the engineer than that of a single or even a double strike, particularly when the low cost for which these matrices must be sold (about 7 cents, Canadian, each) was taken into consideration.

Mr. G. Davis had given a very practical note respecting the older appliances used in the trade for making comparative measurements (page 1201); he had, moreover, shown in figures how these appliances compared with those used by the engineer in fineness of measurement. It was frequently urged in disputes between engineers and inventors that the appliances in practical use by type-founders accepted a lower standard of accuracy. Mr. Davis had clearly shown that the standard degree of accuracy had been arrived at by practical experience and could be obtained equally well with either appliance; for comparative purposes probably the old appliances were quicker to work. The standard degree of accuracy given by Mr. Davis represented first-class work in each respect.

The remarks of Mr. Percy Davis on the Goodson Graphotype were of much interest, and it was a matter of regret that more information was not obtainable in respect to this machine. Mr. Davis had at one time been connected with the Wicks machines, and had had considerable experience in this class of work. The author believed that generally the removal of the metal pot to a distance resulted in a tendency to cast hollow type; the arrangement described for heating the metal tube appeared to present considerable advantages, but the author did not believe that this method for obtaining a constant temperature had been applied on any other machines of the kind.

In reply to Mr. Grant's various questions the author would say:—

(1) There was so much difference between good and bad Linotype work that it was difficult to say how much of the hair-line between characters, seen in the cheaper newspapers, was due to dirt and carelessness and how much to wear. It was certain that where the matrices were renewed in good season this appearance could be largely done away with.

(2) The question of overrunning appeared to be largely influenced by the local conditions; probably with Linotype machines at hand the corrections were made more readily than the older school of compositors would imagine; but, on the other hand, it must frequently be necessary to re-cast a number of slugs.

(3) The author had heard it stated by printers that when corrections had been made in the Linotype matter with slugs cast on different machines, or under different conditions, there was some difference in height-to-paper and consequently a want of uniformity of colour in the printed page.

(4) The use of composing machines supplied with loose type had undoubtedly been restricted by the absence of a satisfactory line-justifying apparatus. There was no more perfect method of line-justifying than that employed on the slug machines, whether in the form of the screw, as devised by Schuckers and used on the Typograph, or that of the folding wedges of the Linotype space-band. These gave equal spacing throughout and filled the line correctly; whereas nearly all the appliances described only approximated roughly to this.

Two machines had been devised for dealing with the justification of loose type; instead of operating in the line, so as to divide the deficiency of length over the number of spaces, these machines operated by means of outside apparatus which prepared spaces of the correct width determined by the machine. The one machine had been described in the Paper (page 1110); the other (F. A. Johnson) attained the same end by sawing or cutting pieces of type-metal of

(Mr. Legros.)
the correct *set* width required from a slug or timber and inserting these in the line.

(5) The difficulty with high spaces, also alluded to by Mr. Gibbs, appeared to the author to be a very real trouble. It was recognised by the inventor of the Dyotype, who had made a special provision for casting low spaces by dividing the body slide into two parts, one of which reduced the effective length of the mould when casting spaces. Where type had no heel-nick it was rather more liable to rise when being planed down, as water could get below an individual space and work it up under the action of the blow.

(6) The author had frequently had occasion to notice the poor results obtained by the mixture of old with new type; this result was quite avoidable by the use of composing machines and fresh cast type either in the form of slugs or in that of loose type. During the period over which *The Times* was supplied with fresh loose type for each issue, from the Wicks machine, he thought that journal had the cleanest appearance of any printed sheet of the kind. Probably the advent of cheap accurate type with a simple composing machine and a thoroughly practical automatic line-justifier would enable such a result to be obtained in the future in face of the competition of the slug machines.

(7) The writer here touched on the biggest question affecting such a scheme as that outlined above. If there were only three widths of faces, condensed, standard and extended, for each body there would still be some twenty-one type-moulds and seven space-moulds required for ordinary work, from nonpareil to pica; but there are modern and old style and other varieties of face required which must be suitably distinguished from each other by a different arrangement of nicks, so that, in all, the number of moulds may soon exceed a hundred and the matrices will run to many thousands. Apart from the capital outlay on these, there is the work of originating faces, so that considerable time, as well as money, must be spent in achieving any tangible result.

(8) The paragraph set up, Fig. 129, with the proposed new characters would show clearly what practical result was arrived at by the change. The new characters could be read with absolute

Fig. 129.

THE SAVING EFFECTED BY REFORMING THE ALPHABET.

The one thing, above all things, that seemingly is required in the printing of newspapers, is the saving of time in going to press. In the second place, the saving of time, and therefore the saving of money in composing, is of the greatest importance and ever-increasing interest to the trade. Thirdly, the mere altering or adding of a unit ensures a saving in space well worth the publisher giving it serious attention. This saving in the case of newspapers affords more space for the advertising, and in the case of the best books and the best periodicals, there would be quite an appreciable saving in paper. The introduction of the two proposed letters θ and ŋ means a three and a half per cent. saving of matter in composing and printing throughout England and America. By dividing this saving between the operators and the proprietors, the aggregate sum gained by each of them yearly would in itself amount to a fortune.

ĦE SAVIŊ EFFECTED BY REFORMIŊ ĦE ALPHABET.

Ħe one θiŋ, above all θiŋs, θat seemiŋly is required in θe printiŋ of newspapers, is θe saviŋ of time in goiŋ to press. In θe second place, θe saviŋ of time, and θerefore θe saviŋ of money in composiŋ, is of θe greatest importance and ever-increasiŋ interest to θe trade. Ħirdly, θe mere alteriŋ or addiŋ of a unit ensures a saviŋ in space well worθ θe publisher giviŋ it serious attention. Ħis saviŋ in θe case of newspapers affords more space for θe advertisiŋ, and in θe case of θe best books and θe best periodicals, θere would be quite an appreciable saviŋ in paper. Ħe introduction of θe two proposed letters θ and ŋ means a θree and a half per cent. saviŋ of matter in composiŋ and printiŋ θroughout Eŋland and America. By dividiŋ θis saviŋ between θe operators and θe proprietors, θe aggregate sum gained by each of θem yearly would in itself amount to a fortune.

(Mr. Legros.)
facility by people who had never seen them before and knew nothing of the suggestion. The value of the saving to be effected in space could be directly estimated by those responsible for the advertisements, because, as Mr. Grant pointed out, it was equivalent each year to the space occupied by the whole of the reading matter in ten copies of any daily paper.

It was difficult to arrive at the figures for the earnings of the compositors, but it would appear that in the London district alone upwards of £1,000,000 per annum was paid to compositors in wages (taking only society men into account); probably in the whole of Great Britain and Ireland about £3,000,000 per annum was so paid. In America, with Canada and with the other English-speaking colonies, the amount would be considerably larger, so that the annual wages earned in composing the English language might well exceed £10,000,000 per annum. The saving in this item alone would, consequently, amount to about £350,000 per annum, apart from savings effected in materials, in typewriting, time occupied in handwriting, etc.

Mr. Longhurst had also alluded to this question and had raised the further point as to whether a similar saving was to be effected in other languages. The author had not been able to find any parallel case in French, but in German it would appear, from a preliminary examination which he had made, that the substitution of three new letters for the combinations sch, ch and ng would enable a saving of more than 4 per cent. to be effected. The Russian letter Ш should not be adopted for sch as it only differed slightly from the lower case m in the serifs and hair-line; it would be desirable that new characters should be designed which should be very plainly dissimilar from all those in present use.

The remarks of Mr. Rolls P. Link (page 1209) as to the increasing size and complication of typecasting and composing machines were full of truth, but the author was of opinion that much of this complication was due to the conservatism of the printing trade and the desire to make the machines do all sorts of things which had previously been done by hand. It was only necessary to compare the new duplex Linotype with its two sets of escapements, two magazines each filled with two letter matrices, and its double distribution gear, with the earlier simple pattern, in order to realise the amount of work which had been done recently with a view to increasing the scope of these machines.

The author agreed with Mr. Link that the printing surface was after all that which interested the printer most; several inventors had endeavoured to simplify the operations by the direct production of a matrix in flong from which a stereotype could be cast. There were, however, two almost insuperable difficulties to be met with in this field, namely, line-justification and correction of proofs. The author quite agreed with the writer as to the change which had taken place in the composing room, but thought that a system of machine composition from new loose type, similar to that in use by *The Times* till recently, if aided by accurate machine line-justification would give a better result than that obtained from the highly complicated machines of the present day.

Mr. Pidgen had given (page 1210) very interesting additional information on the evolution of the Unitype from the Thorne machine; the difficulty of breakage of thin sorts which he mentioned had not been found by the author to be so much a cause of trouble in composing as in distributing machines. The difficulty which gave most trouble, with some kinds of composing machines, consisted in "turned sorts," that is, some of the characters would turn through 90° or 180° between leaving the magazine and arriving in the line; he believed this had been a very serious trouble in the case of some composing machines.

In the observations of Mr. H. Sell (page 1213) one had the views of a man who had first-hand user's experience with one of these machines in composition, and it was of interest to note that he had raised the same objection as other speakers had done to the high space, and had also alluded to the ease of effecting corrections in loose type. It was interesting to find that the line-justification effected by the machine did not, in practice, avoid some hand-work where accuracy was required.

The author desired to thank Mons. de la Colombe for much valuable information on French type which he had incorporated in Appendix I (page 1142).

(Mr. Legros.)

TABLE 13.

Amount of Beard expressed in Points.

Type body.	American common line.	American point title line.	S. B. & Co. point common line.	S. B. & Co. point title line.	Type body.	American common line.	American point title line.	S. B. & Co. point common line.	S. B. & Co. point title line.
5	1	1	1	1	18	4	1	4	2
6	1	1	1	1	20	4	1	4	2
7	2	1	2	1	24	5	1	5	2
8	2	1	2	1	30	7	1	6	3
9	2	1	2	1	36	8	1	7	3
10	2	1	2	1	42	8	1	8	3
11	3	1	3	1	48	8	1	10	3
12	3	1	3	1	54	8	1	11	—
14	3	2	3	1	60	8	7	12	4
16	3	1	3	1	72	14	—	14	4

The late Mr. C. Colebrook had pointed out to the author the desirability of standardizing the line; this had been done in America and the American practice had been followed by the Blackfriars and Caxton Typefoundries, Mr. Walter Haddon, of the latter firm, having been from the first a staunch advocate of standardizing this dimension. Unfortunately the ring founders had not adopted the American point system unaltered for either of the two systems of line in use. Table 13 showed the amount of beard (page 1220) corresponding to the different body sizes in the true American line and in other cases.

It was to be hoped that either the American or the ring standard line would be adopted throughout the trade, as this would prove of great ultimate benefit to the printer.

In conclusion, it might be of interest to record the approximate number of machines of the two most important classes in use at the present time.

LANSTON MONOTYPE: casters, 2,200; keyboards . .		3,200
LINOTYPE MACHINES	about	17,000
MONOLINE MACHINES	about	2,000
TYPOGRAPH MACHINES	over	2,000
Total about . .		24,200

These machines alone represented a capital outlay of over £14,000,000, apart from the sum invested in the works for producing the machines and their accessories.

Of these machines some 17,000 were employed in the United Kingdom, America, and other English-speaking countries, while the remainder were mainly used for other European languages, amongst these being French, German, Dutch, Italian, Spanish, Danish, Norwegian, Swedish, Bohemian, Russian, Roumanian, Polish, Slavonic, Hungarian, Hebrew and Yiddish.

MEMOIRS.

Sir William Beilby Avery, Bart., was 1854, being the son of the late Mr. W. of the late Mr. Thomas Avery, proprietors T. Avery, weighing-machine makers, of death of his father in 1874, the firm passec executors until 1881, when Mr. W. B. A in conjunction with his brother, Mr. He control of the undertaking, which was operations. At that time the firm employ hands, and had works at Mill Lane and We became too small the Soho Foundry was business was converted into a private con a public company, shortly after which participation in the work of the firm, thou the board of directors, and Mr. W. E. Hi director. During the time he controlled many improvements in weighing apparat responsible for the passing of the Weigh 1889, which did much towards improving in use in this country and bringing about administration of the previous Act of 187 the Darracq Motor Car Co., and the Commo of Australia, and was created a Baronet ir place at his residence in London on 28th of fifty-four. He became a Member of this

Thomas Beeley was born at Little Derbyshire, on 27th October 1833. Upon first employed as a cloth-looker in the Mr. Marlor at Newton, near Manchester, a he entered the works of Messrs. Daniel Adamson and Co., at Newton. Beginning as a time-keeper, he worked himself up to the position of general manager, and remained in that capacity until he started in business for himself in 1867 at the Hyde Junction Iron Works. From that time up to his death he was constantly at the works, and the whole of his engineering activities were confined to the development of land-boilers and to the conduct and increase of the works. He was connected with the late Sir William Fairbairn in improvements in the Fairbairn type of boiler, adding to it a nest of tubes at the back of the flue and other small alterations, which resulted in the successful and economical Fairbairn-Beeley boiler. He was very closely associated with the proposals for the experimental boiler burstings during 1874 to 1876, which were undertaken at his works, under the instructions of the Manchester Steam Users' Association, to determine strengths of the various parts of an ordinary Lancashire boiler. His numerous inventions were connected with small details in the construction of boilers, and particularly with machinery for their manufacture. He was much interested in the early development of superheating, of which he was the maker of several types. He also made a great success of the three-flued boiler. For thirty-five years from the commencement of business he never advertised or exhibited or had any representatives. Notwithstanding this, his business judgment and engineering ability inspired the confidence of the profession as well as the public, including many of the large engineering firms of the country, and the Government departments. He kept in a remarkable degree in his older years the willingness and ability to look ahead which had characterised his younger days, and he was just as ready to install new plant as at any period of his career. About 1898 he commenced to leave control of the business to his son, Mr. T. Carter Beeley, and devoted more time to public work. For some years he had been a member of the Hyde Local Board, which was dissolved in 1881 on the incorporation of the town, and was its last chairman. He had lived both at Ashton-under-Lyne and at Dukinfield, and for many years he was a member of the Dukinfield Local Board. During his residence there he became a member of the Cheshire County Council, and was subsequently an alderman, having for the last few years been vice-chairman of the Council. In 1883 he was appointed a magistrate for the County of Chester, and in 1906 he became Chairman of the Dukinfield Petty Sessional Division. For the last two years he had not enjoyed robust health, having suffered from weakness of the heart. Having gone to Blackpool to recuperate, he succumbed to a heart seizure on 5th June 1908, in his seventy-fifth year. He became a Member of this Institution in 1875.

HENRY CHAPMAN was born at Dieppe on 14th March 1835, being the second son of Mr. George Chapman, who was for nearly half a century the British Vice-Consul at that port. He was educated at a private school at Lewes, where he developed an aptitude for applied mathematics, which determined the choice of engineering as a profession. At the age of seventeen he began a five years' apprenticeship in the works of Messrs. Sharp, Stewart and Co., locomotive engineers, of Manchester, and went through all the departments. Upon the completion of his apprenticeship in 1857 he was selected to represent the firm in Paris. This he did with such success that in 1858 he established a business as a consulting engineer, continuing to represent his old firm, though not exclusively. From time to time he added the representation of other firms of machine-tool makers and general engineers, and he was engaged by many of the Continental railway companies in providing designs and specifications for rolling-stock, and in one or two cases even for bridges. When the late Mr. Tweddell evolved his system of applying hydraulic power to machine-tools, he found a strong advocate in Mr. Chapman, who installed one of the first applications of that system in the plate-working shop in Toulon Dockyard. Many other important inventions were introduced into France and other countries under his auspices, and during the past half-century he exercised a powerful influence in the development of a European demand for British engineering productions. He was early associated with the application of water under high pressure, and was one of the promoters and a director of the Hull Hydraulic

Power Co., which was the pioneer of the London and Liverpool companies, of which he was also a director, and later the chairman. He was, too, the chairman of the Hydraulic Engineering Co., of Chester. Another concern in which he took an active part was the Employers' Liability Assurance Corporation, which was organized when Parliament first made employers responsible for accidents. From the commencement of the company he was a director, and in later years vice-chairman.

Prior to the siege of Paris he had established an office in Westminster, and during that period he conducted his Continental business from London. After the war he continued the Paris office as his principal establishment. He became a Member of this Institution in 1866, and was first elected to the Council in 1878, and continued until 1880; he was re-elected in 1899, and in 1907 became a Vice-president. He contributed a Paper in 1881 on "The Farquhar Filtering Apparatus."* During the Paris Meetings of this Institution in 1867, 1878, and 1889 he served as honorary local secretary, and rendered invaluable services. He acted in the same capacity for the Iron and Steel Institute in 1889, and he exercised a most important influence in connection with the successive Paris Exhibitions. In 1878 he was created Chevalier of the Legion of Honour, and was promoted to the rank of Officer in 1889. He was a Member of the Institution of Civil Engineers, of the Institution of Naval Architects, and a life Member of the Société des Ingénieurs Civils de France. For some time he had suffered from gout, and latterly from weakness of the heart, to which he succumbed on 18th October 1908, in his seventy-fourth year.

Engineer Lieutenant Francis James Charlton, R.N., was born at Hexham on 1st August 1874. His education was received at St. Stanislaus' College, Beaumont, and at St. Benedict's Abbey, Fort Augustus, after which he entered in 1890 the Royal Naval Engineering College at Keyham. On completing four years' work

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* Proceedings 1881, page 145.

Naval College, and in 1895 was appointed to H.M.S. "Endymion." A year later he went to Barrow-in-Furness as one of the assistants to the late Engineer Captain (then Fleet Engineer) R. W. Edwards, of H.M.S. "Powerful," the first of the great water-tube boilered ships at that time under construction. In 1897 he proceeded in her to China, where she remained till the outbreak of the South African War, when she was ordered to the Cape of Good Hope. Much to his regret, he was not one of those selected for service at the front, so he remained aboard at Simon's Bay during the months of weary waiting for the return of his messmates after the relief of Ladysmith. He arrived home in the "Powerful" in April 1900, and was shortly afterwards appointed to H.M.S. "Kestrel," torpedo-boat destroyer. From her he went as Senior Engineer to H.M. Battleship "London," for service in the Mediterranean, and after two years he was invalided home in consequence of a severe attack of fever. On recovering he was appointed to H.M. Yacht "Victoria and Albert," in which he served from 1903 to 1907, when he was transferred to the senior list of Engineer Lieutenants, and was placed in charge of H.M.S. "Amazon," an ocean-going turbine-destroyer then being built at Messrs. Thornycroft's works at Southampton. In this post he continued till the time of his death. He was an officer of exceptional ability, as will be gathered from the importance of the ships on which he served. In 1906 he was one of those selected to give evidence before the Admiralty Committee charged with the duty of inquiring into certain matters affecting Engineer Officers and Officers of the Royal Marines. He was greatly interested in motor engines, and recently invented a variable-speed gear applicable to motor vehicles. His death took place at Portsmouth on 25th July 1908, in his thirty-fourth year, as the result of an accident while riding a motor-bicycle in Portsmouth a week previously. He became a Member of this Institution in 1903.

Samuel George Homfray was born at Tredegar, Mon., on 4th July 1855, being the son of the late Captain S. G. Homfray and grandson of Samuel Homfray, who was for thirty years managing partner of Tredegar Iron Works. He was educated at Cheltenham College, and in 1872 entered the Elswick Works of Sir W. G. Armstrong and Co. as a pupil. After this training he was appointed in 1879 assistant London and outdoor manager, succeeding in 1896 to the position of London and outdoor manager, and in 1902 he became senior joint manager of the engine works department of the Elswick Works. He was concerned with many important hydraulic installations and undertakings carried out by the firm with which he was connected, including the swing-bridge over the River Tyne in 1876; the installation of hydraulic machinery on the Manchester Ship Canal, completed in 1894; the Tower Bridge, 1894; Port Talbot Dock, 1899; Surrey Commercial Dock Extension, 1903; Leith Imperial Dock, 1901; Burntisland New Dock, 1901; Grangemouth New Dock, 1906; Cardiff, Queen Alexandra Dock, 1907; Avonmouth, Royal Edward Dock, 1908; and many other works at home and abroad. He took an active interest in Freemasonry, and held at one time and another many important offices. He was a Justice of the Peace for the County of Monmouthshire. His death took place at his residence in London, after an operation, on 14th October 1908, at the age of fifty-three. He became a Member of this Institution in 1895; and he was also a Member of the Institution of Civil Engineers.

WILLIAM RICHARD SUMPTION JONES was born at Newport, Mon., in 1840, and was educated at a private school. Having served his apprenticeship as a mechanical engineer, he entered in 1860 the employment of Messrs. Joseph Wright and Co., railway-coach builders of Birmingham, and remained with them till 1866, when he became works manager of the Lancaster Railway-Carriage and Wagon Co. He, however, only remained there a few months, as in 1867 he was selected by the Secretary of State for India to fill the appointment of deputy superintendent of the government workshops at Rûrki in the United Province of Agra and Oudh (then known as the North West Provinces). At about that time it had been intended to start building rolling-stock in those workshops for provincial light railways then projected, but not carried out until several years later; and this was the reason for his appointment. When, six years later, the term of his agreement expired, he was retained and was graded as an executive engineer of the Indian Public Works Department. He was stationed at Narora in the same province, and the site of the great dam and headworks of the Lower Ganges Canal, then under construction, where he was put in charge of the Workshops division, and carried out the construction of all the heavy ironwork used in the regulating machinery there installed He remained in this appointment until the completion of the headworks, when, in April 1879, he was transferred to the Indian State Railways establishment, and posted to the Râjputâna State Railway, as Deputy Locomotive and Carriage Superintendent, especially to take charge of the completion and equipment of the Central Workshops at Ajmîr. In 1880 he was promoted to the post of Carriage and Wagon Superintendent of the same railway, which by absorption of other lines in 1883 became the Râjputâna-Mâlwa State Railway, and he remained in the same appointment until his retirement in 1893. During his time there the railway increased in length from about 500 miles to 1,500 miles, for which increase he built all the rolling-stock, reducing the tare and increasing the load of the wagons employed. He invented and introduced a system of flexible central buffers and screw-couplers, which was adopted by the Indian Government and made compulsory on all the railways of 3-foot 3⅜-inch gauge. He was a clever mechanical engineer, strong administrator, able financier, and scientific accountant in workshop expenditure. At the request of the Public Works Department, he revised and recast the whole of the regulations in the P.D.W. code relating to railway expenditure and accounts; and with minor improvements these regulations are still in force. In 1893 he returned to England and settled down in London, where he occupied himself in designing, experimenting, and patenting further improvements in his flexible buffers and automatic couplers, including one for the application to the ordinary hook-and-link system in use in the United Kingdom. He however had not perfected this last invention before his health began to fail in 1904, when he was obliged to give up all work, and to leave

London for residence at various health resorts in the hope of obtaining benefit from them. After a long illness his death took place at Folkestone on 12th April 1908, in his sixty-eighth year. He became a Member of this Institution in 1872, but his only contribution to its Proceedings were some valuable remarks and statistics on Mr. J. D. Twinberrow's Paper on "The Capacity of Railway Wagons as affecting cost of transport." *

HENRY LAWRENCE was born in London on 7th October 1825. He commenced his engineering education as a pupil with the firm of Messrs. James Simpson and Co., of Pimlico, London, and made such progress that he was early put in charge of various contracts, of which may be mentioned the Whittle Dene Waterworks, which gave the first gravity supply of water to Newcastle-on-Tyne, and the mechanical engineering work connected with the docks at West Hartlepool. In 1852 he settled in Newcastle, having been appointed general manager of the Ouseburn Engine Works, but previously he had paid a visit to San Francisco in connection with gold mining which flourished there at that time. In those days the voyage was a long and tedious one, and the ship on which he commenced his return journey was wrecked on a small island in the Pacific. There was no water to be found on the island, and in due time the supply obtained from the wreck ran short. His engineering knowledge, however, stood him in good stead, and by means of tanks and other apparatus he was able to improvise a condensing plant so as to distil fresh water from the sea. He remained at the Ouseburn Works for about four years when he was offered a position by his old firm, but in 1860 he returned to Newcastle to become manager of the Walker Iron Works, belonging to Messrs. Losh, Wilson and Bell. With this firm he remained eight years when he was appointed general manager of the Grange Iron Works, Durham, a position which he held for thirty years. He then settled in Newcastle as a consulting engineer, and was actively employed to within a few days of his death. While at the Grange Iron Works in 1878 he

* Proceedings 1900, pages 577 and 598.

brought out, in conjunction with the late Mr. Daglish, an automatic expansion-gear for winding engines, which was extensively adopted and is at present in use on several colliery winding engines. In 1883, in conjunction with the late Mr. Ogle, he invented a differential gear for large pumping engines, which was most successful; and in 1889 he designed and constructed at the Grange Iron Works for the De Beers Mine, Kimberley, the largest winding-engine and head-gear that had, up to that time, been sent to South Africa. He was held in high repute as a valuer of colliery plant. His death took place at his residence at Jesmond, Newcastle-on-Tyne, on 23rd November 1908, at the age of eighty-three. He became a Member of this Institution in 1867.

Sir George Thomas Livesey was born at Islington on 8th April 1834, being the eldest son of Thomas Livesey, then one of the officials at the Brick Lane Works of the Chartered Gas Co. After a somewhat brief education at private schools, he was apprenticed, at the age of fourteen, under his father, who had meanwhile been appointed secretary of the South Metropolitan Co., continuing in this capacity till 1855. In this year he was made assistant engineer, and had charge in turn of nearly all the work that came into direct bearing upon a gas undertaking. Between the years 1855 and 1862 he gradually took over the management of the works, until in the latter year he was appointed engineer to the company, his father retaining the positions of secretary and general manager. In this capacity he was responsible for the enlargement of the Old Kent Road Works, which were doubled in size, the older parts at the same time being rebuilt. This work was all carried out to his designs and under his personal direction. He later acted as engineer for new works of the Tynemouth Gas Co., and was consulting engineer to the Coventry Gas Co., the Aldershot Gas Co. and other companies. On the death of his father in 1871, he was appointed secretary, holding the two positions of secretary and engineer until 1882, when, on amalgamation with the Surrey and Phœnix Companies, he was elected a director of the enlarged concern, and in 1885 he was elected chairman. He brought out several inventions, all connected with the improvement of gas machinery and appliances, purification, etc., two of them the Livesey washer and the Livesey scrubber being in wide-world use today. The modern gas-holder as now constructed owes its inception to him; the original example erected at the Old Kent Road Station became a model for many others at home and abroad.

At the time Mr. Livesey took charge of the management of the works as the company's engineer, the annual output of gas amounted to about 350 million cubic feet. In 1908 the output was over 12,700 million cubic feet. He was responsible for the introduction into the gas-making industry of the sliding scale, whereby, with a reduction in charges for gas, an increase in dividend is allowed. The second connection in which he will be remembered concerns his efforts to encourage thrift and improve the condition of the employés of his company. He considered that gas-supply was tantamount to a public service, and of so great an importance to the public that an interruption of supply should not be jeopardised. This motive, coupled with the desire to enable the employés to benefit by the prosperity of the company, led to the introduction of his profit-sharing scheme, which later on developed into the co-partnership system. He was a director of the Crystal Palace District (now the South Suburban) Gas Co., and chairman for several years, during which the co-partnership system was adopted by that company. His connection as a director with the Commercial Gas Co. was also followed by that business being conducted on co-partnership lines. He at one time or another held most of the important positions in institutions and associations connected with the gas industry, He became a Member of this Institution in 1901; and was elected a Member of Council of the Institution of Civil Engineers in 1906. He was selected as a member of the Royal Commission on Labour, 1891; he also was a Member of the Royal Commission for the St. Louis Exhibition of 1904, and served on the Committee appointed to report on employment of ex-soldiers. He was created a Knight in 1902. His death took place at his residence at Reigate on 4th October 1908, at the age of seventy-four.

William Charles Melville was born in Liverpool on 27th June 1856, being the son of Mr. Samuel Melville, superintendent engineer of the Liverpool Steam Tug Co. On the completion of his education at the Liverpool Institute, he served his time as apprentice with Messrs. Fawcett, Preston and Co., of Liverpool, and afterwards entered the service of the Liverpool Steam Tug Co. as engineer until the death of his father in 1888, when he succeeded him as superintendent engineer. In 1907 he became a member of the firm of Messrs. Hicks, Melville and Co., of Liverpool, marine surveyors and consulting engineers. He was associated with many notable inventions, of which may be mentioned his metallic tube stoppers, and a patent pontoon and crane for wreck-raising purposes, which were described in Papers read before the Institution of Naval Architects and the British Association Meeting in Liverpool. His death took place after an illness of some weeks' duration on 1st November 1908, at the age of fifty-two. He became a Member of this Institution in 1891; and he was also a Member of the Institution of Naval Architects.

William Holmes Nisbet was born in Glasgow on 15th January 1862, and received his education at private schools and at the University of Glasgow. From 1878 to 1883 he served his time in the works of Messrs. Muir and Caldwell and in the locomotive works of the North British Railway at Cowlairs, and on its completion he remained as draughtsman for three years. From 1886 to 1890 he was principal outdoor assistant to the locomotive superintendent of the same railway. In 1890 he was appointed locomotive draughtsman and superintendent of the wagon repairing works of the New South Wales Government Railways, and was also for some time acting manager of the carriage and wagon shop. Two years later he became assistant to the consulting engineer of the Assam Bengal Railways, and from 1893 to 1899 he acted as engineer and manager for the Westinghouse Brake Co. in the Australasian Colonies. In 1899 he was appointed chief mechanical engineer to the Queensland Government Railways, which position he resigned in 1901 to resume control of the Westinghouse Brake Co.'s interests in Australasia.

He retained this position until his death in Sydney on 30th October 1907, in his forty-sixth year. He became a Member of this Institution in 1899.

WILLIAM ANSON PEARSON was born at Athens, Pa., United States, on 29th July 1855. His apprenticeship was served with the Delaware, Lackawanna and Western Railway Co. at Scranton, Pa., from 1869 to 1873, and on its conclusion he remained four years with the same Company as draughtsman and foreman. He was next engaged for one year in the Motive Power Department of the Union Pacific Railroad Co., at Omaha, and in 1878 was employed in their Civil Engineering Department. In the following year he became master mechanic with the Virginia-Trukkey Railroad Co., at Carson City, Nevada, and during the years 1880 to 1884 he acted as superintendent of construction on Comstock Lode, in charge of the connection of all mines with the Sutro Tunnel. After two years in Boston as a consulting engineer, he became in 1886 superintendent of the marine-engine department of the Dickson Manufacturing Co., at Scranton. This was followed by an engagement with the Boies Steel Wheel Co., at Scranton, where he had charge of the design and construction department, which was followed by his being appointed manager of plant. In 1893 he became chief engineer of the General Electric Co., at Schenectady, New York; this position he held until his death, which took place after a short illness on 26th May 1908, in his fifty-third year. He became a Member of this Institution in 1907; he was also a Member of the American Society of Civil Engineers and of the American Society of Mechanical Engineers.

JOHN JOSEPH PLATTS was born at Odessa on 23rd April 1840, being the eldest son of the late Mr. Joseph Platts, chief consulting engineer to the Russian Imperial Admiralty at St. Petersburg. He was at school for some time in Russia, but at the outbreak of the Crimean War the family left Russia for England, and here he completed his education and received his first lessons in engineering from his grandfather, the late Mr. John Tandy, one of Boulton and

Watt's engineers. He served his apprenticesh
Ravenhill, Salkeld and Co., of London, after whi
knowledge of railway and locomotive engineering at
under the late Mr. William Bouch, locomotive m
Stockton and Darlington Railway, with whom he r
of years in charge of the erecting department.
appointed manager of Messrs. Hopson, Gilkes a
Foundry at Shildon, and subsequently had char
extensive outdoor work at Middlesbrough, whi
erection of ironworks plant and blast-furnaces.
the management of the Bridgwater Ironwork
during which employ he was invited by the late
to take the management of his extensive iron and
at Briansk and Ludinovo. Here his knowledg
language was of the greatest assistance to him in
He remained with General Maltzoff for a period of
which, on his return to England he became the
Avonside Engine Works at Bristol, where he rem
time, leaving England again to take up the duti
chief to the Odessa Water Works Co., in Odessa
afterwards appointed manager to the Company, a
these duties also those of engineer. In this positio
upwards of twenty years, filling a post which wa
arduous, owing to the antagonism of the mun
towards the Company. At the wish of the dire
owing to his diplomacy, the purchase of the w
Municipality from the English Company was succe
For a few years after this transfer he remained
the Odessa Municipality and superintended the
waterworks according to plans and designs prepar
the completion of these extensions, which cost ne
resigned his position and retired to England. He w
in sanitation, and during his service with the Muni
acting on his advice and with his professional ass
done to improve the sanitary condition of the c
consulting engineer to the Municipalty in the desi

of the new Municipal Hospital, in the construction of the Kisheneff Lunatic Asylum, the Odessa Municipal Laundry and Bakery, and a number of municipal enterprises of a nature to improve the health of the city. He introduced into Russia the principle of bacterial filtration of sewage, and was the author of a number of Papers which he read before the Russian Imperial Technical Society. His death took place at his residence near London on 21st June 1908, at the age of sixty-eight. He became a Member of this Institution in 1878.

ANDREW CASSELS RAMSAY was born at Chatham on 4th February 1867. He received his scholastic education at various schools in Glasgow, and in 1882 he commenced an apprenticeship of five years in the works of Messrs. Duncan Stewart and Co., of London Road Iron Works, Glasgow. During that period he attended evening classes at the Andersonian College and the College of Science and Art, of Glasgow. On the completion of his articles he remained with the firm for two years as a journeyman and in the drawing office of the marine department. In September 1889 he went for six months as second engineer in the Asia Minor Steam Ship Co., and then entered the Egyptian Public Works Department, subsequently becoming architectural draughtsman and clerk of works on the building of the Mena House Hotel at the Pyramids, Cairo. On its completion he re-entered the Egyptian Public Works Department in March 1891 as draughtsman, and in the following year he was appointed chief engineer in the Salt Department of the Egyptian Government. In 1899 this Department was handed over to the Egyptian Salt and Soda Co., and he was engaged to be their works manager and consulting engineer. Subsequently the company was amalgamated with an oil and cake factory, and he was appointed works manager at Mex, which position he held until his death. During his service with the Egyptian Government he received from the Khedive the Order of the Medjidieh (4th class), and the Order of the Osmanieh (4th class) on leaving the service in 1899. His death took place at Mex on 10th April 1908, at the age of forty-one. He became an Associate Member of this Institution in 1902.

George Banks Rennie was born in London on 1:
1832. He was the son of the late George Rennie wh
associated with many maritime works, grandson of th
Rennie, and nephew of the late Sir John Rennie,
familiar in the annals of engineering. The career
intended for him was that of a naval officer, and he
Royal Navy as a midshipman in 1844. The at
engineering were however too strong, for in the cour
years he left the Service and joined his father, witl
undertook various works in connection with railway
in Belgium. In 1860 he was commissioned by t
Government to design the first iron floating-dock ever
This work was carried out successfully, the type of do
originated being known by the name of the Rennie fl
The work was undertaken in connection with his
was known as J. and G. Rennie. Their enterprise
scope in the improvement and construction of mari
H.M. Ships "Bacchante," "Calliope," and "Caly
engined by the firm. He took an active part in public
was for many years a member of the Surrey County Counc
also one of the Governors of the Agricultural College at
this Institution he contributed a Paper on the "Pumping
for emptying the Dry Docks at Chatham and at Rio de
and a Report on the North-East Coast Exhibition
Engineering, etc.† His death took place at Denford,
on 15th November 1908, in his seventy-seventh year.
a Member of this Institution in 1859, was elected a
Council in 1878, and served as a Vice-President from 18
He was also a Member of the Institution of Civil En
Institution of Naval Architects, and of the Royal Institu

Allan Renny was born at Arbroath, Forfarshire, on
1866. He was educated at the High School of his nativ

* Proceedings 1874, page 145.

† *Ibid.* 1882, page 472.

in 1882 commenced an apprenticeship of five years with the firm of Messrs. Alexander Shanks and Son, engineers, of Arbroath. During that period he attended technical classes in the evenings. On the completion of his articles he remained for a year with the firm as draughtsman, and then joined, as fourth engineer, one of the British India Steam Navigation Co.'s steamers. Having passed as first class engineer, he joined in 1893 the Tanjong Pagar Dock Co., as shop foreman at the Penang branch, and was promoted to be superintendent in the following year. In 1899 he left the Dock Co. to undertake the erection and supervision of sugar plant in the Malay States, and in 1901 he started business on his own account in Penang as consulting engineer and marine surveyor. Subsequently he joined the service of Mr. Robert Young, *Member*, and was engaged in connection with the construction of the municipal tramways, and a variety of other engineering work. He was surveyor in Penang for the Germanische Lloyd and Bureau Veritas. He took an active part in the affairs of the Engineers' Institute in Penang, of which he was President in 1907. His death took place at Kuala Lumpur, in the Malay States, on 7th April 1908, in his forty-second year. He became a Member of this Institution in 1906.

John Walton Spencer was born at Newburn on 20th June 1843, being the son of the late Mr. John Spencer, of Newburn Steel Works, Newcastle-on-Tyne. All his life he had been identified with these works, from the active management of which he retired in 1905, being chairman of the Company from 1897 until his death. In addition to being a director of several other industrial companies, he took an active interest in local affairs, and was the first representative of the Walbottle Division on the Northumberland County Council. In the early days of the Volunteer movement he identified himself with it, and subsequently attained the rank of major of the battery of the Northumberland Volunteer Artillery. He was elected a Member of this Institution in 1867, and served as a Member of Council from 1902 up to the time of his decease. On the occasion of the Summer Meeting in Newcastle-on-Tyne in 1902, he entertained the Members at the Newburn Works. He was a

Member of the Iron and Steel Institute, and took part regularly in the discussions on those papers dealing with steel manufacture. Latterly he had resided at Droitwich on account of his health. His death took place at Alnmouth on 28th August 1908, at the age of sixty-five.

George Kelson Stothert was born at Bristol on 24th March 1833. He was articled to the firm of Messrs. Stothert, Slaughter and Co., Bristol, of which his father was Principal, and which was subsequently converted into the Avonside Engine Co. In 1854 he entered into partnership with the late Mr. Ernest T. Fripp, as a builder of marine and stationary engines and of ships, under the style of G. K. Stothert and Co., of the Steam Ship Works, Hotwells, Bristol. Some years afterwards Mr. Fripp retired, and Mr. Stothert carried on the business as sole proprietor down to the date of his death. He was one of the pioneers of iron shipbuilding in this country, and during his career constructed a large number of steamships and sailing vessels, the former being fitted with machinery made at the works. It may be of interest to note that one of these early iron vessels, the "Meander," built in 1855, is still in actual service, being registered at Marseilles under the name of the "Orient." In recent years his business, in addition to ship-repairing, has included the construction of the smaller type of coasting steamer, tugboats, etc., and their propelling machinery; also the construction of engines and boilers and general millwright work. Among his inventions may be mentioned a surface condenser without circulating pump, and an improved vertical multitubular boiler. His death took place at his residence at Clifton, on 3rd October 1908, in his seventy-sixth year. He became a Member of this Institution in 1877; he was also a Member of the Institution of Civil Engineers.

Josiah Vavasseur, C.B., was born at Braintree, Essex, in 1834. After receiving a general education, he was apprenticed for six years to the firm of Messrs. James Horn and Co., engineers, Whitechapel. Part of this time was spent in the pattern and model shops, and in the fitting and erecting shops; he was also four years in the drawing-office, during two years of which he was head of the designing department. On completion of his apprenticeship he started a general engineering business on his own account at Southwark, and his first connection with artillery was the designing, in 1861, of a rifling-machine for the rifling of the smooth-bore guns then in use; this was a portable machine, built for transporting to the guns which required grooving. He remained in private practice until 1862, after which, until 1866, he was associated with the Blakely Ordnance Co., which took over his works. He designed and constructed various types of guns and mountings and built-up steel pieces of ordnance, which were supplied in large numbers to several foreign nations. In 1866 he invented the copper rotating ring, or band, for the projectiles of breech-loading guns. On the winding up of the Blakely Ordnance Co., he, in 1867, acquired the premises of the company at Bear Lane, Southwark, and continued the business there in the name of J. Vavasseur and Co., the works being styled the London Ordnance Works. From 1867 to 1883 he was actively engaged in perfecting his system of constructing built-up steel guns, and in carrying out improvements in the construction of gun-mountings. In 1877 he originated the naval hydraulic gun-mounting with which his name is associated, and this soon found favour in the British service by reason of the ease and certainty with which it worked, and it was eventually used in every navy of the world. Orders having become so numerous, he decided in 1883 to merge the whole of his interests with Messrs. Armstrong and Co., of Elswick. Since that date he continued an active director of Sir W. G. Armstrong, Whitworth and Co., until within the last two or three years, when failing health prevented his attendance. He was created a Companion of the Order of the Bath in 1896. His death took place at his country seat at Thetford, on 13th November 1908, at the age of seventy-four. He became a Member of this Institution in 1862; he was a Member of the Institution of Civil Engineers, and an Associate of the Institution of Naval Architects.

WILLIAM WARREN was born at Tetney, Lincolnshire, on 8th March 1843. He served an apprenticeship from 1857 to 1864 in the

Monkwearmouth Engine Works of Mr. George Clark, at S
and on its termination he was engaged as a journeyma
year. In 1865 he went to sea as an engineer, remaini
capacity for fifteen years, when he returned to Mr. Clar
having charge of the outside department from 1881 to 188
latter year he was appointed works manager, and held th
until his death, which took place in Sunderland on 18
1908, at the age of sixty-five. He became a Memb
Institution in 1897.

INDEX.

1908.

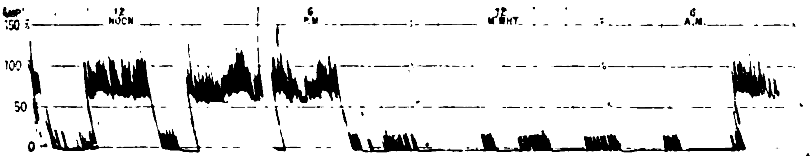
Parts 3–4.

Fig. 5. *Charging Floor of Retort-House.*
Operation of Filling a Retort.

Fig. 6. *Discharging Floor of Retort-House.*
Operation of Filling a Producer Fire.

(Mr. J. Herbert Canning's remarks.)

Fig. 16. *Diagram showing additions to the load upon a Dynamo caused by four periods of driving a Coal Breaker. 16th Jan. 1908.*



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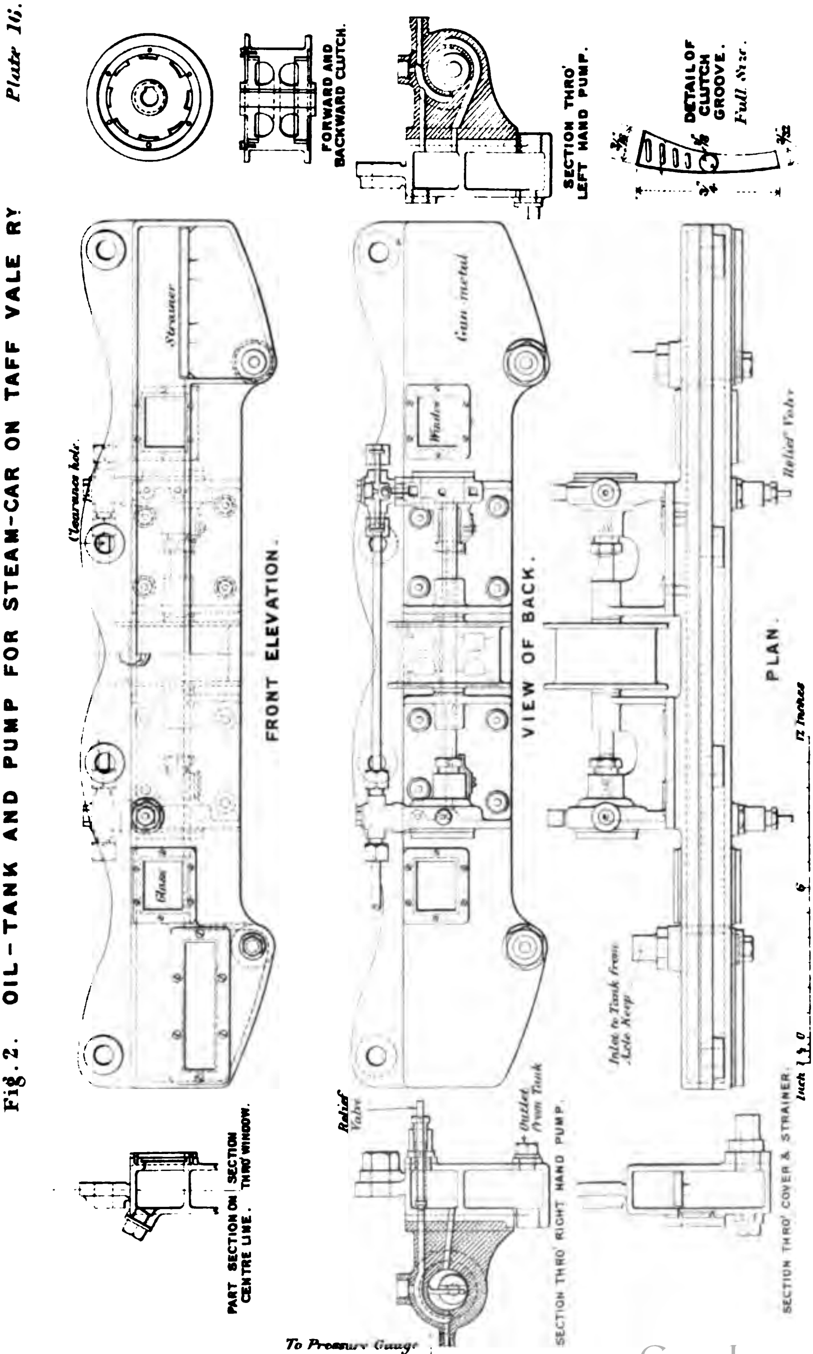

Plate 16.
Fig. 2. OIL-TANK AND PUMP FOR STEAM-CAR ON TAFF VALE RY.
FORWARD AND BACKWARD CLUTCH.
SECTION THRO' LEFT HAND PUMP.
DETAIL OF CLUTCH GROOVE. Full Size.
Strainer
Clearance hole
Glass
FRONT ELEVATION.
Gun metal
Washer
VIEW OF BACK.
Relief Valve
Inlet to Tank from Axle Keep
PLAN.
Inch 1 ½ 0 6 12 Inches
PART SECTION ON CENTRE LINE.
SECTION THRO' WINDOW.
Relief Valve
Outlet from Tank
SECTION THRO' RIGHT HAND PUMP.
SECTION THRO' COVER & STRAINER.
To Pressure Gauge

Plate 17.

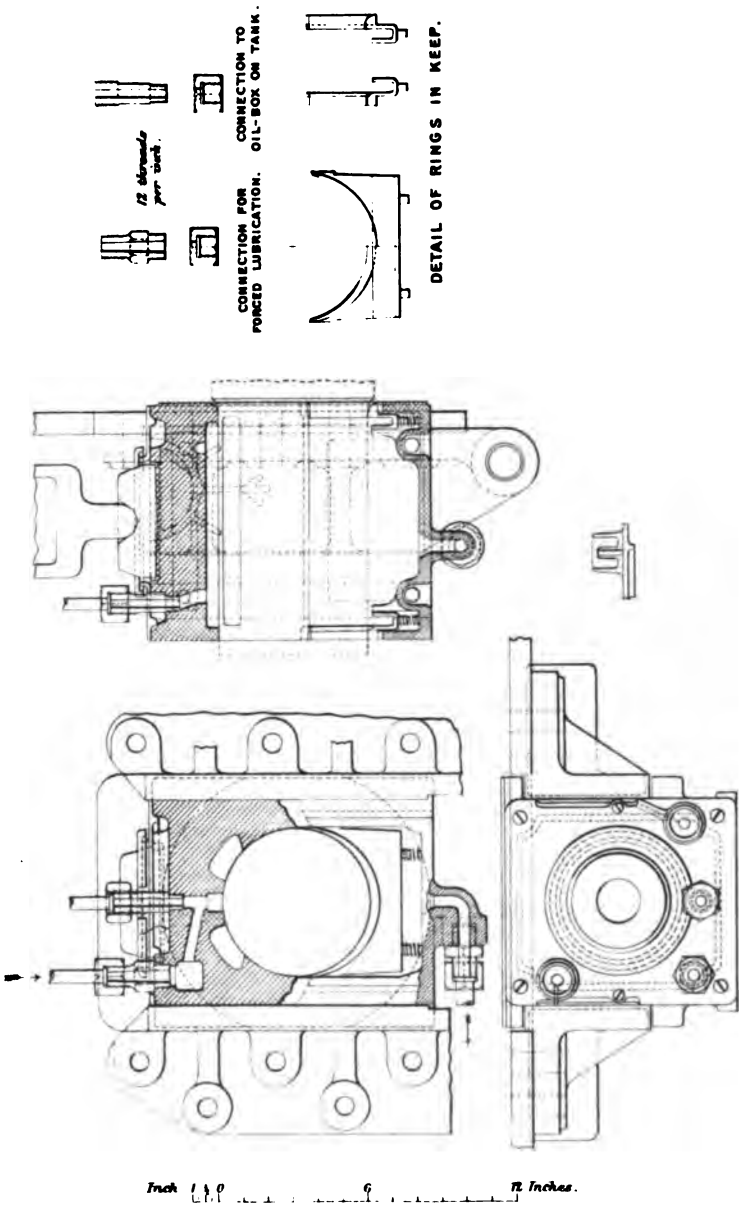

Fig. 3. DRIVING AXLE-BOX AND KEEP FOR STEAM-CAR ON TAFF VALE RY.

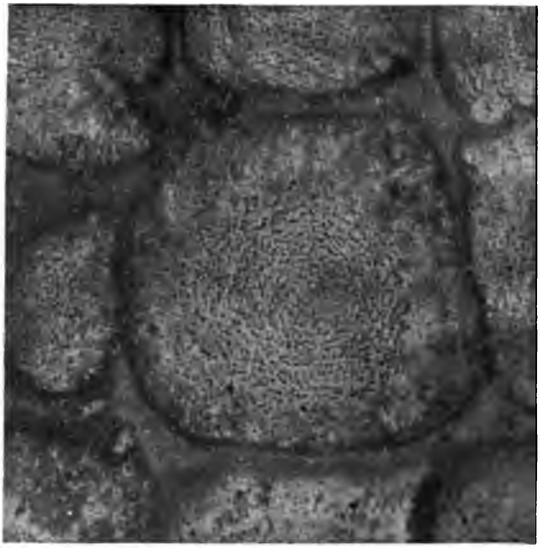

Fig. 1.
Cathode Surface, lead coated with copper, showing effect of impingement of jets of electrolyte.

Fig. 2. ***Copper Cone to determine critical speed.***

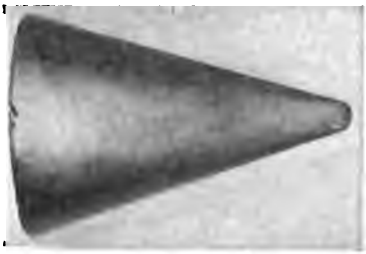

Fig. 3. ***Vat used for Centrifugal Process.***

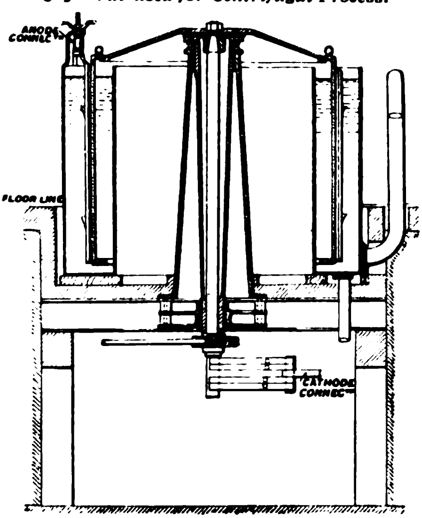

Fig. 8. ***Apparatus for depositing Copper on Iron Rolls.***

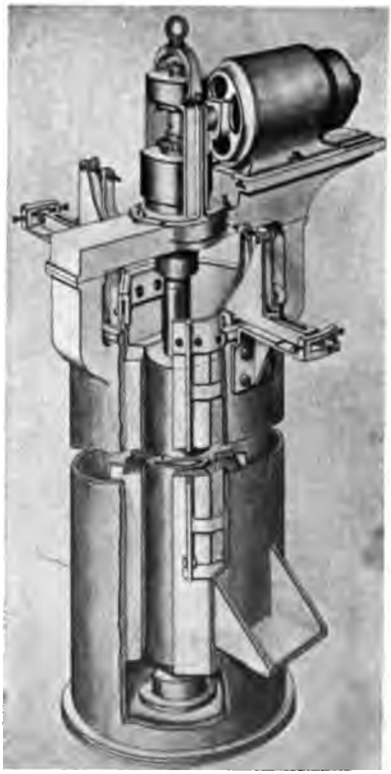

Fig. 10. *Radial Crystalline Structure of Copper Nodules.*

Fig. 11. *Crystalline Structure of Deposited Copper.*

Fig. 12. *Copper Trees, effect of Free Acid on Nodule Formation.*

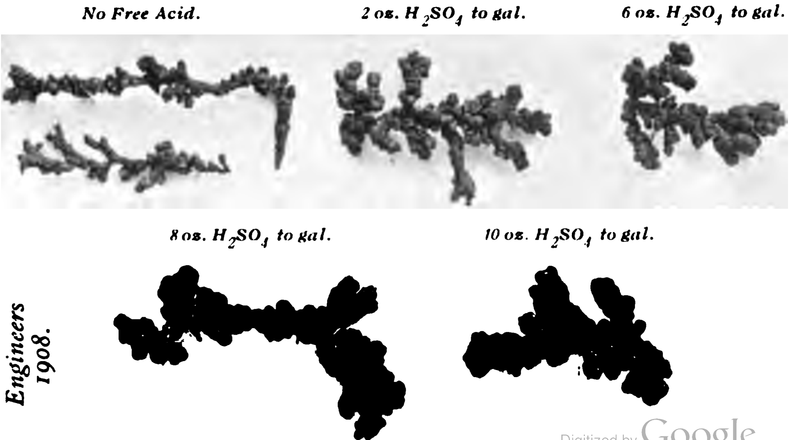

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Fig. 13. ***Atomiser.***

Fig. 14. ***Filter.***

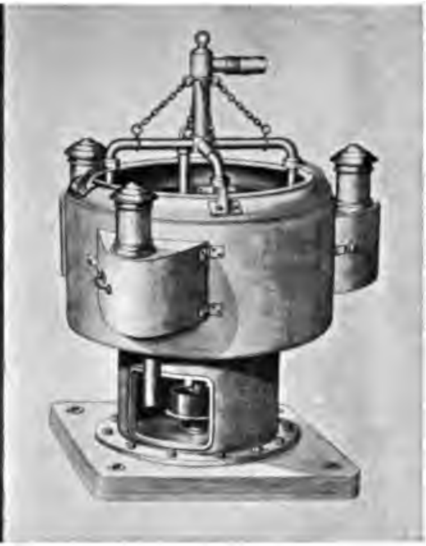
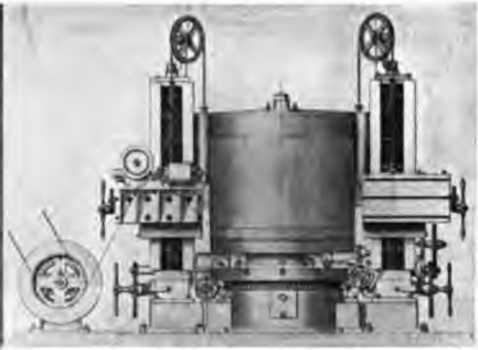


Fig. 17. ***General Arrangement.***

Fig. 18. ***Lathe for Unwinding Copper Strip.***



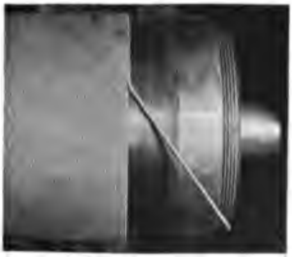
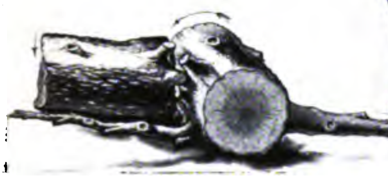


Fig. 19. *Mandrel, showing method of unwinding copper strip.*

Fig. 20. *Section of Copper Strip, showing cause of cleavage.*

Historical Examples.

Fig. 1.
Suggested Origin.



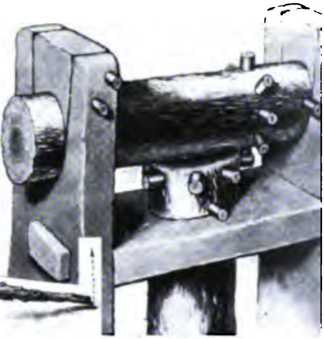


Fig. 3. *Wind-mill with Wooden Gear.*

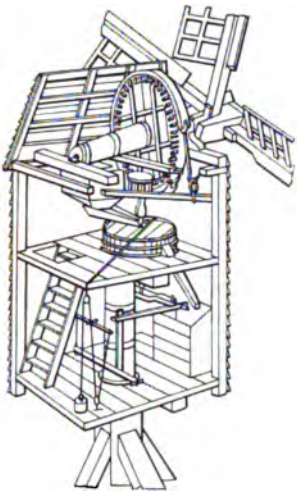


Fig. 4. *Old Water-*

Fig. 5. *Hard wood Wheel and Pinion.*

Fig. 6. *Water-Clock,*

Figs. 7 and 8. *18th Century Wheel-Cutting Machines for Clockmakers.*

Fig. 9. *Wheels with Machine cut Teeth.* (Bodmer.) 1820-30.

Fig. 10. *Wheel-Cutting Machine.* About 1824-34.

Fig. 11. *Wheel-Cutting Machine.* (Whitworth.) 1834-44.

Fig. 12. *Cutter.* (Bodmer.)

Fig. 13. *Wheel-Cutting Machine.* (*Whitworth.*)

Fig. 15. *Machine for Cutting Wheels.* (*Shepherd, Hill & Spink.*) *1851.*

Fig. 16. *Gear-Wheel Moulding Machine.* (*Jackson.*) *1854.*

Fig. 14. *Forming-Machine for Milling Cutters.*

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Fig. 19. *Wheel-Cutting Machine. Paris Exhibition, 1867.*

Fig. 20. *Cutter and Wheel. Teeth backed off on a Slotter or Shaper.*

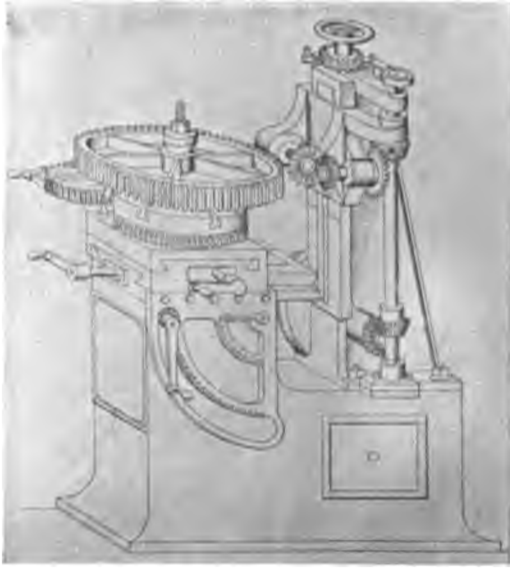


Fig. 21. *Spur-Gear Planing Machine. (Gleason.)*

Fig. 22. *Gear-Hobbing Machine.*
(Juenpt.) 1893.

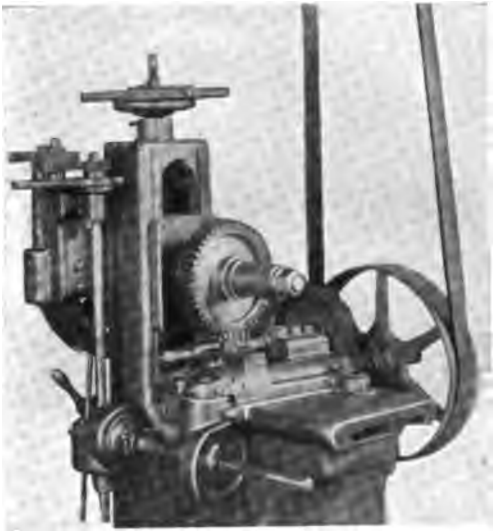


Fig. 23. *Gear-Hobbing Machine.*
(Pfauter.)

Fig. 24. *Gear-Hobbing Machine.* (*Holroyd.*)

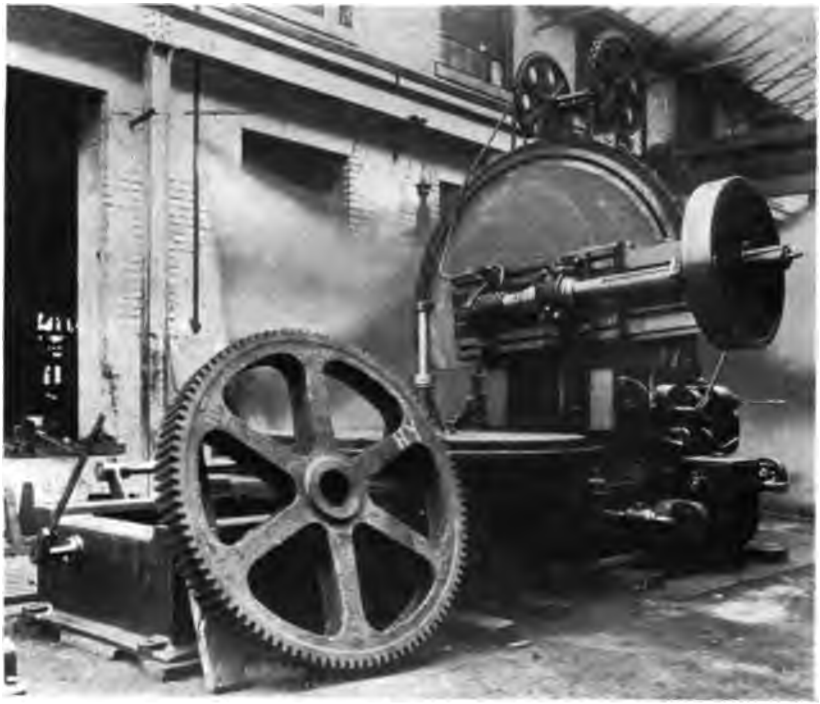
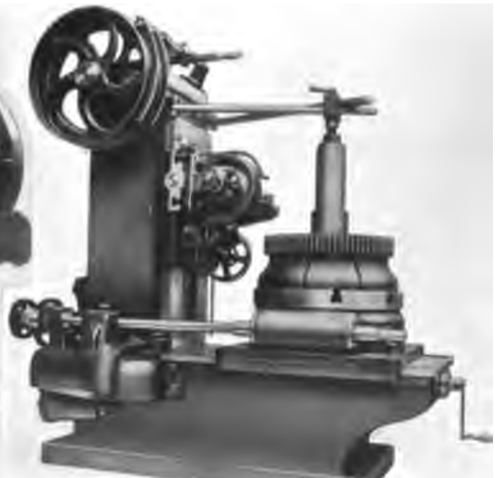


Fig. 25. *Gear-Hobbing Machine.* (*Reinecker.*) *1894.*

Fig. 26. *32-inch Gear-Hobbing Machine.* (*See next Plate.*) (*Humpage, Thompson and Hardy.*)



32-inch Gear-Hobbing Machine, Fig. 26.
Fig. 27. *Speed-Gear and Details.*

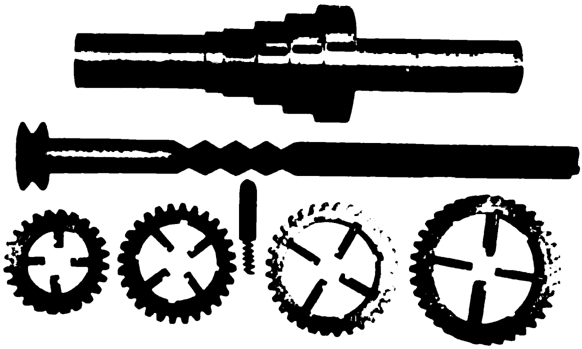


Fig. 29. *Feed-Gear.*

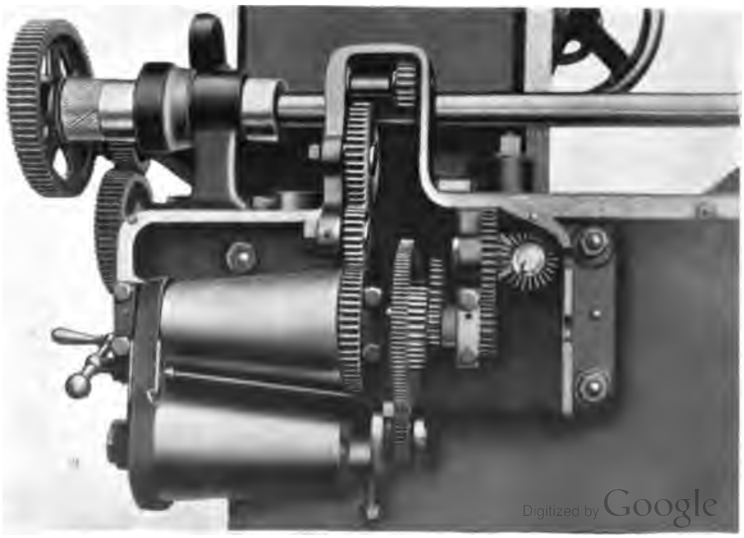
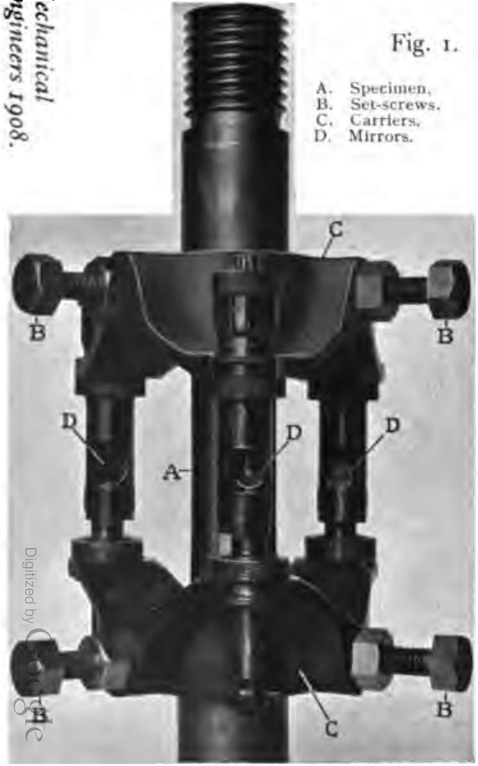


Fig. 1. *Sphingometer.*

A. Specimen.
B. Set-screws.
C. Carriers.
D. Mirrors.



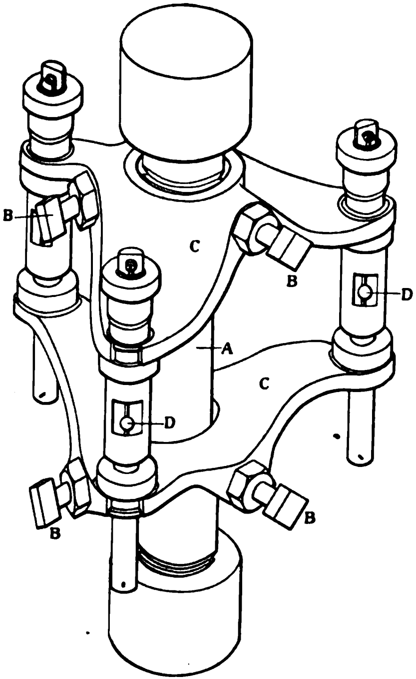
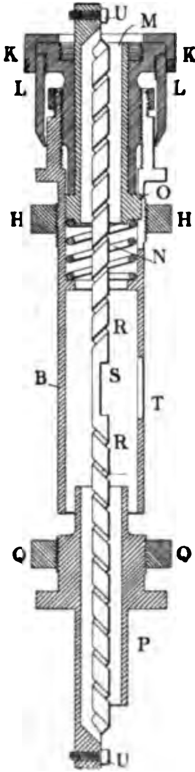


Fig. 2. *Sphingometer Twisted-Strip and Case.*



B. Outer casing fastened to upper clamp by
H. A locking ring.
K. Micrometer.
L. Clamping ring.
M. Tube, maintained in contact with micrometer by
N. A spring.
O. Feather Key to prevent M rotating.
P. Hollow casting fastened to lower clamp by
Q. A locking ring.
R. Twisted phosphor-bronze strip.
S. Mirror holder.
T. Aperture in outer casing.
U. Fastening screws.

Fig. 14. *After 8,400 Blows.*

Fig. 17. *After 5,000 Blows.*

Fig. 15. *After 12,000 Blows.*

Fig. 18. *After 19,000 Blows.*

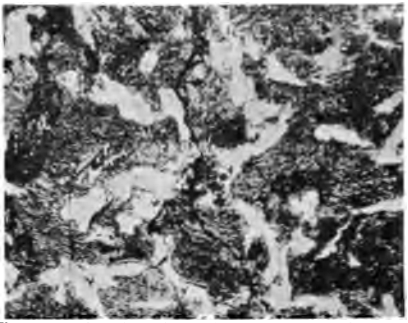


Fig. 16. *After 29,000 Blows.*

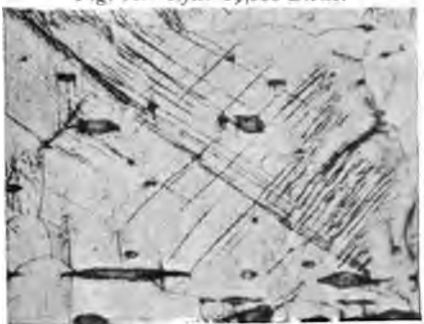


Fig. 19. *Swedish Iron, Fractured at 1 Blow.*

Fig. 20. *Mild Steel (0·20 % C) after 50,000 Blows.*

Figs. 14, 15 and 16.
Swedish Iron, heated to 1,000°C. (1,832° F.) and slowly cooled.

Figs. 17 *and* 18.
0·6 % Carbon Steel, heated to 1,000°C. and slowly cooled.

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Magnification.
Figs. 14 *to* 18.
= *100 diams.*

Fig. 19.
= *33 diams.*

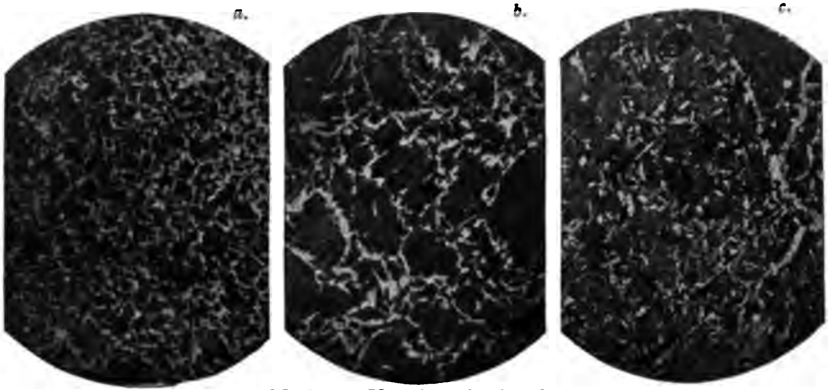
Fig. 20.
= *3 diams.*

IMPACT TESTING.

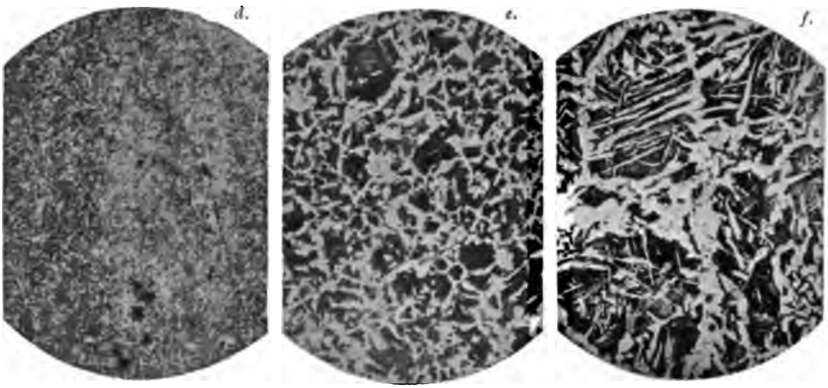
(Mr. Alexander Jude's remarks.)

Hard Mild-Steel.

Three Fine Grain. *Two Medium Grain.* *Three Coarse Grain.*



Medium Hard Mild-Steel.



Medium Soft Mild-Steel.

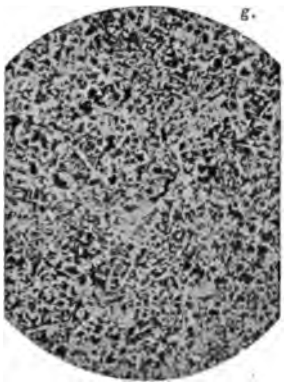


Fig. 36.

Examples of the Relation between Size of Grain and Mechanical Properties. × 23 *diams.*

	a.	b.	c.	d.	e.	f.	g.	h.
Ult. Tensile Strength, Tons.	40.1	39.4	40.84	35.5	37.5	36.1	34.9	33.6
Elongation in 2 in., % ...	28	25	Broke Short	32.5	29.5	30.5	34	34
Reduction in area, % ...	40	36		46.8	38	43.5	47	46
Tenside	0	3		0	2	6	0	3
Izod Impact (relative only)..	5.5	4.5	1.1	6.5	3.8	2.15	6.9	1.6

Mechanical Engineers 1908.

(Mr. Bertram Blount's remarks.)

Fig. 38. *Sankey-Hurry-Blount Shock-Test Machine. Height 9 Feet.*

(Dr. Stanton's opening remarks.)

Fig. 37. *Impact Tests on Specimens cut from a Fractured Crank-Shaft (Table 19).*

Untreated Specimen. *Restored Specimen.*

(Mons. Pierre Breuil's communication.)

Fig. 39. *Tensile Tests, made with various Steels.*

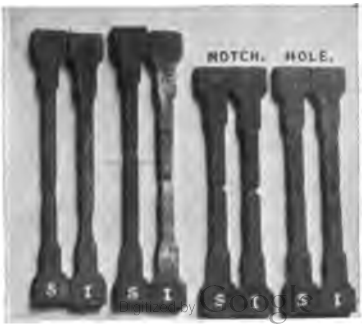
(S) *Slow or ordinary Tensile Test.* (I) *Impact or Tensile Test by means of Shock.*

Phosphoric Iron.

Hard Steel.

Very Mild Steel.

Mild Steel.



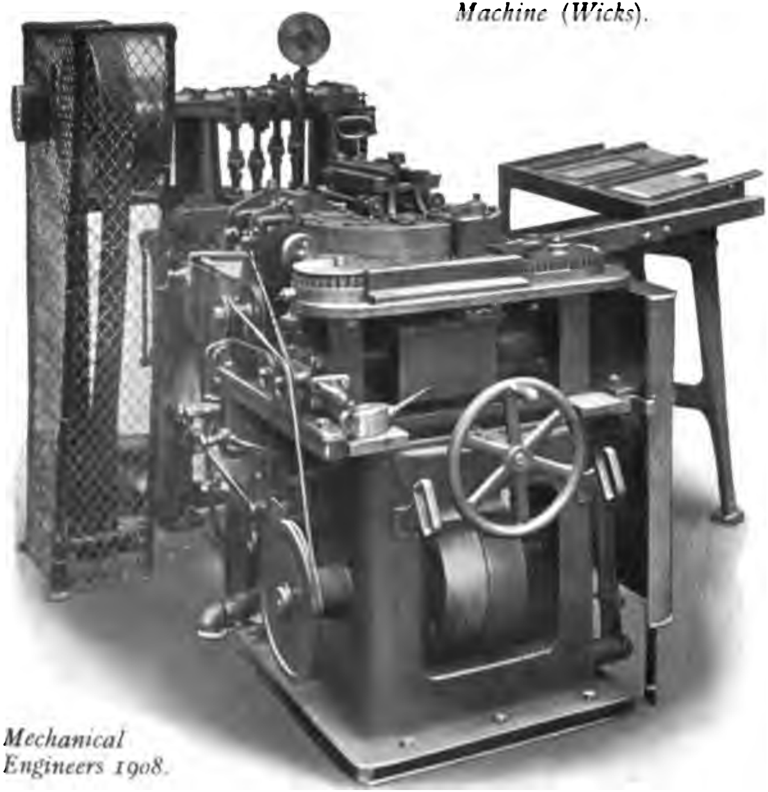


Fig. 47. ***Rotary Typecasting Machine*** *(Wicks).*

Mechanical Engineers 1908.

Fig. 55. *Type Composing Machine (Wicks), with Automatic Line-justifier (Stringer).*

Fig. 64. *Distributing Machine (Pulsometer).*

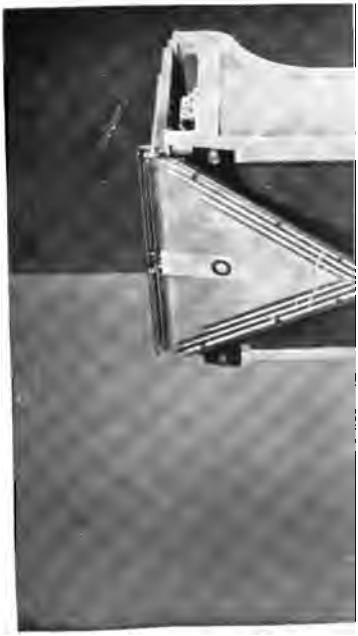
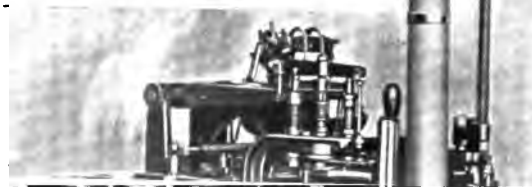


Fig. 59. *Composing Machine (Pulsometer).*

Fig. 71.

Casting and Setting Machine
(Lanston Monotype).



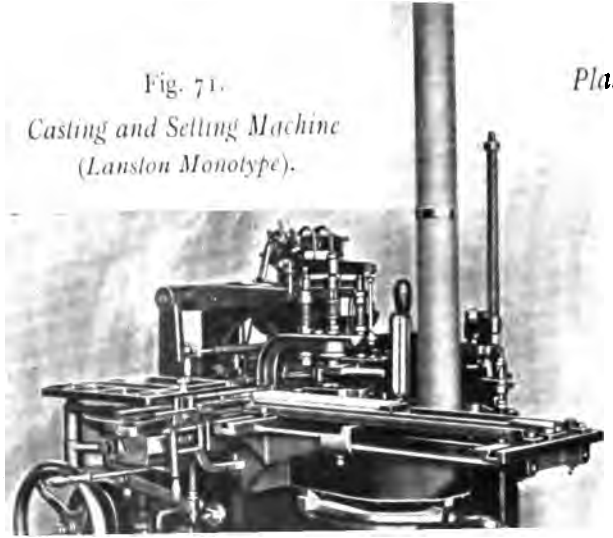
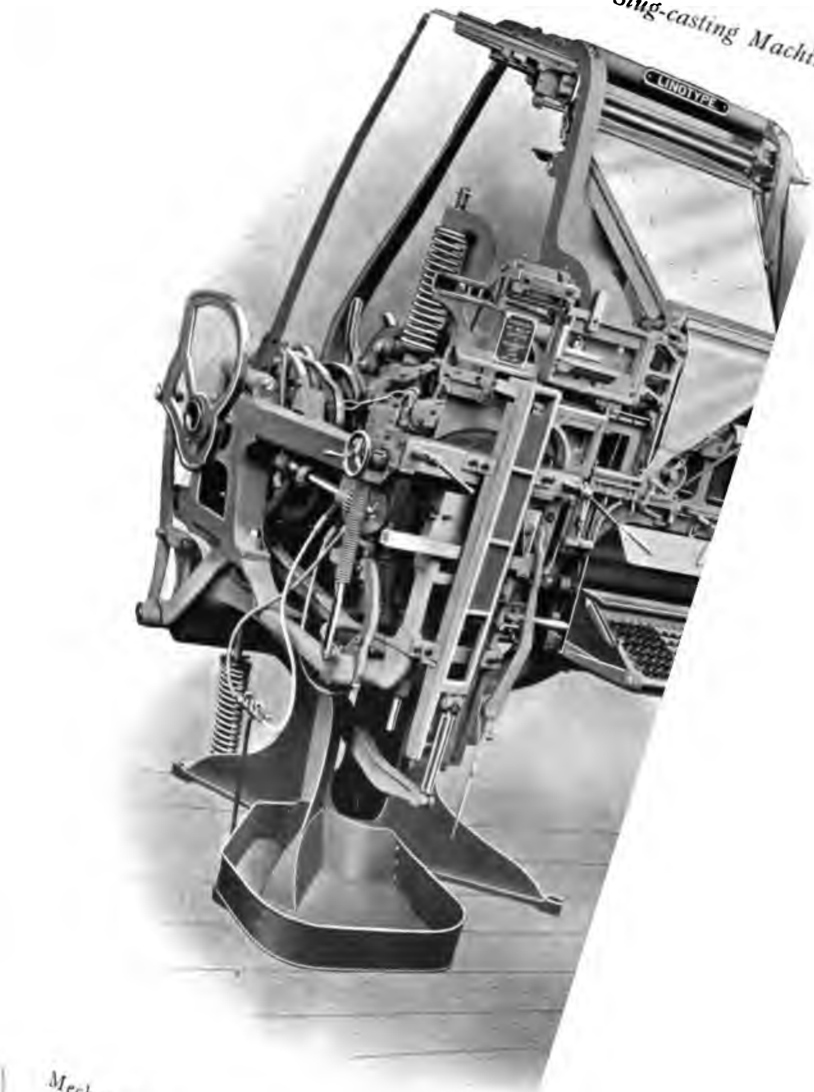


Fig. 71.
Casting and Setting Machine
(Lanston Monotype).

Mechanical Engineers 1908.

Fig. 77.

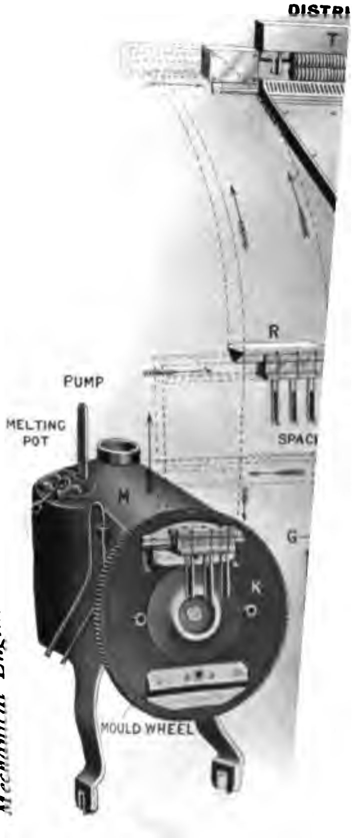
Matrix Composing and Slug-casting Machine (



Mechanical Engineers 1908.

ready for casting the slug.

(L



Mechanical Engineers 1908.

(*Linotype*).

Fig. 89. *Matrix Composing a*

Mechanical Engineers 1908.

Fig. 92.

Matrix Composing, Line-justifying, and Typecasting Machine

(Stringertype).

Fig. 93. *The Lock-up Test for Accuracy of Type.*

Fig. 1234567890.

THE LOCK-UP TEST FOR ACCURACY OF TYPE.

TYPE CASTING AND COMPOSING MACHINERY. The Institution of Mechanical Engineers, London, 1907.
TYPE CASTING AND COMPOSING MACHINERY. The Institution of Mechanical Engineers, London, 1907.
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TYPE CASTING AND COMPOSING MACHINERY. The Institution of Mechanical Engineers, London, 1907.

Typecasting and Setting Machine (Pinel Dyotype).

Fig. 98. *Matrix-wheel.*

Fig. 100. *Perforated Strip. Half size.*

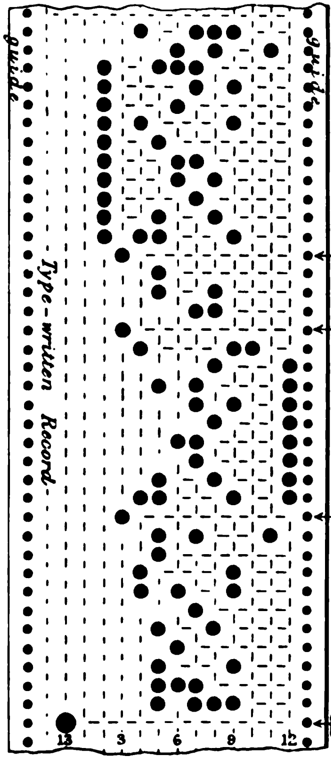


Fig. 101. *First Machine.*

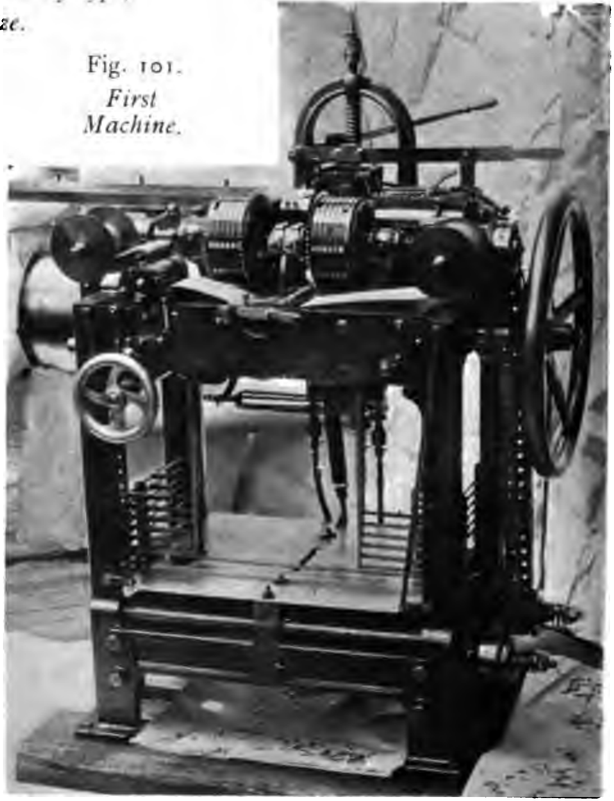


Fig. 97. *Single Matrix, For 50 divisions. Full size.*

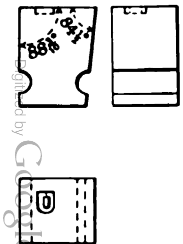
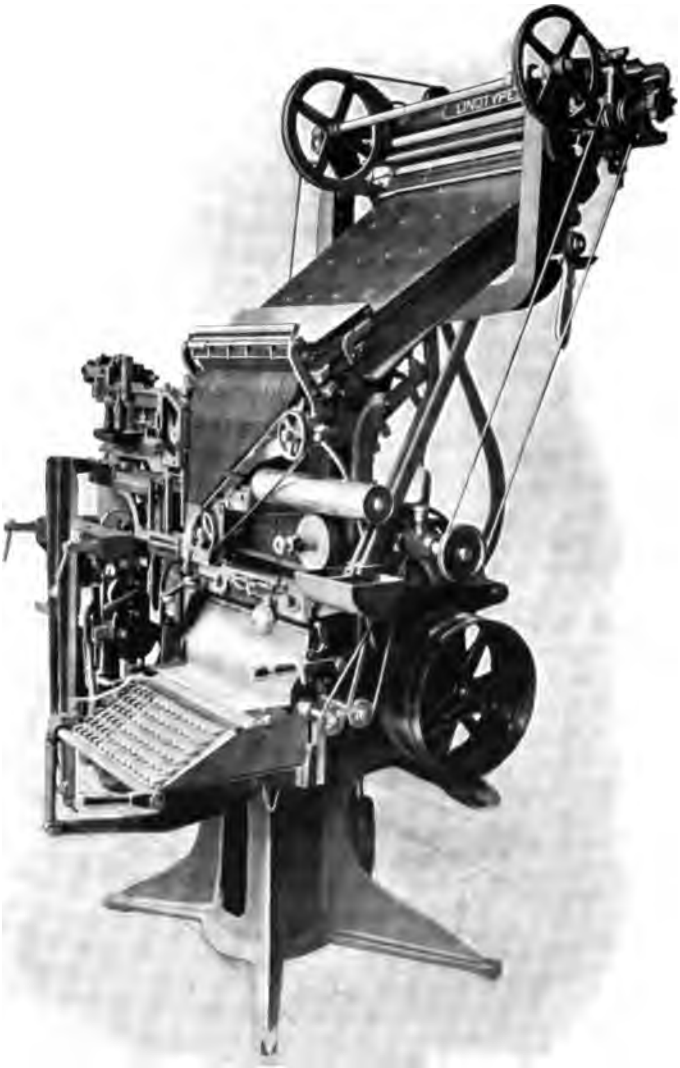


Fig. 102. *Double Magazine*

Matrix Composing and Slug-casting Machine

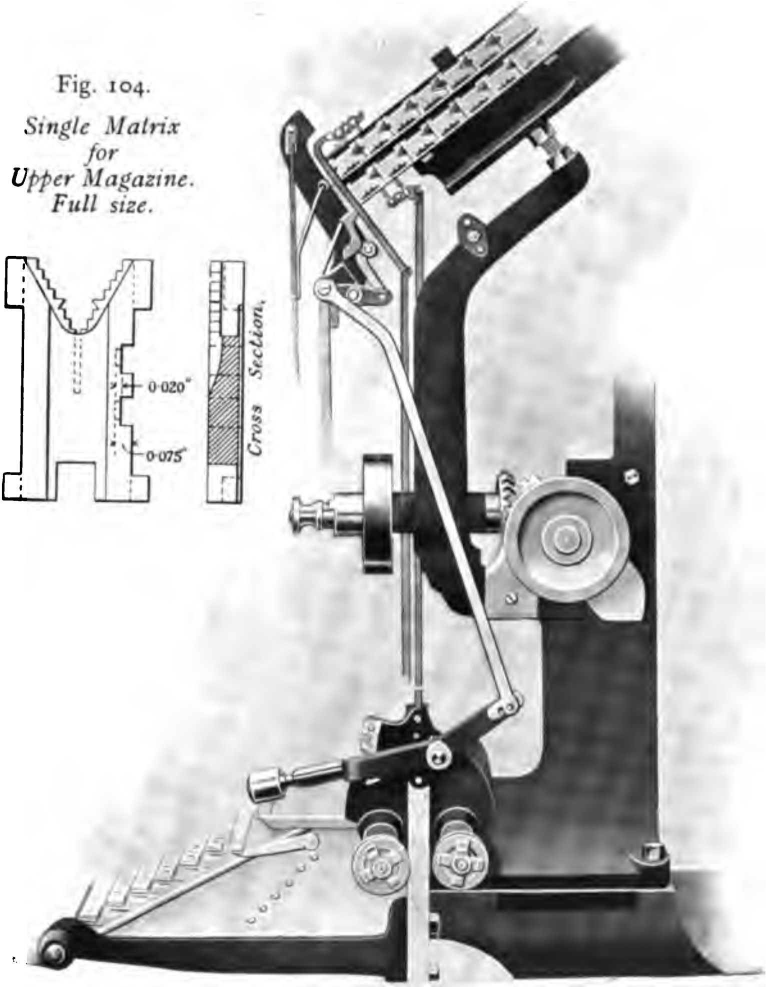
(Linotype).



Double Magazine
Matrix Composing and Slug-casting Machine
(Linotype).

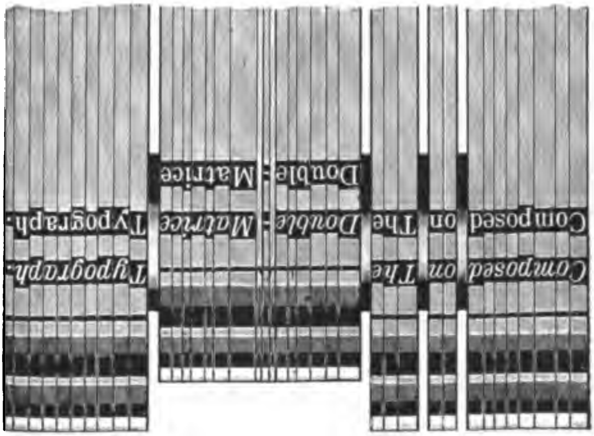
Fig. 103. *Arrangement of Escapements and Shift Key.*

Fig. 104.
Single Matrix
for
Upper Magazine.
Full size.



showing upper portion
tilted back.

Fig. 107. *Line of Two-letter Matrices Composed and Line-justified.*



Mechanical Engineers 1908.

Figs. 119—122. *Assembly Channel of Matrix Composing and Slug-casting Machine (Typograph).*

Fig. 119. *Assembly Channel Empty.*

Fig. 120. *Assembly Channel filled with line of Two-letter Matrices.*

(Continued on Plate 45).

Matrix Composing and Slug-casting Machine
(Typograph).
(*Continued from Plate* 44).

Fig. 121. *Vice-jaw closed but Line not yet justified.*

Fig. 122. *Line-justified ready for Casting.*

(Mr. Albert Pidgen's communication.)

Fig. 127.
Unitype
Type distributing,
Composing,
and Line-justifying
Machine
(Thorne).

Fig. 128.
Thorne Machine.