The Mining Electrical Engineer.

OFFICIAL JOURNAL OF THE ASSOCIATION OF MINING ELECTRICAL ENGINEERS.

EDITED BY E. DINSDALE PHILLIPS.

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Our Larger Page.

We were more than pleased to receive many letters of appreciation following the announcement that this Journal was to be brought into conformity with the agreed standard size of page for technical publications. It is the little word of acknowledgment which encourages the greater effort. Beginning with the next issue the size of our pages will be enlarged to give a printed page area of 10 inches by 7 inches. The advertising man will welcome the extra room given him for the exercise of his talents in artistic and forceful display and for the elaboration of his selling story in text: the reader too will find the improved and larger style more comfortable in perusal.

With the July number the "M.E.E." enters its eleventh volume. It is still quite a juvenile, so far as technical publications go, and perhaps that may be counted as one of the reasons why it has been so ready to adopt this progressive move —even though it does involve a distinct departure from its established custom and standard, and though it means considerable initial expense. It is the old custom that dies hard. Some of our venerable respected contemporaries would probably flout the very suggestion that they should break the book-shelf level of their stolid ranks of volumes built up by and effectively serving past and nearly forgotten generations of engineers. Even we, who are but young in building a permanent record of engineering in one of its modern special phases, cannot help but confess to a twinge of regret at forsaking the familiar form of the M.E.E. in its earliest years. To those readers, and we trust they are but few, who do not take quite kindly to the idea of a rising step in the grey row of bound volumes: to them we would gently plead that we could hardly preach the policy of economy and turn aside from an obvious method of avoiding waste. Which, after all and without sentiment, is the primary great reason for the change, and which was fully explained in this column last month.

The July Number.

Not only will the next number of this Journal mark the introduction of a continuing new standard in its general form and appearance, but that particular issue will be largely of a special character. It will contain a full account of the happenings at the A.M.E.E. Annual Convention. The arrangements for the four days' meeting in London have all been excellently planned to meet the conditions for success in such an affair: the programme is full and diverse; it is designed to add much to the visitors' engineering experience and to kindle still greater interest in the work of the Association—which useful objects are to be attained in pleasant circumstance and place. By means of picture and story we hope to give those members who have not been able to attend an interesting and useful account of the proceedings: for those who were present the printed record will be a permanent means of recalling to them the lessons and pleasures of a notable gathering. As usual, we expect to be able to include also an art portrait plate of the new President of the Association. Another supplement to the July number will be the Index, Contents and Title Page of the concluded Volume Ten.

A.M.E.E. Progress.

The end of a volume of the "M.E.E." and the coincident occurrence of the A.M.E.E. Convention are as the dawn of a new year to the members of the Association. It is now that the older members cast a backward look and survey the past years in comparison with the new secretarial reports and auditors' figures just to hand. All members indulge in pondering the future. We do not know what the official reports of the past year will show, nor would we attempt to hazard any guess—but, to our mind the Proceedings of the Association as recorded in these pages during the last twelve months clearly indicate a firm tenacity of purpose and thorough maintenance of enthusiasm on the part of members. The past session was marked by an exceptionally good series of papers. Many of them were original in the way the authors approached their subjects and tackled their problems. In particular, the papers showed that the authors were fully alive to those vital engineering questions, which being outside those pertaining to the actual getting of coal are yet closely relevant to the production of still cheaper fuel and the still closer conservation of the useful fuel contents. The progression of new technical points constantly arising in connection with and as the outcome of the spreading of the grid are closely followed and understood; all phases of generation, transmission and distribution find place in these papers; mechanical gears, illumination, raw materials—in short and in effect the mining electrical engineer as represented by the members of the Association is rapidly strengthening his claim to be recognised as a real engineer in the full and correct meaning of the term. That fact surely is established by the papers and discussions of the past Session.

Then again, the "special" work of Committees and Council in regard to official matters such as standardisation, certificates of competency, rules and regulations, safety and research, and in other directions has from time to time and regularly during the past year received well-deserved commendation.

So it would appear that the new A.M.E.E. year is full of promise of great strides towards attaining the well known objects for the gaining of which the Association was established and which year by year it pursues with ever increasing success. The success of the A.M.E.E. is ours: we too look forward to being enabled to give increasingly greater values and services.

NEW BOOKS.

H.M. STATIONERY OFFICE.

The following, printed and published by His Majesty's Stationery Office, can be purchased through any bookseller or directly from H.M. Stationery Office at the following addresses: Adastral House, Kingsway, London, W.C.; 1 York Street, Manchester; 1 St. Andrew's Crescent, Cardiff; 120 George Street, Edinburgh; or 15 Donegall Square, W., Belfast.

Mines Department—REGULATIONS AND ORDERS RELATING TO MINES under the Coal Mines Act, 1911. 1929 Edition, including Orders up to 11th February, 1930. Price 1s. nett.

This book contains all the orders (including Regulations) of a general nature relating to mines under the Coal Mines Acts which were in force on 1st January, 1930, and its publication has been slightly delayed in order that it may include also the new General Regulations in regard to First Aid, which came into force on 1st April, 1930.

In this edition, further improvements have been made in re-arrangement of the matter under subject groups, with the object of enhancing its utility as a book of reference for mine managers and others. The book also contains reference lists of Permitted Explosives, approved types of Safety Lamps, Safety Lamp Glasses and Breathing Apparatus, and memoranda on the Official Tests of Safety Lamps, Explosives and Rescue Apparatus. A list of recent Parliamentary and other Official Publications relating to the Coal Mining Industry is printed in an appendix.

EXPLOSIVES IN COAL MINES ORDER of the 15th April, 1930. Price 11d. nett.

In April, 1929, there was issued a report by the Explosives in Mines Research Committee on "The Testing of Explosives for use in Fiery Coal Mines." In that report the Committee formulated a revised test designed to give greater regularity in its results than the test formerly carried out at Rotherham, and thus to afford better means of controlling the uniformity of Permitted Explosives while maintaining an ample margin of safety.

The Secretary for Mines adopted the Committee's recommendations, and since August, 1929, a large number of explosives have been tested in the official testing gallery at Buxton, including both new compositions and explosives already on the Permitted List which the manufacturers desired to submit for the revised test.

On 15th April, 1930, the Secretary for Mines made the Order under Section 61 of the Coal Mines Act, 1911, (here published) amending the First Schedule to the Explosives in Coal Mines Order of the 1st September, 1913, relating to "Permitted" Explosives.

FLAME-PROOF AIR-BREAK SWITCHES, WITH OR WITHOUT FUSES: and

FLAME-PROOF AIR-BREAK CIRCUIT BREAKERS, are two new British Standard Specifications which have just been issued and which are respectively No. 126 and No. 127. British Engineering Standards Association, 28 Victoria Street, Westminster, London, S.W. 1. Price 2s. 2d. each, post free.

These Specifications, which are suitable for use with a.c. and d.c. voltages, not exceeding 660 volts, have been reviewed by the Colliery Committees of the Association with a view to making them suitable for the latest requirements of the coal mining industry in this country. Provisions are included dealing with design, construction, rating, sizes and marking. The question of tests is fully dealt with, type tests being laid down for mechanical strength, breaking capacity, flame-proofness and temperature rise, while special dielectric and performance tests are also incorporated.

A useful addition has been made to the Specifications by the inclusion, in the form of an Appendix, of some notes on the Problems of Flame-proof Enclosure, which have been based upon the Reports of the Safety in Mines Research Board, and which are inserted for the information and guidance of purchasers and users rather than for the instruction of manufacturers.

ELECTRIC MOTORS AND GENERATORS FOR MINES: (Specification No. 270) and MINERS' HAND LAMP BULBS (Specification No. 377) are also recent issues of The British Engineering Standards Association which are of first interest to mining electrical engineers. They too are published at the price of 2s. 2d. each, post free.

NEW BRUNSWICK: Its Natural Resources and Development: by L. O. Thomas, B.Sc. Published by the Department of the Interior, Canada.

This is an attractively arranged 166 page publication containing 33 photographs, 10 sketch maps, and a general map in colour, which gives valuable detailed information about the natural resources of the province of New Brunswick and the opportunities thereby presented for an industrial activity very much greater than has hitherto been attained in that maritime country. The contents are divided into distinct sections such as Farming, Furs, Forests, Fisheries, Waterpower Production and Manufacturing etc.

Of particular interest to readers of this Journal will be the 31 page section relating to minerals. This includes a brief sketch, with map, of the geologic formation of the province, and a second map, with table, showing the mineral occurrences and their stage of development, concerning which details are given in the text.

Copies of the book can be obtained from the Director, Natural Resources Intelligence Service, Department of the Interior, Ottawa, Canada.

Central Scotland Electricity Scheme. Crossing at Kincardine: A 3050 Feet Span.

JAMES R. LAIRD.

BEING located near where the grid O.H. line crosses the River Forth from Higginsneuk to Kincardine and the work being both difficult and interesting, the author will describe in detail the process of the crossing. Boring revealed that on the south side the depth from the surface to the rock head was about 70 feet. This necessitated a unique form of piling. The illustrations Figs. 1, 2, and 3 are views of the pile driver consisting of a lattice tower about 90 feet high on one side of which guides were fixed throughout its entire height. The guides were arranged to accommodate the steam hammer which consisted of a fixed piston rod the cylinder being the hammer and was double acting. The cylinder and piston could move from top to bottom of the guides, steam being carried in a flexible hose.

Fig. 1.

The piler or pile shell consisted of a steel tube about 18 inches in diameter and about 2 inches thick. It was open at the bottom, and the top was fitted with a solid flange to take the blow of the hammer and about 18 inches from the top a branch was provided, angled upwards to facilitate the flow of concrete from the concrete mixer down the interior of the pile shell.

When the piling machine was in position, a cast iron shoe or shod was fitted to the bottom end of the pile shell. Fig. No. 5 shews the entry of the shod into the ground. The hammer was then put into service and drove the pile shell down into the ground at a fair speed. The ground was so soft that the pile shell would go down several feet by its own weight. The top of the pile shell was engaged with guides to preserve the plumb of the pile. An hour was usually sufficient to drive the pile home to the rock head, this being indicated by the solid sound and the pile shell refusing to go down further, Fig. 6.

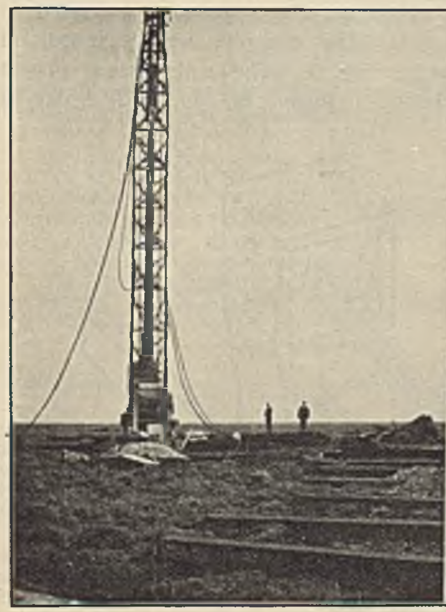


Fig. 2.

Fig. 3.

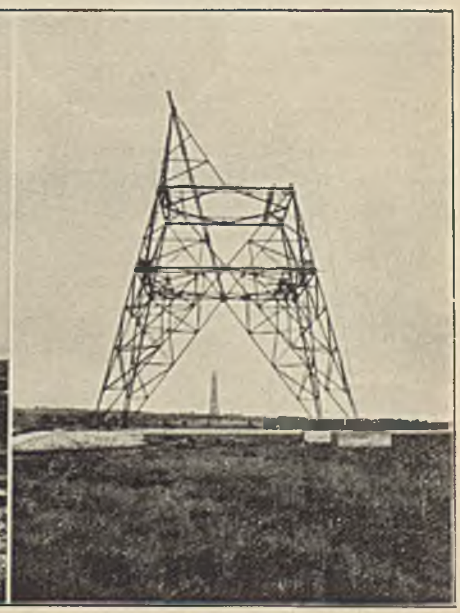


Fig. 4.


Fig. 5.

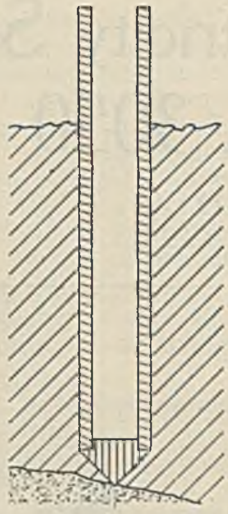


Fig. 6.


Fig. 7.


Fig. 8.


Fig. 9.

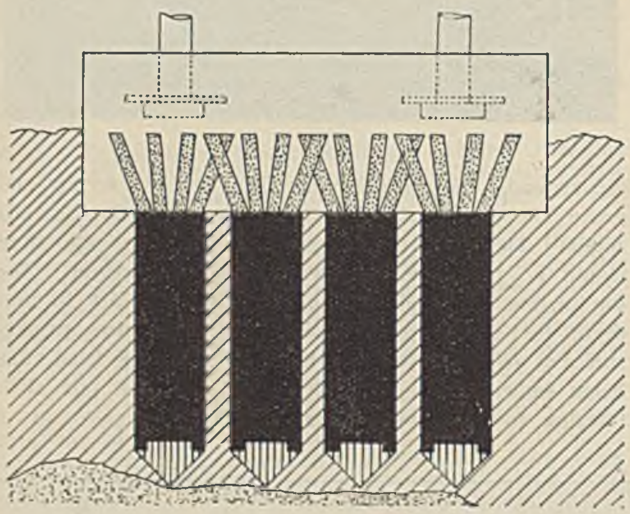


Fig. 10.

The hammer was then winched to the top of the tower to clear room for the introduction of the iron mesh. These were assembled ready and consisted of (See Fig. 7) a spiral of about $\frac{3}{8}$ in. round steel braced all its length by $\frac{7}{8}$ in. diameter rods, the spiral being fixed to the rods. The blank flange was removed from the top of the pile shell and the spiral assembly was let down inside the pile shell. Rapid setting cement was then fed in from the cement mixer until the pile was formed. The hammer was then lowered and by an arrangement of lugs and links, the hammer tamped the pile shell upwards, leaving the concrete pile and leaving a two-inch annular space round the pile, Fig. 8. The soil rapidly closed round this, and left the pile so far finished.

Twelve similar piles were formed in each butt and the pile driver was removed to the next butt position. The soil round the twelve piles was now excavated to a depth of 10 feet. The concrete was stripped off the spiral and rods, Fig. 9. The rods were splayed out into the shape of a funnel or fan, and a plat of

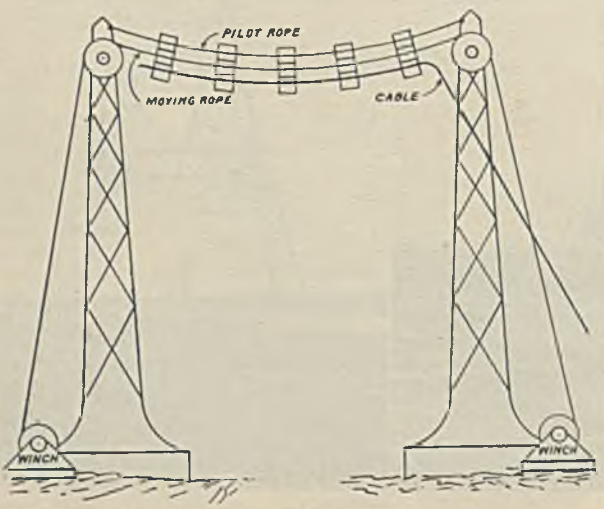


Fig. 11.

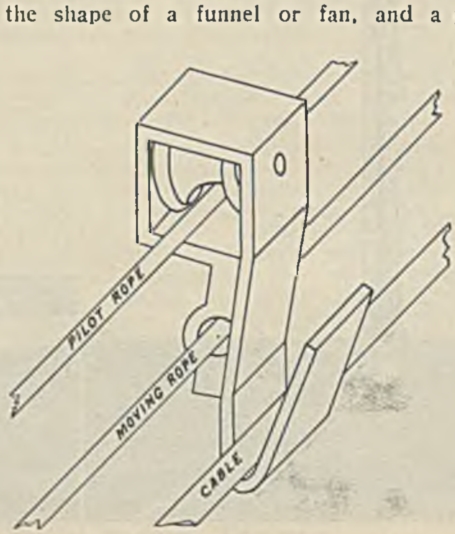


Fig. 12.

concrete (with boxes for foundation bolts mounted on a template) was then formed, finishing six feet or so above ground level, Fig. 10. In each butt there would be about 200 tons of concrete.

When the butts were finished, the towers were erected, as shewn in the illustrations, Figs. 4, 13, and 14. The rock occurred about 15 feet below ground level on the north side so that no piling was required. Behind each high tower, which is 340 feet high, and containing about 160 tons of steel, a stumpy stay or anchor tower was provided, to make off the ends of the special cable crossing the river and also the lines going from each end of the tower span to Bonnybridge and Dunfermline respectively, Fig. 14.

The method of taking the cable over is worth describing. A petrol-driven winch was provided at each tower to facilitate erection. The sequence of the crossing was as follows (see Fig. 11). A pilot wire was stretched and fixed between the towers as near the top of the tower as consistent with the necessary stability. A wire rope was then taken from the winch on the north side over pulleys to the top of the tower across the river to the tower on the south side down the tower to the winch on the south side. These ropes were ferried over the river so that there were now a fixed rope and a moving rope. A number of rider clips were provided (Fig. 12) which rode on the stationary rope by a bridled pulley and was clamped to the moving rope: the cable resting in a Vee guide formed at the bottom of the bridled pulley carrier. These rider clips were fixed to the moving rope every 100 feet and carried the cable over, the cable being clamped at one end to the the carrier rope. The operation was similar to a main-and-tail haulage the aluminium conductor being the train

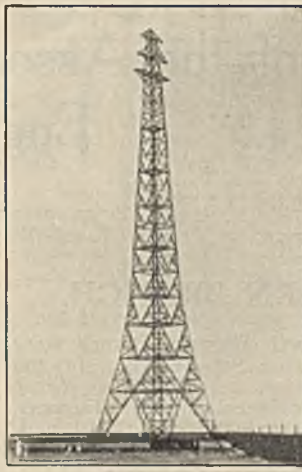


Fig. 13.

Fig. 14.

of tubs, the only difference being that the two ropes, main-and-tail, were joined together. When the cable was strained up it rose up out of the Vee formed in the clamp and left the way clear for the return of the clamps and moving rope for the next cable. Four cables were taken over in this manner, all of the same sectional area: three live conductors and one earth conductor, disposed symmetrically on the tower for stability and bracing. The whole job took about four weeks to complete and in not too congenial weather. This does not claim to be an accurate or official account of the crossing or the measurements other than approximate: it is intended only to give members an idea of the crossing and how it was accomplished, and possibly the particulars may come in useful should a similar line problem ever come their way.

MINES DEPARTMENT TESTING STATION.

For reasons of administrative economy, and also with a view to securing closer collaboration between the staffs of the Mines Department Testing Station and the Safety in Mines Research Board, the Testing Station has been transferred from London to a portion of the buildings occupied by the Board in Sheffield. The address of the New Testing Station is:— Mines Department Testing Station, St. Thomas Street, Sheffield. The telegraphic address and telephone number are as before, viz.: Telegraphic Address: "Testing Sheffield"; Telephone Number, Sheffield 23082.

The Station will continue to be under the direction of the Superintending Testing Officer, Captain C. B. Platt, M.B.E.

BELGIAN CO-OPERATION IN RESEARCH.

The British Government recently proposed to the Belgian Government that a scheme of co-operation in mine safety research, similar to that which was arranged in 1928 between this country and France, should operate between Great Britain and Belgium.

This proposal has been accepted, and arrangements are being made for a full interchange of information acquired by safety research in the two countries, including unpublished as well as published reports.

A similar arrangement has recently been concluded between Belgium and France and the circle of co-operation between the three countries is therefore complete. Full co-operation in mine safety research has been effective for the past 6 or 7 years between Great Britain and the United States of America.

ENGLISH ELECTRIC CO. LTD. AND THE U.S.A.

The English Electric Company Ltd., announce that they have entered into a comprehensive arrangement with the Westinghouse Electric International Company, of New York and Westinghouse Electric & Manufacturing Company, of East Pittsburgh, Pennsylvania, U.S.A., whereby there will be an exchange of technical information between the two organisations on steam turbines and electrical apparatus. The arrangement includes the granting of licences for the use of patents and for the manufacture and sale of various products.

Under this arrangement the English Electric Company Ltd., will have the benefit of the results of the extensive research work carried on by the Westinghouse Electric & Manufacturing Company.

The English Electric Company, in making the above announcement, wish to make it clear that the technical and manufacturing link thus established does not carry with it any control from America. The British interests in control of the English Electric Co., Ltd., believing that a moderate financial interest on the part of the American Westinghouse Companies would be highly desirable, have offered a participation in the ordinary shares of the Company at par, but this participation will, in any case be under 10% of the total.

Proceedings of the Association of Mining Electrical Engineers.

NORTH WESTERN BRANCH.

On May 17th last, the North Western Branch were the guests of the North Wales Sub-Branch. In the morning the Llay Main Collieries, near Wrexham, were visited. Mr. Waite, the chief engineer, and Mr. Furness, chief electrical engineer, conducted the party and very thoroughly explained and described the mechanical and electrical plant After the inspection, the Colliery Company kindly provided lunch.

Mr. R. F. Bull (President of the North Western Branch) proposed a vote of thanks to the Llay Main Colliery Company for permission to visit their colliery and for their hospitality. Mr. Hugh Jones (President of the North Wales Sub-Branch) ably seconded the vote of thanks.

Mr. Mottram, General Manager of the Company, responded to this toast; being supported by Mr. Waite and Mr. Furness.

A general meeting of the Branch was subsequently held in Chester and five members and two associate members were elected.

A short paper entitled Square Driving Ropes was read by Mr. E. J. Christian, followed by an interesting discussion.

Mr. Waite then gave a descriptive outline of the plant at the Llay Main Collieries.

The whole day proved very interesting and enjoyable and the hope was generally expressed that it would prove to be the forerunner of many more similar joint visits and meetings.

Square Driving Ropes.

E. J. CHRISTIAN.

Though every mining man is familiar with round driving ropes, but there are some who are not yet acquainted with square driving ropes. This brief paper is an endeavour to indicate the salient points of square ropes.

The square driving rope consists of eight strands plaited. There are two sets of four strands each, plaited in such a way that they become four right hand and four left hand strands. This gives a well-balanced rope, free from any tendency to twist and turn, and causes each strand to pull its full load.

The square plaited rope has a much higher tensile strength than a round rope, to take one figure to illustrate this: a 1¼ inch round rope has a tensile strength of 15,000 lbs., a square rope to run in the 1¼ inch groove and do the same work has a tensile strength of 22,000 lbs.

The advantage of this greater tensile strength for dealing with an overload is obvious. Harm comes to a rope from overload when it is stretched beyond its resilient point, even though it does not break the rope, fibres are ruptured and the length of life of the rope shortened. Engineers connected with pits where the air current is affected by the position of the cage, know all about overloads on fan ropes.

The square ropes go through a special process of drying and stretching during manufacture with the result that the finished ropes are practically stretchless. The resultant saving of splicing charges for tightening ropes, can be appreciated by men of experience. Square ropes have run for many years on severe motor drives without being tightened or touched in any way. After the rope is made, it is stretched to what is considered the best running tension, and the rope is then marked by tickets at five feet pitch. By this means ropes are spliced at the best running tension regardless of what they measure when on the floor.

No special grooves are required, any ordinary standard rope groove being used. Square ropes have been put on very many drives previously driven by round ropes. The ropes are set in grooves with one side of the rope against one side of the groove, and one corner of the rope against the other side of the groove. They do not always stay in that position and frequently run on two corners of the rope. The most remarkable feature about the square rope is its extraordinary pliability. Virtually there is no bending of the rope when going round the pulleys, it is rather a sliding of the strands one upon the other. It will readily be apparent that this flexibility is of incalculable value when ropes have to work on small diameter pulleys running at high speeds. On such drives round rope fibres are soon broken up and the life of the round rope is short.

Comparative figures are:

Pulleys 2 ft. by 5 ft. 8 ins.; Six 1 in. square ropes; 70 h.p.: 720 r.p.m.: 20 feet centres: rope speed, 4560 feet per minute. The round ropes on this drive averaged six months' life, against square ropes five years and six months life. These square ropes are still running. The speed ratio is 11 to 1.

Pulleys 3 ft. 4½ ins. by 6 ft. 6 ins.; ten 1⅜ inch square ropes; 218 r.p.m.· 17 ft. 7 ins. centres; rope speed 2307 feet per minute. The h.p. fluctuates from 180 h.p. to 280 h.p. in less than a minute. The round ropes on this drive average six months' life, against square ropes three years and 4 months' life. The speed ratio is 7 to 1.

Some square rope drives have been running over twenty years. They hardly ever wear out. On the average, taken over a number of years and a number of variegated drives, the length of life of a square rope is about three times as long as the life of a round rope on the same drive.

The square rope is so pliable that the minimum diameter of pulley recommended for square ropes is eighteen times the diameter of the rope, against thirty times the rope diameter recommended for round ropes. Even this low ratio is exceeded where difficult conditions have to be met.

Some misapprehension prevails with regard to the punishment dealt out to ropes by quick running small diameter pulleys. Some people argue it is the rope speed wihch determines the punishment, but it is really the number of bends the rope makes per minute and the diameter of the bend. Compare a 28 ft. pulley at 80 r.p.m. and a rope speed of 7000 feet per minute, with a 3 ft. pulley at 748 r.p.m. and a rope speed of 7000 feet per minute. There can be no doubt about which rope will perish first. Square ropes will work at any speed that the pulleys can run at, 6000 f.p.m. is regarded as an ordinary speed. The fastest speed run up to now is 10,000 f.p.m. The pulleys were specially made for this speed. It can be taken for granted that the pulleys would burst before the square rope fails to drive because of the rope speed being too high.

With regard to cost, the real cost of a rope is how much per year it costs to transmit so much power from one pulley to another. If the price of a square rope were as much as the price of a round rope, which it is not, the fact that its life is three times (or more) that of a round rope reduces the cost beyond the dreams of a miser.

A further economy results from the fact that usually no tightening is required. Most square rope drives are never tightened, a few are tightened once. If they have to be tightened twice investigation usually reveals that the drive is overloaded.

Many engineers who have had unfortunate experiences with round hemp ropes and have sworn allegiance to round cotton ropes in consequence, look askance at hemp ropes of any description. But the action of a round rope as compared with a square rope, in going round a pulley, is quite different. The round rope bends and cotton being a soft fibre deforms and returns to normal easier than does hemp, which is a hard fibre and often breaks up under the action. But the square rope does not bend, the strands slide one on the other and hemp being a hard fibre stands the sliding action better than cotton which, being a soft fibre, tends to tear and disintegrate. The fact that Lancashire cotton spinners use square hemp ropes may be taken as good evidence that square hemp ropes are better than round cotton ropes. It is, however, as well to mention that, just as there are good and bad round ropes, there are good and bad square ropes. The author knows of a case where a set of square ropes lasted only about a fortnight. Sometimes square ropes are not very popular where firms employ their own splicer, because, if he is a sharp man he can see that the introduction of square ropes probably means the end of his job.

MIDLAND BRANCH.

Air-break Switchgear at the Coal Face.*

Discussion.

(*Meeting held 26th February*, 1930.)

Mr. R. WILSON, in opening the discussion, said that Mr. Baldwin in his paper, condemned the use of oil-immersed switchgear at the coal face. He also went so far as to condemn its use in those places where Rule 132 applied. If Mr. Baldwin's ideas were correct and there was a real danger where oil-immersed switchgear was used, then those present who were responsible for the colliery electrical equipment must feel alarmed. He (the speaker) must, however, doubt whether the position was as bad as Mr. Baldwin tried to make it appear. He, personally, had never come across a case of breakdown, or of the ignition of firedamp due to the production of hydrogen or acetylene in oil-immersed switchgear, and he asked the members present to relate any experiences they might have had of the trouble suggested by Mr. Baldwin, also to express their opinions of Mr. Baldwin's idea. Mr. Wilson also said that he noticed that the circuit breaker described by Mr. Baldwin was of the drum type, and whilst this type might give a minimum of trouble in maintenance it might have a very low rupturing capacity.

Mr. F. SMITH said he had had both types of switchgear in use for many years and he had not found much difference with them in the matter of trouble, but he was not much in favour of the barrel switch. The time limit was too long and might cause the destruction of the oil. He would prefer the draw-out switch.

Mr. W. WRIGHT said he had had an oil-immersed switch explode, but it was called upon to do more than it should. He would like to ask what was the rupturing capacity of the switches.

Mr. BALDWIN.—About 1250 k.v.a., a.c.

Mr. BROWN thought that in comparing oil-immersed and air-break gear a lot depended upon whether it was movable or stationary switchgear. With stationary gear it was much easier to give more massive construction than on coal face switchgear.

Mr. W. WYNESS said that with regard to underground switchgear we were not logical; for the apparatus most in use we very often fall back on air-break. Often at the coal face there is an oil-immersed gate end switch; and then forward to the coalcutter an air-break controller is used. The reason was the difficulty of designing oil-immersed gear for use at the coal face.

Mr. WILLIAMS asked Mr. Wright what type of tank had the oil-immersed switch which exploded.

Mr. WRIGHT said it was a cast iron tank, not flame-proof.

Mr. WYNESS asked whether it was necessary to condemn one type of gear. Would it not be better to find where air-break could be used instead of oil-immersed. What was required was the type of gear to use under any given circumstances.

Mr. WILSON said that Mr. Baldwin had stated that confidence in oil-immersed gear had been misplaced, and that was why in his opening remarks he (Mr. Wilson) asked whether results did warrant the condemnation that Mr. Baldwin had applied to it.

Mr. PEACH, referring to the question of gas, said that whilst an oil switch was maintained as it should be and kept full of oil would obviously be unable to fill with gas at the same time.

Mr. F. SMITH said that an air-break switch used with a coalcutting machine, and there being a certain amount of moisture about, collected some of this. At night-time it breathed out and condensed, but he had never had that experience with oil-immersed gear.

Mr. ROUTLEDGE said he could endorse Mr. Smith's remarks respecting condensation in coalcutter switches. Speaking of troubles with oil-break switchgear, he had had dealings with a large number of oil switches, and could remember only three cases where they had had explosions, two in 3000 volt gear badly designed, and they had had a case of explosion of firedamp in a coalcutter, and that particular machine was one which it was very difficult to alter and make flame-proof. The trouble was due to this machine being worked in a dead-end where there was no ventilation; if properly ventilated there was no risk. Personally, he did not like oil-break gear on coalcutters. Mr. Wyness's remarks about the logical results of using air-break at the coal face may be correct, but it would mean scrapping all the switchgear to do that. Mr. Routledge said he took it that Mr. Baldwin's switchgear was limited to 550 volts. What were they going to do with air-break gear on 3000 volts. It seemed to him that they would require very large cases to keep it in. He saw no reason why oil-break gear, if properly maintained, should not continue to be useful. The problems coming forward with the use of conveyors were rather different; there was very little space, and there was a lot to be said for air-break switchgear in such places.

Mr. WILSON said he did not suggest that we should scrap all the gear we have, but he did know that this question of oil-immersed and air-break switchgear was receiving very careful attention. The Mines Department was considering it very seriously, and it might be interesting to know that air-break switchgear was made for 3000 volts, but it certainly had the disadvantage of taking up a great deal of room.

Mr. W. WYNESS said he had very great pleasure in proposing their best thanks to Mr. Baldwin for reading his paper. He thought one of the objects of the Association was to obtain information as to the best kind of switchgear to use.

* See *The Mining Electrical Engineer*, May 1930, p. 434.

Mr. NORTHCOTT seconded the vote of thanks, and Mr. Baldwin in replying, said he was sorry not to have been able to go more deeply into the subject, but he would like to thank those present for the way they had received the paper.

LOTHIANS BRANCH.

High Power Metal Cylinder Mercury Arc Rectifiers.

G. HENDERSON.

(*Paper read 8th March*, 1930.)

When one looks back a matter of ten years, it is difficult to think of the power rectifier of that period as being the forerunner of the plant we see to-day. The developments which have brought about this change are the outcome of continuous research and experience of those who persevered in spite of the many set-backs, disappointments and innumerable obstacles and criticism. In the early days, purchasers of such plant used to think in a few hundred of kilowatts, now they think in thousands. The time given to research has enabled much of the puzzling phenomena associated with the rectifier to be more perfectly understood, with the result that the baffling troubles which used to be experienced have been eliminated and can be considered a thing of the past.

The principle of operation of the Mercury Arc Rectifier is now so well known that it is hardly necessary to give details in this paper. A great deal of literature has been published within recent years in which the fundamental considerations are considered fully and to which reference should be made by those desirous of acquiring a more intimate knowledge of that side of the subject. The present paper deals more with the practical article as manufactured to-day and the service it is rendering.

Principle.

Stated very briefly, the Mercury Arc Rectifier is a converter for transforming alternating current into direct current. It is in effect an electric valve, the mercury arc when operating in a vacuum having the peculiar property of permitting the passage of a current in one direction only. The formation of an arc depends on the existence of electrons such as are produced at the cathode when brought to white heat and under the influence of an electric field. To obtain the valve action the anode must be maintained at a considerably lower temperature than the cathode. The latter is conducting to electrons in both directions, whereas the anode conducts in one direction only.

The rectifying effect described is not the peculiar property of mercury only but is simply due to the arrangement of the two electrodes whereby one is brought to white heat by electronic emission and the other is maintained at a temperature below that at which the formation of electrons is possible. It is essential that the metal of the negative electrode be such that, after vaporisation, it can be condensed easily and returned automatically without requiring to be replenished. It is necessary, therefore, to take a metal that is fluid at ordinary atmospheric temperature; this being the reason why mercury is used.

To utilise both halves of the a.c. wave, a transformer is interposed between the incoming supply and the rectifier. The secondary of this transformer is divided into two parts, the mid or neutral point being brought out and forming the negative pole of the d.c. system, while the outer ends of the winding are connected to the positive electrodes (anodes). The simple single-phase arrangement has been referred to, so far; in practice the number of anodes is increased to 6, 12, 18, or 24, according to the capacity of the rectifier under consideration. In the general case, not more than a six-phase secondary is utilised and, where the anodes exceed this number, they are connected in parallel.

The d.c. wave form of the six-phase rectifier is quite satisfactory for all ordinary commercial uses. The magnitude of the undulations that exist can be still further reduced, if necessary, by means of wave filters. Two forms of secondary windings are used according to circumstances. The most general is the double three-phase which is used in conjunction with what is known as the absorption reactance coil, connected on the neutral side of the transformer secondary. The other form of connection is the fork or double fork, which dispenses with the absorption coil, but which entails a somewhat larger transformer.

At one time it used to be considered that the losses in the arc were practically constant at all loads. This supposition, however, has been proved to be incorrect. The pressure drop in a rectifier arc varies between 15 and 35 volts, depending upon the type and size. The drop is made up of the sum of three separate drops due to the anode, the cathode and the arc itself. In the electrodes, it is practically constant and is independant of their composition, the current density or the vacuum. In the arc, however, the drop is very variable and depends upon the vacuum, the current density and the sectional area of the arc. It is directly proportional to the vacuum and inversely proportional to the current density and arc section. For long tubes of small section with a vacuum of only 1 mm. to 2 mm. Hg. through which is passed 3 amps. to 5 amps., the drop would amount to 0.8 volts to 1.2 volts per om. of arc length but, in large rectifiers, where the vacuum is very much higher and the current density amounts to several hundred amperes, the drop is reduced to 0.1 volts per om. or less. Thus it is that, with large rectifiers, the arc drop amounts to about 10 volts.

Experiments have demonstrated that it may be possible to make rectifiers for low voltages in which the anodes are close up to the cathode, say within 1 mm. or less. Such an arrangement would enable an efficient outfit to be marketed and thereby overcome the usual objection of low voltage rectifiers, namely, that of low efficiency. It should be mentioned that the drop in the arc varies only as the current. It is not influenced by the voltage, so that the higher the d.c. voltage, the better will be the efficiency. Consequently, where the d.c. pressure is low, i.e. of the order of 250 volts or less, the efficiency cannot compare with that obtainable with the synchronous machine. If, however, it is found possible to build something on the alternative lines suggested, with the anodes almost in contact with the cathode, the disadvantage of low efficiency disappears.

In polyphase rectifiers, the load current at any instant is taken by the anode having the highest positive potential with respect to the neutral of the transformer secondary.

The undulations are formed by the peaks of the sine waves of the transformer secondary phase voltages. Each phase assumes a maximum positive potential once each cycle and consequently the number of pulsations per cycle is equal to the number of phases. The total pulsations per second are, therefore, equal to the product of the frequency of the a.c. supply and the number of secondary phases.

If reactance could be eliminated under load conditions, the current would pass instantly from anode to anode at the points of intersection of the waves so that the "on load" wave form would be the same as that at "no load." As, however, reactance is present, the current does not die down or build up instantly in any phase. Consequently, two phases carry current simultaneously as the current in one phase is dying down and the current in the other is building up.

The d.c. voltage during the period of overlapping is equal to the mean of the overlapping phase voltages. In practice, the magnitude of the angle of overlap and, therefore, the shape of the d.c. voltage wave under load depends somewhat on the nature of the load. The magnitude of the ripple naturally decreases as the number of phases is increased.

Construction.

In referring to the construction of the rectifier, it is necessary to deal first with an important feature which has been very largely responsible for the success of the high power rectifier, viz.: the sealing. The steel clad rectifier is made up of a number of parts, all of which must be capable of being dismantled easily and which, when assembled, must be able to maintain a very high degree of vacuum within the working chamber. The various parts must, therefore, be separately sealed and, in the high-power rectifier, the sealing medium is mercury which is the most efficient and lasting form of sealing yet devised. So satisfactory is the seal that cylinders which have been exhausted and then left for months untouched retain vacua of 0.02 mm. to 0.3 mm. Hg. Such results cannot be obtained with any other form of packing such as rubber, lead or aluminium.

An advantage of the mercury seal which is not always realised is that leakage quickly shows itself in the gauge by the slow sinking of the mercury. The tightening of a nut or two and the leakage is stopped. The design of the seals is such that the mercury is not in contact with the air. The mercury vapour within the rectifier cannot possibly come into contact with the surrounding atmosphere and it is, in any case, condensed without loss due to the cooling provided.

The illustration, Fig. 1, shows a high power rectifier of modern design. It consists of two cylinders, the cylinder at the bottom, in which the arc operates, and the long narrow cylinder at the top where the mercury is condensed. Both cylinders are closed in, as shown, by heavy plates and, in the centre of the bottom plate, the cathode is placed. The anodes, of which there are 6, 12, 18, or 24 according to size, are mounted through the anode plate at the top of the arc chamber. They are insulated by means of special porcelain insulators and sealed in the manner already described. At the top of the condensing cylinder is a solenoid for the operation of the ignition rod, which passes down the centre of the rectifier. The cathode, arc chamber and condensing cylinder are all water-jacketted, the water being supplied either from the town mains or circulated through a separate re-cooling system, according to circumstances. The whole rectifier stands upon insulators which are mounted on the floor direct. In some rectifiers, the anodes are air cooled, while in others, water cooling is adopted, as in the type shown in Fig. 1, the water being thermo- syphon circulated.

It is interesting at this point to note that the Peebles-Brown Boveri type of Mercury Arc Rectifiers, as illustrated, are in service in various sizes from 300 amperes to 10,000 amperes at d.c. pressures of 220 to 500 volts for power and lighting service, 500 to 6000 volts for traction, and 12,000 volts for wireless work.

Ignition and Excitation.

Those who have seen some of the older plants will remember that the ignition and excitation circuits were separate, the ignition being obtained by means of d.c., a small motor-generator set being provided for the purpose. A radical change has been made within recent years, the two circuits being interconnected and the arc now being started automatically by a.c. Current is supplied by a small excitation transformer which is energised when the main oil switch is closed through the medium of auxiliary contacts on the latter. The ignition and excitation is automatically controlled so that an arc cannot form between the two excitation anodes and the cathode unless the polarity is correct. The whole operation of getting a modern high-power rectifier into commission from the moment the primary oil switch is closed is a matter of two or three seconds.

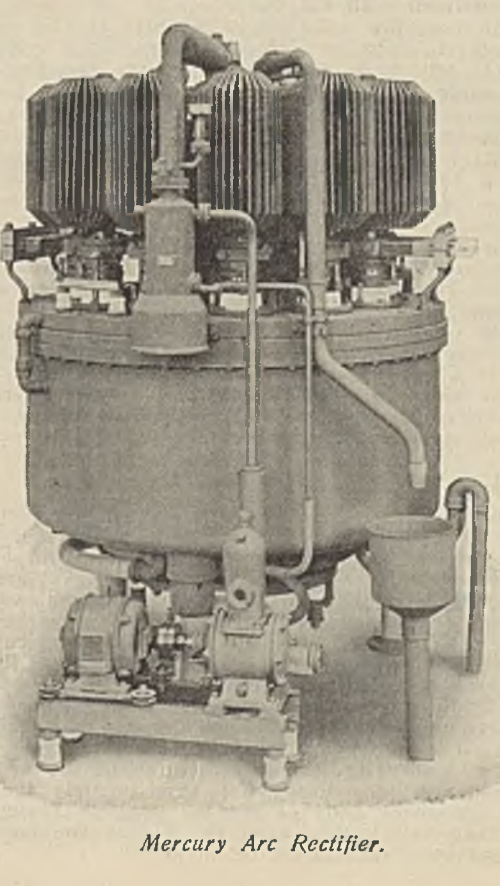
Vacuum Pumps.

To exhaust the rectifiers and maintain the high degree of vacuum necessary for the successful operation of the plant vacuum pump sets, of small size but having a high extraction capacity, are utilised. The design in use has been very thoroughly tried out and is absolutely reliable. The set consists of a preliminary vacuum pump with valve controlled by oil under pressure, and a high vacuum mercury vapour pump.

The high vacuum pump will only operate when in series with the preliminary vacuum pump because of its low compression ratio. This pump compresses the gases extracted from the rectifier to a pressure of 0.5 mm. Hg. The initial vacuum due to the rotary pump is of the order of 0.04 mm. Hg., the overlapping of the two characteristics being sufficient to ensure stable operation. The preliminary vacuum pump is of the oil-immersed pattern, the oil used for sealing being a special mineral variety with a flat viscosity curve.

The duty of this pump is to discharge to atmosphere the mixture of air and gas extracted from the rectifier by the high vacuum pump. The pump is so designed that the same oil is used to seal off the vacuum pipe and the joints of the pump, to lubricate the rotating parts and to control the automatic vacuum value. The pump is of the totally-enclosed pattern with a labyrinth gland for the shaft where it passes through the casing.

To enable the vacuum to be ascertained, a special form of hot wire gauge is used in conjunction with a direct reading instrument. The operation of the gauge depends upon the variation in the thermal conductivity of gases with the pressure which surrounds them. The gauge consists of four resistances, of which two are in the vacuum and two in the atmosphere. The two in the vacuum are contained in a glass tube of H form which is fitted into the vacuum piping. The four ends of the platinum wire are connected in the form of a Wheatstone bridge, which is supplied with a constant current.



Mercury Arc Rectifier.

As the vacuum increases, the temperature of the wires in the vacuum increases. A millivolt meter is used to register the variations in the voltage that result and is calibrated to indicate vacuum directly.

Regulation.

It has already been mentioned that two forms of transformer secondary connections are used, depending upon the service conditions to be complied with. The first is the simple six-phase and the second is the fork or double fork connection. The first is the one most widely used, but to enable the inherent regulation to be kept within reasonable limits, an absorption reactance coil is made use of, this being connected into the neutral point of the transformer. Without this coil, on account of the abnormal transformers that must necessarily be used, the inherent regulation may be as high as 12% but, with the coil, this is reduced 4% to 5%. The effect of the absorption reactance coil is to cause the phases to overlap and, in consequence, two or more anodes supply current at any instant instead of only one. It will be appreciated that the over-lapping of the phases, whereby the maximum current per anode is reduced considerably, results in a much lower r.m.s. value for the phase currents and, as the drop is proportional to the current, the regulation is better correspondingly than that obtainable without the absorption reactance coil. This coil has a peculiar characteristic. For all ordinary loads it follows the normal shunt characteristic with a drop of about 4% to 5% but, at very small loads, i.e. about 15 amps. or less, the curve rises rapidly—a matter of 15%. The coil consists of two sets of winding with a common magnetic circuit which act in opposition and which produces a powerful throttling effect, causing the overlapping of the phases as already explained.

It follows from what has been said that a plant operating without absorption reactance coil, requires a transformer and rectifier of larger dimensions than a plant provided with the coil.

For those few cases where the high rise of pressure at small currents is inadmissible, the fork connection is employed. With this connection the resulting regulation curve is a straight shunt characteristics from no load upwards but there is no overlapping of the phase currents and in consequence, the r.m.s. phase current is higher for both the phase windings of the transformer and the anodes of the rectifier which entails the provision of larger transformer and rectifier for a given output.

The question is frequently asked—is it possible to operate rectifiers in parallel with other forms of converter? The answer most decidly is in the affirmative, assuming that the usual requirements for parallel operation are complied with, viz.: that the characteristics of the different forms of converters are approximately similar. There are a large number of high-power rectifiers running in parallel with rotary converters and other converters, either in the same substation or in other substations on the same network.

Efficiency.

The rectifier is a very attractive proposition from the point of view of efficiency. This would scarcely be noticeable for pressures below 460 volts except at very light loads but, where the higher d.c. pressures are concerned, especially those used for traction, say 550 volts up to 3000 volts and higher, the superiority of the rectifier is indisputable. The efficiency curve is almost flat and horizontal down to about ¼ load, it being immaterial generally from the efficiency point of view whether the plant is operating at full or ¼ load because under both conditions the efficiency is practically the same. The reason for the efficiency being better with the higher d.c. pressures is due to the fact that, with rectifiers, the losses are approximately the same at all pressures and, as higher outputs are obtained from the same rectifiers at the higher pressures, the efficiency must necessarily be higher.

The overall efficiency, including all losses, from the h.t. terminals of the transformer to the d.c. busbars at ½ to ¾ load would be as follows for typical plants:—

1500 k.w.	1500 volts	96.5%
500 k.w.	480 volts	93.3%
2500 k.w.	500 volts	93.7%
1500 k.w.	600 volts	94.5%
250 k.w.	220 volts	89.0%
3750 k.w.	1500 volts	96.8%

The above figures have been given at loads between ½ and ¾ load because it is generally found that, on the average, plants operate between these values. On highly varying loads the effect of the high efficiency of the rectifier, as compared with that obtainable with other forms of converters is very marked. The advantage in favour of the rectifier is accentuated, due to the extremely high low load efficiency with the result that the capitalised value of the benefit gained is considerable and it has been found, in some cases, that the cost of the plant has been wiped out within about four years, due to the difference in the amount of the energy taken by the rectifiers as compared with what would have been required for rotary machinery.

The power factor is very satisfactory and, in general varies between 0.95 lagging at full load to 0.92 lagging at quarter load, though as high a figure as 0.97 lagging has been obtained.

It is now becoming common practice for converter substations to be automatically controlled, the plant being set into operation and shut down according to service requirements.

The automatic control of the high-power rectifier is very much simpler of solution than the automatic control of rotating machinery, primarily, because of the fewer operations that are necessary. For instance, the rectifier has not to be synchronised and the question of polarity does not come into consideration.

There is no class of load for which d.c. is required which cannot be dealt with by the rectifier. It is surprising to find that although the Brown-Boveri Co. Ltd. have installed about 1,250,000 k.w. of high-power rectifier plant, not 5% of that is installed in the British Isles, one can only put this down to the fact that all the development work has been done on the Continent, and up until now have only been manufactured abroad.

In conclusion, the Author has to thank Messrs. Bruce Peebles & Co. Ltd., Edinburgh, for granting permission to give the details covered in this paper.

WEST OF SCOTLAND BRANCH.

Gear Drives.

HENRY E. MERRITT, D.Sc.

(*Paper read 19th February,* 1930.)

Gear drives form an essential part of practically every industrial plant using power and particularly where electric power is the motive source, but probably no industry uses such a wide variety of gear drives in such a diversity of applications as is the case in mining. Citing the more important drives, there are:

(a) Geared Turbo-Generator Sets,
(b) Fan Drives,
(c) Pump Drives,
(d) Winder Gears,
(e) Haulage Gears,
(f) Conveyors,
(g) Screening Plant.

It may reasonably be said that each of these drives has its own special characteristics and requirements. To deal with the question under these separate headings would, however, lead to a certain amount of overlapping and duplication, and it is therefore proposed to subdivide treatment of the subject under the classifications of the various types of gear employed. Re-arranging the above classifications, subject to some modification in individual cases, the several types of gear are :

Turbo-Generator Sets and Fan Drives: Turbine reducing gear units.

Pump Drives, Winder Gears, Haulage Gears, Conveyors, and Screening Plant: Helical Gears and Helical Gear Units.

Haulage Gears, Conveyors, and Screening Plant: Worm Gears and Worm Reducing Gear Units.

TURBINE REDUCING GEAR UNITS.

The features distinguishing turbine gearing from other kinds are the high powers and speeds with which they deal. These in turn call for an exceptional degree of accuracy both in the cutting of the teeth, the balancing and mounting of the gears, and the lining up of the turbine, gear, and driven unit. With a few minor exceptions in the case of small powers, turbine reduction gears are of the double helical type and the teeth are cut by the hobbing process. The choice of this process is dictated by the considerations that, firstly, the process is continuous both as regards cutting and division; secondly, that the hob can be produced with a high degree of accuracy; thirdly, that the hob has the largest number of cutting edges of any gear-generating cutter, and these are successively brought into action as the hob travels across the face of the blank.

The accuracy of the machines and hobs employed has been brought to a considerable degree of perfection, and a test carried out on one of the machines used by the author's firm showed a maximum cumulative pitch error on a 10 foot diameter gear of 0.0025 inch. Similarly the errors of pitch in a profile-ground hob are not more than 0.0005 inch per inch, and are often less.

In order to ensure smooth running at high speeds, very great care, coupled with experience, is necessary. The pinion, of nickel chrome steel, is ground on the journals, the teeth being finish-cut after heat treatment, and the pinion finally balanced. Similarly the wheel, consisting of a weldless rolled steel rim shrunk on to a cast iron or cast steel centre, is cut after the wheel has been finally machined and pressed on to its shaft, and it is also balanced.

The mounting requires equal care. Plain bearings, lubricated with circulated oil, are invariably used and are carried in the bottom half of the casing. The top halves of the bearing are, of course, independent of the upper half of the casing, which serves only to keep the unit oil-tight and dustproof. The gears usually run "over and inwards" so that the load on the pinion bearings is in the upward direction and this must be taken into account when the bearings are designed.

The supply of oil may either be derived from the turbine system on the lubrication system may be self-contained. In the latter case a pump of the rotary gear type is driven from the slow-speed shaft, circulating the oil through a cooler and thence to each bearing and to a series of nozzles directing sprays on to the entire face width of the teeth. For the lubrication of this type of gear a turbine oil is recommended, having a viscosity of between 100 and 130 secs. Redwood at 140 degs. F. This temperature is not often exceeded on the outlet side of the lubrication system although it is by no means the maximum safe temperature. The pressure at the spray nozzles and bearings is usually from 8 lbs. to 10 lbs. per sq. inch, which is sufficient to form a fan-shaped unbroken spray about five or six inches wide from each nozzle.

Considerable care is necessary to design efficient oil retaining devices which will prevent the escape of oil and oil-mist along the shafts at turbine speeds. This is, of course, particularly necessary in turbo-generator sets, in order to prevent access of oil to the windings of the generator, quite apart from the cumulative cost of a continuous leakage of oil.

The question of oil aeration has also to be considered at high speeds: this is largely a matter of careful design of the outlet piping and reservoir. A point which should not be overlooked is that oil mist is highly inflammable and should be given time to dissipate before a naked light is brought near any inspection hole.

Erection and alignment require care with all gearing, but particularly with turbine gearing. Two "flexible" claw couplings usually connect the turbine with the pinion shaft but these should not be depended upon to take care of mal-alignment. They simply provide for the difference in position of the pinion and turbine shafts in the standing and running conditions. This change in position is caused by the lift of the pinion shaft due to the direction of tooth load, modified by the thickness of the oil film in the bearings and the possible difference of the expansion of the turbine and gear casing at the running temperature. In lining up, the effect of deflection of the turbine and generator shafts must also be allowed for.

The efficiency of turbine reduction gearing is remarkably high, the principal loss being bearing friction. In tests carried out by the National Physical Laboratory on behalf of the author's firm, the actual tooth friction under average conditions was found to be less than one-half of one per cent. and the overall efficiency will rarely be less than 98 per cent. This is, of course, due to the use of the fine pitches employed, whereby the ratio of the average sliding velocity of the teeth to the pitch line speed is very small.

HELICAL GEARS.

For transmitting power between parallel shafts, helical gearing is at once the most efficient, quiet, and compact drive, and for these reasons finds considerable application. Helical gears are superior to straight spur gear drives in load carrying capacity and in quietness of running, with the further advantage that the quietness of running is not so seriously impaired by tooth wear as is the case with spur gears.

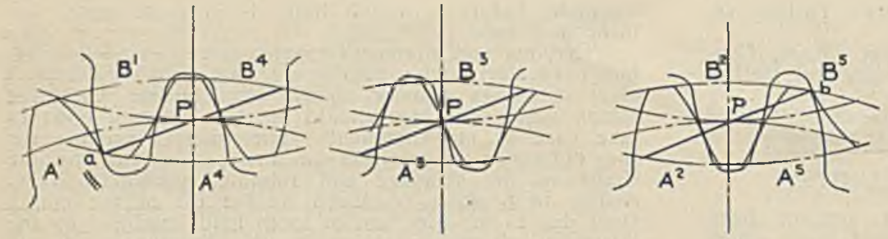
Load carrying capacity is limited by two considerations:

(a) the strength of the teeth to resist breaking, and

(b) the resistance to "pitting" and abrasion as determined by the surface stresses along the line of contact. Of these two considerations, that of breaking strength is relatively unimportant, since the resistance of a gear tooth to breaking depends on the pitch and this can always be adjusted in the design stage by suitably selecting the numbers of teeth. The surface stresses are, however, almost independent of the pitch and are controlled principally by the gear diameters and face width.

The comparison between a pair of helical and a pair of spur gears of the same material, pitch, numbers of teeth, and face width, is shown qualitatively by Figs. 1 and 2. Tracing the stages of engagement of the spur gears shewn in Fig. 1, it is seen that load is suddenly applied to the whole length of the driven gear at A, the extremity of the tooth. At this instant there is a second line of contact between the driving and driven gears, but with further rotation of the gears, the first driving tooth passes out of engagement and the whole load is carried by the teeth along one line, the length of which is equal to the face width of the gears. Furthermore, at the instant a pair of teeth enter into contact, the velocity of sliding between the teeth is considerable, being equal to the product of the relative angular velocity of the gears and the distance of the point of contact from the pitch point P. As the gears rotate, this distance (and consequently the sliding velocity) diminishes and is zero at the pitch point P, after which the direction of sliding reverses and rises to a maximum again as the limit of contact is reached. Not only, therefore, does the load on any tooth fluctuate rapidly, but this fluctuation is accompanied by enormous changes in the sliding velocity between the teeth, and these two factors lead to erratic wear of the tooth profiles and hence to noisy running.

Totally different conditions exist in the case of the helical gears shewn in Fig. 2. A helical gear can be regarded as being built up of a series of thin spur gears displaced angularly relative to each other, and



a b c

Fig. 1.

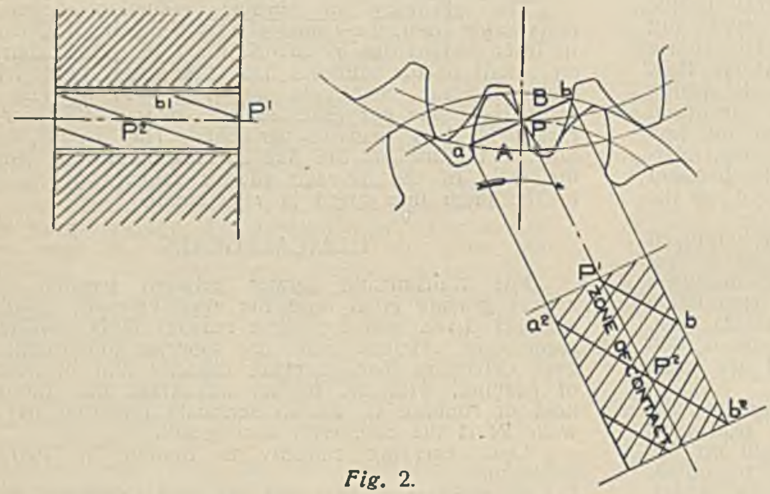


Fig. 2.

contact between the gears is no longer straight across the face but along diagonal lines extending from top to bottom of the teeth. These diagonal lines move from end to end of the teeth and there is one complete line for every pair of teeth in contact. At every instant therefore the total conditions of engagement are the same and there is no violent application of load to any tooth; furthermore, there is no tendency to irregular wear.

The total length of the line of contact for every pair of teeth in contact is considerably greater than the length of line contact of the corresponding spur gears. This increases the load carrying capacity both as regards strength and surface stress; strength, because a greater length of tooth is carrying the load; surface stress, because of the greater length of line contact and the flatter curvature of the teeth on the normal section.

It is hardly possible, within the confines of this paper, to deal with the technical aspect of the load carrying capacity of gear teeth, but it is perhaps desirable to deal with it in general terms in so far as the effect of tooth form on allowable tooth load is concerned. It sometimes happens, for instance, that new tooth forms are introduced which are represented (or misrepresented, as the case may be) as having much greater load carrying capacity than those in ordinary commercial use. For this reason the author has made an analysis of a variety of tooth forms, the results of which are described and tabulated in Table I.

From the point of view of surface stress, the load carrying capacity of a pair of helical gears (the materials, pitch, numbers of teeth, and face width being fixed) depends upon the spiral angle, the total length of the lines of contact and the relative radius of curvature of the surfaces. The two last-mentioned quantities are controlled by the pressure angle and the spiral angle of the teeth.

Increasing the spiral angle increases the normal tooth reaction for a given tangential load, and at the same time increases the relative radius of curvature and decreases the total length of line of contact. The net result is that the positive and negative variations practically cancel out and there is consequently no particular spiral angle which gives substantially better results than any other. The statement, sometimes made, that a spiral angle of 45 degs. is greatly superior to all others is not borne out by the facts.

As far as involute teeth with their constant pressure angle at every point of contact are concerned, increase of pressure angle increases the relative radius of curvature and decreases the total length of line of contact. These again almost cancel out, and the net result is that, theoretically, there is not 10 per cent. variation in load carrying capacity over the whole range of tooth designs encountered in practice which are usually of 20 degs. pressure angle. This difference is so small that it could be lost many times over by imperfections in tooth shape due to inaccurate cutting. The same conclusions hold good for what may be described as "fancy" tooth shapes with curved lines of contact, except that the comment on the matter of accuracy of cutting occurs with even greater force. Table I. shews the tooth characteristics and comparative load carrying capacity of various tooth forms. It is interesting to note that if the addenda of the 20 degs. pressure angle helical teeth are made proportional to the normal pitch the surface stress is equal on all of them within 2 per cent.

TABLE I.

Gear Ratio = 30/150
Pitch = 1 D.P.
Face width = 10 inches.
Tooth Load = 10,000 lbs. tangential.

Pressure Angle.	Spiral Angle.	Addendum.	Normal Tooth Load.	Total Length of Line of Contact.	Relative Radius of Curvature at Pitch Line.	Load per inch of Line Contact.	Load per inch. Relative Radius.
degs.	degs.		lbs.				
20	—	1.0	10000	10	4.275	1000	234
14½	—	1.0	10000	10	3.13	1000	320
20	22½	.88	11420	16.95	4.665	674	144
20	30	.88	12100	18.02	5.00	670	134
14½	22½	.88	11130	21.26	3.408	524	153.5
20	45	.71	14600	17.71	6.23	823	132

DOUBLE HELICAL GEARS.

A single helical gear produces an end thrust proportional to the cotangent of the spiral angle. In Continental and American practice the spiral angle is sometimes made small and the axial load taken up by thrust bearings, but the method almost invariably used in British practice is to use double helical gears, whereby the end thrusts due to right and left handed spirals cancel out.

There are a number of types of double helical gear, corresponding to the methods employed in cutting the teeth. These are: (a) hobbed teeth of the turbine type, (b) staggered tooth gears, also produced by hobbing, (c) planed double helical gears with continuous teeth, and (d) end-milled gears.

In the case of turbine gears, the teeth are of fine pitch and relatively large face width, and hobbing with a single thread hob of large diameter necessitates a gap of considerable width between the right and left hand helices. Where the pinion is relatively slender, a centre bearing is arranged in this gap (Fig. 3).

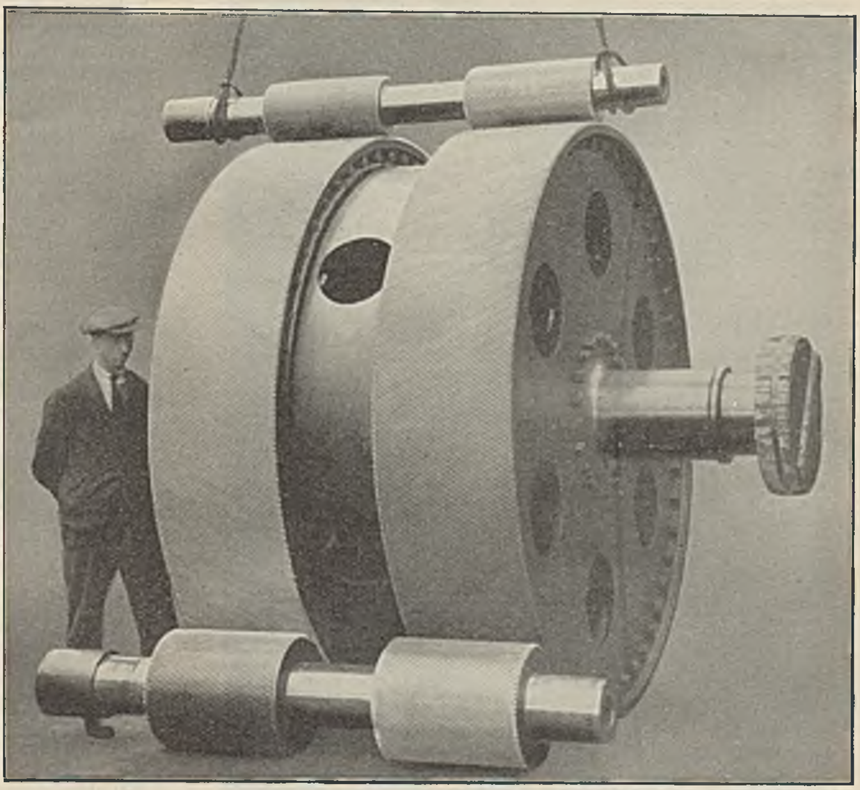


Fig. 3.

In other cases, however, every effort is made to reduce this gap to a minimum in order that as much as possible of the total face width may be rendered effective. Hobbed gears have the minimum gap when the teeth are "staggered." In this way the hob threads, when finishing cutting one helix, clear themselves in the tooth spaces of the opposite helix, and the non-effective portion of the face width is equal to one circular pitch, although at first sight it appears to be less than this amount.

Double helical gears with continuous teeth and with the whole of the face width effective, Fig. 4 can be cut from the solid by means of the "Sunderland" planing process. This is a true generating process in which the cutting tools one for each helix, are of the form of straight-sided racks. The cutters are alternately reciprocated at an angle equal to the spiral angle of the teeth, and come to rest in a plane in the centre of the face width. Each cutter thus clears the chip left by the preceding stroke of the other and the correct involute profile is generated on every section.

The fourth type, the end-milled gear, is cut by a rotating end-mill, having a profile corresponding to the form of tooth to be produced. The helix is formed by slowly rotating the blank as the cutter is fed across the face, and to produce a double helical tooth the direction of rotation of the blank is reversed when the cutter reaches the centre of the face width. The effect of this is to produce teeth which are joined at the apex, but they are not "continuous" in the sense that the whole of the face width is effective. The reason for this is that at the point of reversal the re-entrant angle of the teeth is curved to the radius of the cutter, whereas in the opposite side of the teeth sharp corners are left which must be rounded to clear the curved re-entrant corners by a further milling operation. It is not possible to form the teeth at this point so that they will make effective driving contact and the loss of effective face width is roughly equal to between one-half and two-thirds of the circular pitch. It is clear therefore that teeth produced by this process are at a disadvantage compared with planed double helical teeth in respect of effective contact area. There is the further consideration that the profile of the end mill cannot be produced as accurately as a hob or Sunderland cutter.

It is, of course, possible to effect two reversals of rotation when end milling a helical gear and thus produce "triple helical" teeth. This type of gear at one time enjoyed a quite considerable vogue, due to the mistaken idea that a double helical gear should run with the apex leading and that in consequence a gear which is required to run both ways (winder gears, for instance) should have an apex pointing each way. The fact is, however, that a hobbed or planed double helical gear will run equally well in both directions and there is no justification for wasting two portions of the face width at two apexes. A hobbed staggered tooth double helical gear is fully as good as a triple helical end milled gear as regards effective face width, and being (if well cut) considerably more accurate in pitch and tooth profile will run better and more quietly.

GEAR MATERIALS.

From the point of view of surface stress the load carrying capacity of a gear material increases at a considerably greater rate than its tensile strength and the use of high-tensile material reduces the dimensions of the gears and housings and hence reduces the total cost.

The use of low tensile materials, such as special fabrics and cast iron, is limited to drives which are not subject to heavy overloads and shock, and on which safety does not immediately depend. Mild steel is not a particularly good gear material, and steel gears whether cast or forged, should not have a carbon content of less than 0.3 per cent. The limit in the other direction, dictated by considerations of machineability is about 0.55 per cent.

To obtain higher load carrying capacity, either case-hardening steels may be used or direct-hardening steel, hardened after cutting, may be employed. Of these alternatives, case-hardening gives the hardest surface, but in the case of large gears, the distortion consequent upon hardening may be serious and surface-hardening may be preferable.

The operation of surface-hardening consists in traversing an oxy-acetylene flame across the face of the tooth immediately followed by a quenching water jet. As first introduced, this involved the element of personal skill to such a degree that the results were usually very erratic, but this objection is removed by the Shorter process, in use by the author's firm. In this process the gear to be hardened is immersed in water, whilst cooling jets are directed on the teeth in the neighbourhood of the flame in addition to the quenching jet. The flame itself is traversed by mechanical means

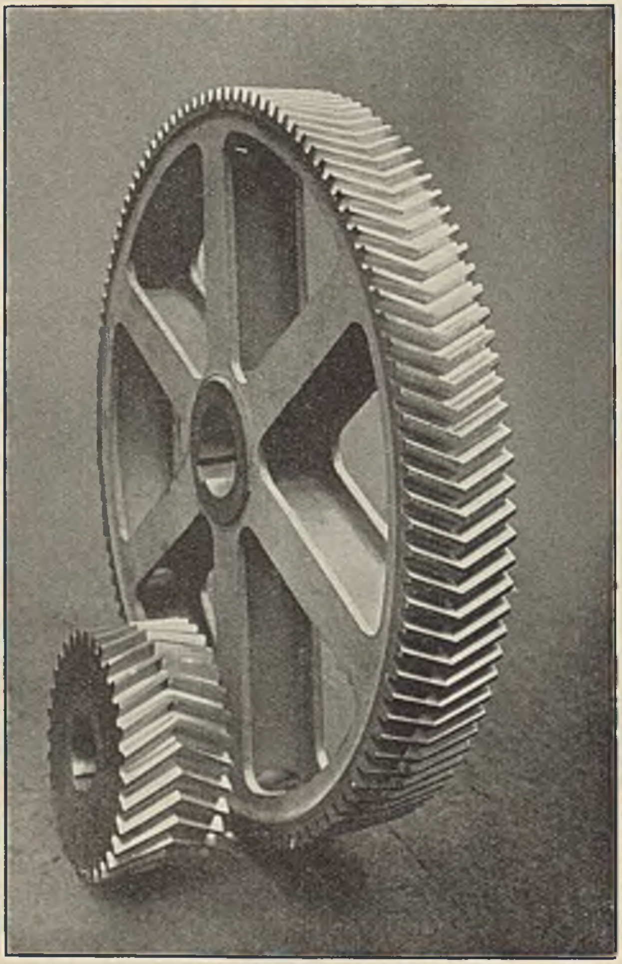


Fig. 4.

across the face of the tooth to be hardened at an accurately adjustable and controllable speed. In this way distortion of the body of the gear is practically nil and a high degree of uniformity in the hardened teeth is secured.

It is a counsel of perfection that every gear should be totally enclosed, continuously lubricated, and protected from dust and abrasive matter, but this is not always possible of achievement. It is when working under unfavourable conditions that case-hardened and surface-hardened gears show up to the best advantage. If the lubricant contains any abrasive material, a soft gear will act as a lap and the particles of foreign matter embed themselves in the surface and wear the harder gear away. Under these conditions a mild steel pinion is quickly destroyed by a fabric or cast iron wheel.

LUBRICATION.

Gears may be lubricated by splash or by spray, the selection being governed principally by the speed of the gears. Splash lubrication can be used up to about 3000 ft. per minute peripheral speed, the gears being allowed to dip from ¾ inch to 1½ inch at the standing oil level. If the gears dip too far, the churning loss will be excessive, and will make its presence known by a high running temperature. At speeds above 3000 ft. per minute spray lubrication becomes necessary, and is really to be preferred at lower speeds if the added complication of a pump, strainer, and piping can be accepted.

The proper selection of oil depends upon the speed of the gears and the method of lubrication. The load between the teeth tends to expel oil from between the surfaces in contact, this action being resisted by the rolling action, which brings the newly-lubricated surfaces into action, and by the viscosity of the oil. The higher the tooth velocity, therefore, the lower can be the viscosity, and whereas a slow-speed haulage gear may demand a heavy oil of the steam cylinder type, a high speed turbine gear will run on a light turbine oil.

Economy in lubrication is not measured by the cost of oil per gallon and can be achieved only by selecting an oil of proved quality, capable of standing up to the arduous duty of gear lubrication. Furthermore, it should be kept clean. Gears inevitably wear, and the particles which are worn off the teeth, if allowed to remain in circulation, will tend further to damage both gears and bearings. If, therefore, a circulating system, with strainer, is not used, it is recommended that the gear be drained, washed, and filled with clean oil every six months, the oil drawn off being filtered and made ready for further use. At more frequent intervals a small quantity should be drained off from the bottom of the case after the gear has been standing some time, and filtered, being meanwhile replaced by clean oil. A magnetic separator may with advantage be fitted in the gear case at a point where the velocity of the oil is not excessive.

MOUNTING.

Accurate gear cutting is thrown away if the gears are not mounted with equal precision. Gears are designed to carry the load distributed uniformly across the face width, and any lack of parallelism of the shafts will cause irregular loading across the teeth, with risk of breakage and a certainty of noisy running.

Where plain bearings are used, they should be liberally proportioned and lubricated either by pressure-fed oil, or alternatively by ring oiling. The bearing must be kept protected from the ingress of foreign matter. In the frequent circumstances in which these requirements are difficult of fulfilment, ball and roller bearings provide a solution. These bearings are admirably adapted to gear mounting; they are easy to lubricate and to protect; they are substantially free from wear and hence need no adjustment; they keep the gears in correct alignment and they involve minimum power loss in bearing friction.

The gears should also be free from external loads which may lead to mal-alignment. As already mentioned in connection with turbine gears, the alignment of rigid couplings should be carried out with the greatest care and if the stability of the foundations is open to suspicion, flexible couplings should be used.

Double helical gears tend to centre themselves relative to each other but, for the best running, both wheel and pinion should be definitely located and isolated from external thrusts.

DOUBLE HELICAL GEAR UNITS.

From the foregoing remarks it might be assumed that gears are delicate things requiring laboratory care in cutting and mounting. This is not so; all that need be said is that they require care and attention to certain principles. For this reason a number of gear manufacturers standardise a range of totally enclosed reducing gears, in various types, and with one, two and sometimes three stages of reduction. Design and manufacture of the housing and bearing arrangements by the gear maker tends to ensure that the gears will run under the most favourable conditions, and at the same time, quantity of production means lower cost and speedier delivery.

WORM GEARING.

Whilst comparison is difficult, it is probably true to say that worm gearing has been the subject of more scientific research, and has been developed to a higher degree, as compared with its elementary form, than any other form of gearing. It has had to make head-way against great prejudicies consequent upon the imperfections of the earliest drives, and it is only within the last few years that it has come to be accapted as a form of drive of high efficiency and load carrying capacity, with peculiar advantages under certain conditions.

It is curious that early worm drives, being very inefficient, were often used as irreversible drives, whereas to-day there is nothing a worm gear designer likes less than to be asked to furnish an irreversible worm gear.

TOOTH ACTION OF WORM GEARS.

In order to appreciate the advantages of worm gearing, it is necessary to understand the nature of the tooth action between a worm and a wheel. There are two main types of worm gear, known as the "parallel" and "globoidal" types respectively. In the first of these, the worm is a true screw, i.e., the threads are of helical form. This type is the easier to treat analytically, to manufacture, to inspect, and to mount.

If a screw be rotated, the threads appear to move in the axial direction. On a section containing the axis, every thread is similar and symmetrical and thus represents a rack which on rotation of the worm will move endwise. The wheel teeth on the same section will have the same form as those of a pinion of the same diameter. If the threads of the worm are of standard rack section, the teeth of the wheel will be of involute form and this type of gear is thus known as involute worm gearing. On other sections, the threads of the worm, owing to their helical form, are no longer symmetrical, but they are still similar and move uniformly, so that the rack and pinion analogy still holds good. This enables the tooth profiles and the extent of contact to be determined mathematically. With an ordinary rack and pinion, the line of contact is a straight line extending across the teeth and moving uniformly from top to bottom, but when the rack is replaced by a worm this no longer applies, because the tooth profile is constantly changing across the face width. Contact between the worm and wheel is still line contact, but the line of contact is now curved and does not move uniformly over the teeth. The way in which it moves determines the load carrying capacity and efficiency, and this in turn is controlled by the worm thread profile.

The conventional involute form of thread has a section corresponding to the standard involute rack tooth, which is straight sided and has a pressure angle of, usually, 14½ deg. This angle is unfortunately chosen, because it leads to "undercut" teeth and a concentration of the lines of contact, at the root of the teeth. Fig. 5 shews in end view and section the form of tooth and the motion of the line of contact over the tooth.

Further comment on this point may be desirable. Between the teeth there is a sliding velocity determined by the dimensions and speed of rotation of the worm, and independent of the actual tooth profile. An ordinary bearing running at the speed and pressure of worm gearing could not be lubricated, but the presence of lubricant between the threads of a worm and the teeth of the wheel is due to the fact that newly lubricated surfaces are constantly being brought into contact. This is controlled by the "rolling velocity," i.e. the speed of motion of the line of contact over the tooth surface. Obviously any concentration of the lines of contact will adversely affect the lubrication and will at once reduce the efficiency and increase the rate of wear.

It does not follow directly, however, that the absolute maximum of rolling velocity is necessary, because pushed to the limit it comes in conflict with load carrying capacity. Load carrying capacity depends upon the length of the line of contact and the more widely spaced these lines of contact are over the tooth area, the less must be their total length. The precise rolling velocity to be adopted is determined by experience. Fig. 6 shows the original "D.B.S." patent high efficiency worm gear, represented in the same manner as the gear of Fig. 5. This, it will be noticed, has a totally different and greatly improved distribution of contact, and a gear of this kind obtained efficiencies of over 97 per cent. when tested at the National Physical Laboratory. The total length of line of contact is less than in the gear shewn in Fig. 5 but this is more than offset by the improved contact conditions between the teeth.

A further modification has however been introduced in the last year or two, known as the "D.B.S." "extended contact" worm gear. Although produced on the same principles as formerly, a change in methods of tooth design has resulted in a substantial increase in length of line of contact, whilst maintaining an ample rolling velocity. This is shewn by Fig. 7. In these diagrams the effect of the rolling velocity over the worm threads cannot be seen, but in the gear of Fig. 2c this velocity is increased very considerably as compared with that shewn in Fig. 6, the area swept out by the line of contact in its movement over the worm threads having been nearly doubled. The maximum useful face width of the wheel has also been increased.

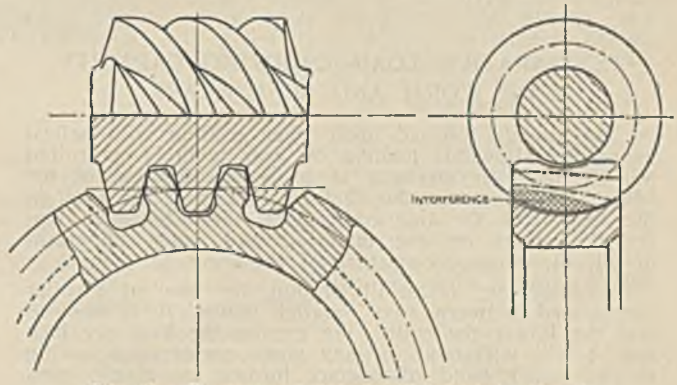


Fig. 5.—Contact of Standard Involute Tooth.

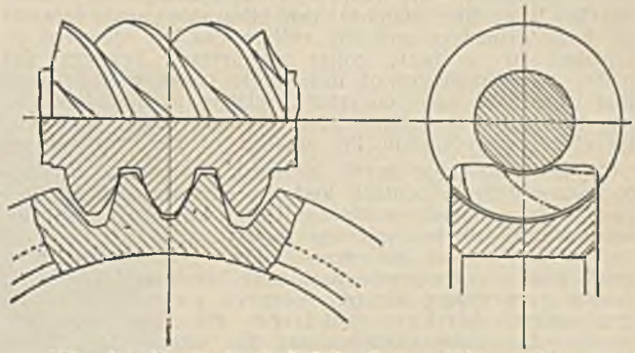


Fig. 6.—Contact of D.B.S. Patent Worm Gear.

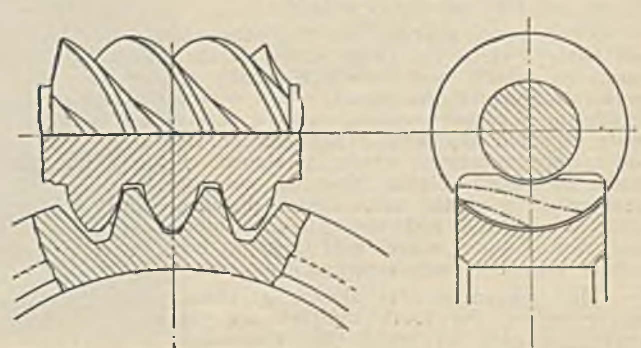


Fig. 7.—D.B.S. Extended Contact Worm Gear.

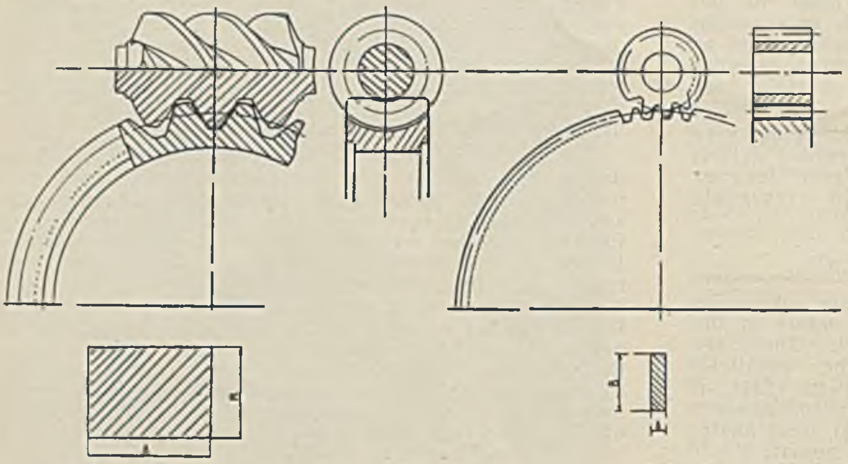


Fig. 8.

COMPARATIVE LOAD CARRYING CAPACITY OF WORM AND SPUR GEARS.

As already touched upon when dealing with helical gears, the allowable loading on gear teeth is controlled not so much by strength as by a consideration of the surface pressure on the teeth. This is a question of the length of the line of contact, the allowable compressive stress on the material, and, most important of all, the relative curvature of the teeth.

Considering, as an illustration, the case of a roller compressed between two parallel plates, it is obvious that the larger the roller, the greater the load per inch that it will withstand for any given compression, owing to the wider band of contact formed by elastic compression of the material. The allowable load is theoretically proportional to the diameter. If two rollers of unequal diameter are placed in contact with their axes parallel (i.e. line contact) the allowable load depends on both diameters and the rollers can be regarded as replaced by a single roller compressed between flat plates . The diameter of this single roller will be such that it has the same curvature, relative to the plates, as the two original rollers have to each other, and will therefore be less than the smaller of the two rollers.

Two spur gear teeth in mesh correspond exactly to two rollers in contact, and the curved tooth profiles (which correspond to the rollers) will have a radii of curvature of between one quarter and one third of the pitch radii of the gears. Hence the tooth of a small pinion corresponds to a very small roller indeed. For a given centre distance between the shafts of two spur gears, therefore, the larger the gear ratio the smaller the pinion diameter and the smaller the radius of curvature of the tooth, and the allowable load per inch of face width decreases, approximately, with the square of the pinion diameter.

With worm gearing, on the other hand, this does not apply. Here the tooth shape of the pinion corresponds to a rack, and does not greatly change with the gear ratio; whilst the wheel, which corresponds in tooth profile to a pinion meshing with a rack, is of substantially constant diameter regardless of gear ratio. The radius of curvature, which is almost constant for all ratios, is much higher than is possible with a spur gear working at the same centre distance. In fact, for ratios of 5 to 1 and upwards, a hardened steel worm and bronze worm wheel will carry as high, or a higher torque than two case-hardened spur gears.

This comparison is shewn graphically in Fig. 8, where below the tooth outlines are shown two rectangles in each of which the dimension A represents the length of the line of contact and B the relative radius of curvature. The area therefore represents the allowable tooth load for the same materials, modified by an increase of about 30 per cent. when the worm wheel is made of bronze owing to the greater comparability of this material as compared with steel and the consequently greater area of contact.

WORM GEAR MATERIALS.

Experience has shewn that, in general, the best combination of materials is a casehardened, ground and polished worm, meshing with a bronze worm wheel. This generalisation is, however, subject to qualification. As regards the worm itself, any casehardening material will give a surface hard enough to withstand the surface pressure, but so great is this pressure in high duty drives that, whilst the surface may stand up, the stresses transmitted through the outer layer may result in separation of the case from the core, leading to "flaking." In order to provide a sufficiently tenacious bond, great care is required in selecting the carburising compound, whilst an alloy casehardening steel such as a 3½ per cent. nickel casehardening steel is to be preferred to the ordinary low carbon material.

Still greater differences in load carrying capacity follow slight differences in analysis and method of casting of the worm wheel bronze. The earlier worm wheels were of phosphor bronze, sand cast, and until a few years ago this material was the best available. The application of chill casting was the first improvement, leading as it did to a much harder bronze of finer structure and better wear resisting properties. A further step forward, of equal or even greater importance, was the adoption of centrifugal casting to worm wheel blanks, developed by the author's firm. Numerically, the comparative load carrying capacity of these bronzes, as determined by special fatigue and wear-testing machines evolved by the author, are as follows :—

Sand Cast	850
Chill Cast	1100
Centrifugally Cast	1400

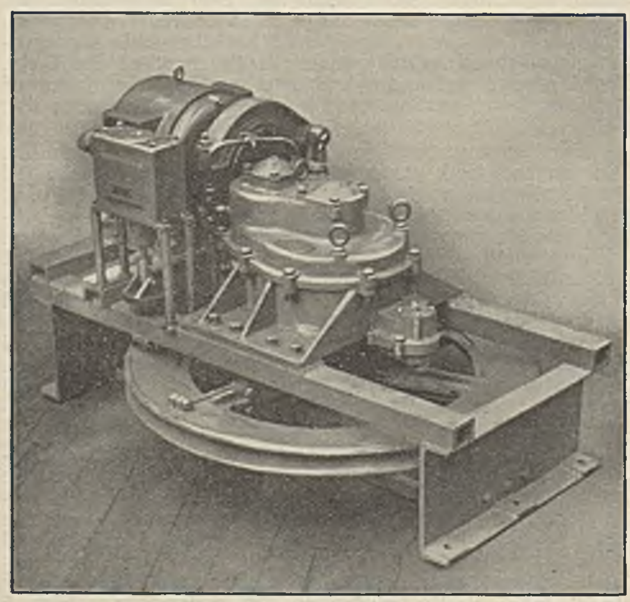


Fig. 9.—10 *h.p. Worm and Spur Endless Rope Haulage by Beckett and Anderson. Total Ratio* 41.5 *to* 1.

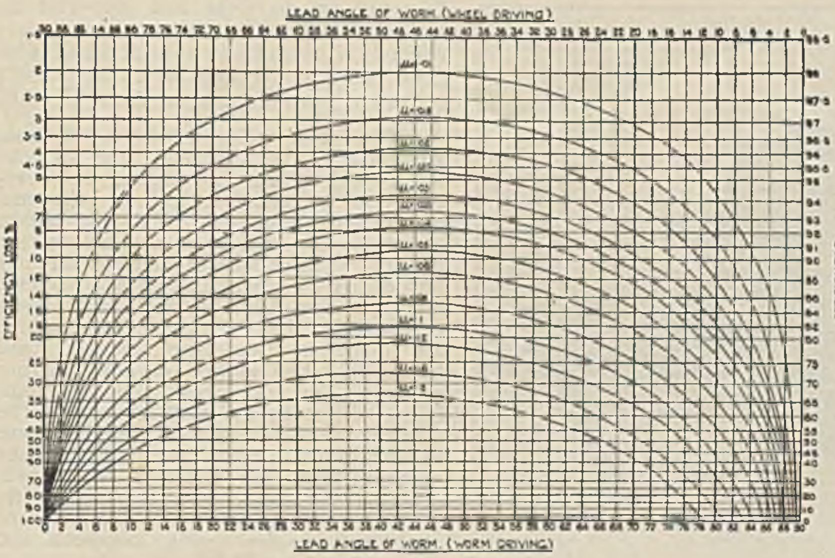


Fig. 10.

A further feature of the centrifugally cast worm wheel of great practical importance is the absolute uniformity of structure throughout the rim, whereas the chill cast blank is apt to vary considerably at points beyond the influence of the chill.

WORM GEAR EFFICIENCY.

The efficiency of a worm gear drive depends upon the geometrical form of the worm threads and the co-efficient of friction. The latter quantity in turn is controlled by the lubricant used and the velocities of rolling and sliding. Where the worm thread profile is correctly designed, the co-efficient of friction can be predicted with considerable accuracy. As is to be expected, it falls off considerably as the speed of the gears increases and, contrary to the opinion once held, there is no limit to the speed at which worm gearing will run.

As applied to "D.B.S." worm gearing the Table II. indicates the variation in co-efficient of friction with speed, using a good mineral oil and a castor-base oil respectively.

TABLE II.

Rubbing speed feet/min.	Mineral.	Castor.
100	.051	.041
500	.034	.029
1000	.030	.026
1500	.028	.024
2000	.026	.023
3000	.024	.022

Knowing the co-efficient of friction, the efficiency of the drive can be read off from the chart (Fig. 10) for any given lead angle, this chart having been calculated from the usual expression :—

$$\text{Efficiency} = \frac{\tan\ (\text{lead angle})}{\tan\ (\text{lead angle} + \text{angle of friction})}$$

A full load efficiency test recently carried out by the author's firm gave the following results, which accurately confirms the above data and at the same time indicate the high efficiency of modern worm gearing. Incidently, this was the first time the gears had been run, and an increase in efficiency with continued running would certainly occur.

Input horsepower	49.8
Output horsepower	47.3
Efficiency	95%
Wormshaft speed	1160 r.p.m.
Wheelshaft speed	280 r.p.m.
Rubbing speed	1850 ft. per min.
Lubricant ...	Duckham's "D.B.S." Worm Gear Oil

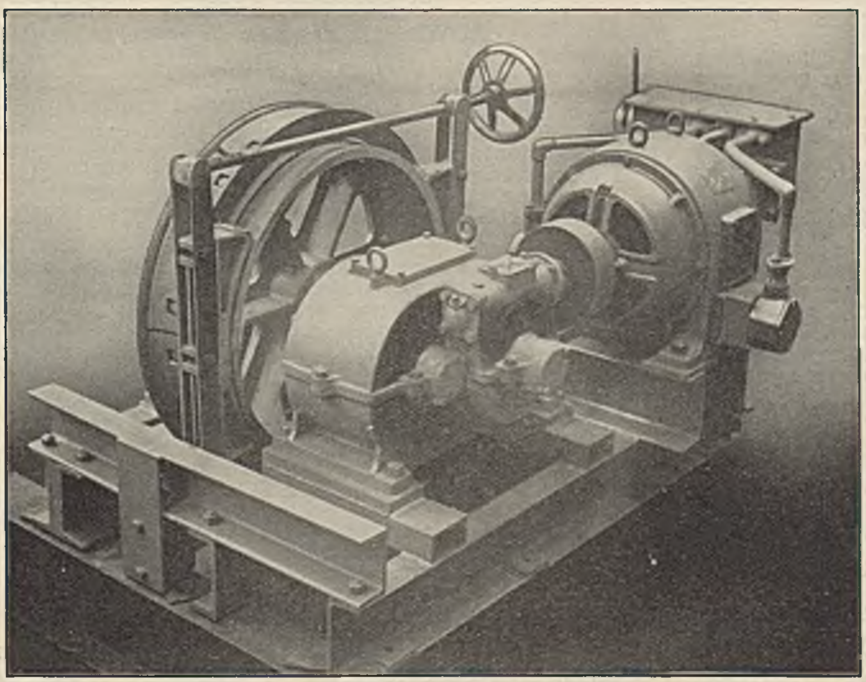


Fig. 11—15. *h.p. Worm and Spur Geared Endless Rope Haulage by Beckett and Anderson. Total ratio* 41 *to* 1.

LUBRICATION.

Worm gearing makes greater demands upon the lubricating properties of an oil than any other form of gear. The combination of high surface pressure and high rubbing velocity calls for the maximum degree of "oiliness"—a quality apparently quite independent of the physical properties of an oil. The variation of the co-efficient of friction with rubbing speed clearly indicates that the tooth surfaces are separated by a film of lubricant which is built up by the relative movement of the teeth, but the precise nature of the friction is largely a matter of hypothesis.

A considerable amount of research has been carried out on the subject, and all the evidence shews consistently better results with castor oil, or oils consisting mainly of castor, as compared with mineral oils. The difference is from 20 per cent. to 25 per cent. in favour of castor, in respect of tooth friction, as compared with the next best mineral oil. This difference, regarded as tooth loss, is small as regards the efficiency—the difference, say, between 95 per cent. and 96

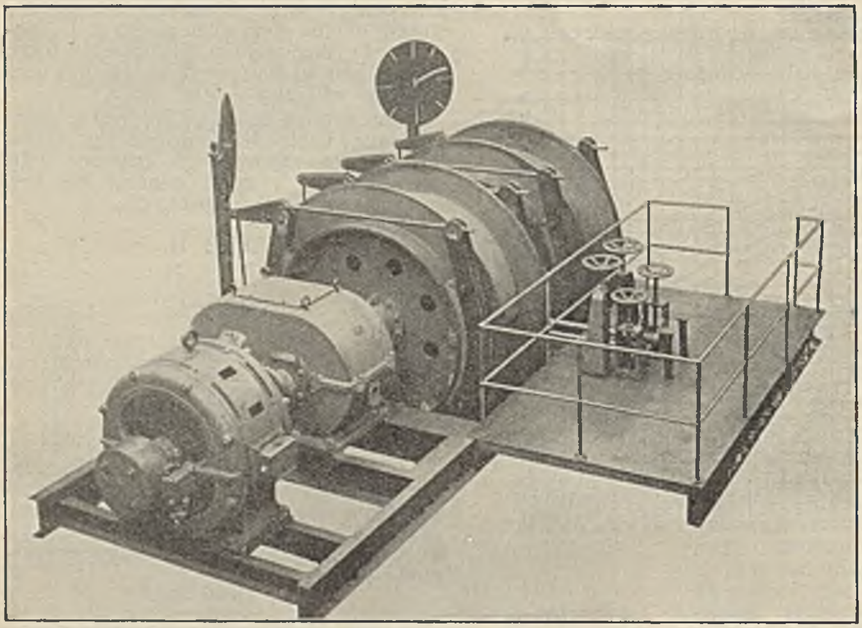


Fig. 12.—200 *h.p. Main and Tail Haulage, Beckett and Anderson: Double Reduction Spur Gear: First Stage, D.B.S. Double Helical: Total Ratio,* 730 *to* 30.

per cent., but the effect on the temperature rise is in direct proportion to the frictional loss. In the case cited, therefore, the allowable horsepower which can be transmitted for a given temperature rise is in inverse proportion to the percentage loss, i.e., in the ratio of 5 to 4. Alternatively—since in industrial applications the rating of a gear is determined less by the load carrying capacity of the teeth than the heat dissipating capacity of the casing—the use of a lubricant giving a higher efficiency permits a smaller gear to be employed.

WORM REDUCING GEAR UNITS.

The comments already made on the mounting of helical gears apply with equal force to worm gears, and the use of ball and roller bearings throughout is equally desirable. Worm gears, however, provide an extra problem in bearing design owing to the necessity for catering for a heavy end thrust at high speed. Early practice was to use a double ball-thrust unit on the worm-shaft, in conjunction with plain journal bearings, and plain bearings for the wheel shaft. The next step was to substitute ball or roller bearings for the worm-shaft journal bearings. At high speeds, however, double-thrust bearings, particularly of large size, are not always satisfactory, owing to the centrifugal force on the balls, and the introduction of the double-purpose bearing, capable of carrying both radial and thrust load, has led to their increasing use in worm gear mounting, and in the best practice both worm and wheel shafts are carried in bearings of this type.

Simplification of plant design has led to an increasing use of totally enclosed worm reducing gear units, whereby the necessary rigidity and accuracy of mounting are most easily secured. This point, touched upon in dealing with helical gear units, needs no amplification.

A final point centres round the use, in conjunction of electric motors and worm reducing gears. Correct alignment is necessary, not only initially, but permanently, and any possible cause which may lead to mal-alignment is to be avoided. Frequently, however, worm gears mounted on ball bearings are coupled to electric motors with plain bearings and, quite apart from the frequent attention which such bearings need, they are apt to wear and give rise to mal-alignment. For mining purposes, particularly, it is difficult to understand why plain bearings are used at all when ball or roller bearings can be fitted instead.

The other principle cause of mal-alignment is movement of the foundations, which can, of course, be overcome to a certain extent by the use of flexible couplings. Both the above objections are, however, avoided by the use of "geared motor units" recently introduced by David Brown & Sons Ltd. in conjunction with the British Thomson Houston Co. Ltd. In these units, which are made in two types, vertical and horizontal, the motor is ball bearing mounted and is carried on a flange bolted direct to the gear housing. The combined unit is carried on the base of the gear housing only: it is thus immune from the effect of the movement of the foundation, is permanently in line, and requires a minimum of attention, besides being compact and very easily installed.

In concluding this rather disjointed paper, which it is realised must of necessity be incomplete, an attempt has been made only to indicate some of the more important considerations governing the design and performance of gear drives. It is, however, hoped that sufficient information has been given to show that gear specialists have "done the State some service" in their endeavours to further the efficiency and reliability transmission of power by gearing.

DONCASTER SUB-BRANCH.

Probable and Practical Methods of Lighting at the Coal Face.

EDWIN LYON, B.Sc. (Tech.)

(*Paper read 22nd February,* 1930.)

In Herman Melville's epic of the Whale, "Moby Dick," in a chapter headed "Lamps," the following lines will be found: "In merchantmen—oil for the sailors is more scarce than the milk of Queens . . . But in the whaleman, as he seeks the food of light, so he lives in light. He makes his berth an Aladdin's Lamp."

Now think of those who also toil for the food of light—not on the sea—but in the depths of the earth. Those who are surrounded by coal, from which is produced almost all the artificial light in the world. Are they provided with the best illumination? Do they work by an Aladdin's lamp? It is a sorry state to have to admit that the miner works by what is practically the lowest working illumination in the world. The following figures show the average illumination common to certain trades.

Work.	*Illumination Foot Candles.*
Filament mounting	500
Lamp assembling	100
General rough work	10
Mining: Cap Lamp	1
„ Hand Lamp	0.1

Why is this? Has every avenue of alternative illumination been explored? Are we taking the utmost advantage of every scientific discovery which may lead to better lighting underground?

Coal direct into Light.

We know that at present the "conversion" of coal into light involves numerous and complicated processes, with a resulting very low overall efficiency. From when the coal leaves the face, work is continually expended on it—in carrying it to the surface, burning it in boilers, and "converting" the steam into electricity. Finally the current is applied chemically to change the plates of the cell to "store" the current. After all these processes and "conversions," the miner takes his lamp down the mine to the face, whence the coal is being drawn.

How much would be saved if the coal could be "converted" into light at the coal face. Such a process appears ridiculous and impossible—but lots of seemingly impossible things have been done during the last decade.

Suppose that a collier, by taking a pound of coal, quite a small piece, say 3 inches square, and inserting it into a contrivance about the size of the present lamp, could get all its stored energy in the form of light. Take an average figure for the calorific value of coal—13,450 B.T.U. per pound. By Joule's Law we find the total available energy of this pound of coal is equal to 4000 watt-hours. In a 10-hour shift 400 watts would be available, and using a modern electric lamp this could mean 400 c.p. for the whole shift. This is 200 times the energy available in the present portable lamp.

Even if this "conversion" could be carried out with the same degree of efficiency as that of the modern power station, with a thermal efficiency of 20%, and using 1½ lbs. of coal per unit generated, this could be used to give a light of 50 c.p. for 10 hours using only 1 lb. of coal.

Looking at the available energy in the coal from another point of view—the production of gas. One pound of coal will produce 6 cu. ft. of gas (550 B.T.U. per cu. ft.). This with an ordinary low-pressure incandescent gas burner would be capable of maintaining a light of 12 c.p. over a 10-hour shift.

But such methods for the direct treatment of conversion of coal are not yet possible.

Man-made Light.

Let us turn to possible methods which may appear to offer at first sight, a more efficient means of providing light. Consider—on first principles—even the most ridiculous. Can the collier, by actual manual work, make his own light? Can some of the energy he exerts be economically transformed to light?

Examine a simple example—a small generator driven mechanically by a falling weight which is raised at the limit of its travel. Aim firstly at securing as much light as the present portable hand lamp—1 c.p. or 2 watts. The theoretical energy required to produce 2 watts would be 100 foot-pounds per minute.

Assuming a 5 ft. drop, this would mean the raising of a 20 lb. weight *every minute*, or a 40 lb. weight every 2 minutes and so on—and this assuming 100% efficiency in the generator.

Not a very efficient method—but one which shews the surprising energy in the small accumulator of the miners' electric lamp.

There are several hand lamps on the market which operate by continuous hand leverage or clock-work driving a small generator, but these are useless for real hard work in the pit.

The Thermo-Electric Pile.

Another method not used commercially—but which has always appealed as an unexplored avenue, is the thermo-electric pile. In the early days of electricity this was looked upon as a possible means of producing power—utilising the Thomson and Peltier effect to produce differences of potential in two dissimilar metals with their joints at different temperatures.

Unfortunately the e.m.f. of a single joint is very low—of the order of 16 micro-volts per deg. C. The high resistance of the number of joints necessary—and of the elements, reduces the efficiency to the order of 5%.

Imagine a portable thermo-electric lamp made to carry boiling water. If the whole range of the fall in temperature from 100 deg. C. to 50 deg. C. could be efficiently used, it would require a supply of 12 lbs. of water to give a light equal to the ordinary hand lamp for the full shift. In addition there would be the weight of the generator and lamp itself.

Primary and Secondary Batteries.

The general present day practice is to use primary and secondary batteries as a source of power for portable lamps. Primary batteries are useful when used intermittently, when the battery has time to recover from the effects of polarisation. For continuous work such as mine lighting, they are useless and expensive. Secondary batteries or accumulators are used with success and economy. They are cheaper to operate than candles, carbide lamps, or flame lamps.

Floodlighting.

So far our considerations have been confined to portable lamps. It is not, of course, essential that a mine should be lit by portable lamps. It would be a definite advantage if the illumination could be obtained from fixed or transportable lamps which required no attention in the matter of recharging. Surface floodlighting with high voltage lamps is made use of in Germany. Although the regulations relating to the use of electricity at the face are said to be more stringent than our own, similar equipment would not be considered safe or permitted in this country.

It may be possible to ensure some degree of safety by means of devices operated by pilot wires, but connecting and disconnecting for extension would be a potential danger, and a multiplication of safety devices and interlocking arrangements becomes cumbersome and expensive.

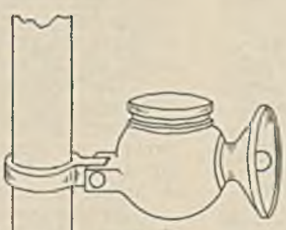


Fig. 1.

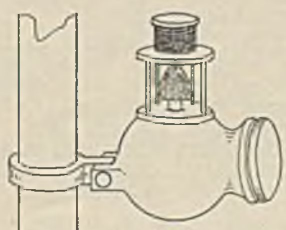


Fig. 2.

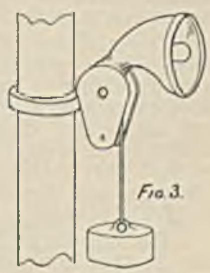


Fig. 3.

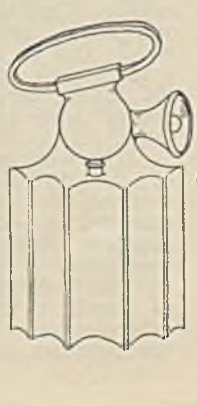


Fig. 4.

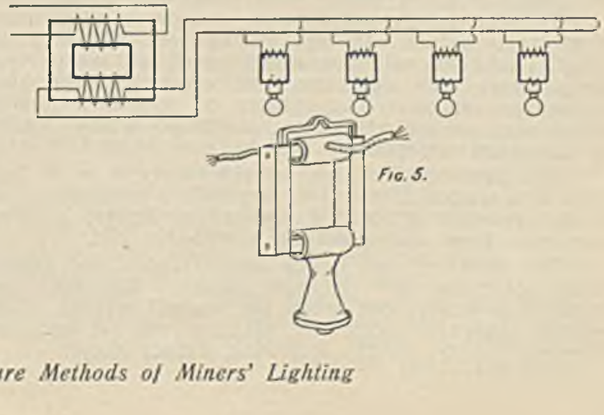


Fig. 5.

Future Methods of Miners' Lighting

A system of low voltage lighting by means of step-down transformers has been suggested, but when the voltage becomes high enough to give any real advantage, the attendant danger so far appears too great to justify the use of this system.

A Transformer Core-Coupling System.

With regard to coupling connections, it would be possible to put a lamp into commission by connecting the cores of small transformers without breaking the electrical circuit in any way.

With such a system a ring-main could be laid in the form of a cable with coils an inch or so in diameter wound on hollow bobbins, connected in parallel with the line, and formed say 10 feet apart. The whole cable would form one complete reinforced unit.

The core could be permanently in the circuit of each primary winding, split or opened to permit the insertion of a loose secondary coil with its lamp.

The bulb could be changed or the unit moved without breaking the circuit when the current was flowing—breaking only the magnetic flux.

Objections to this method can be seen. For example, the self-induction of the circuit would be high and the danger from sparks correspondingly greater. At the same time it offers a solution to one problem in low-voltage distribution—the drop in volts could be compensated for by a gradual change in the primary turns, so that constant voltage would be given in all secondary windings whatever their position on the line.

Further, the voltage of the main leads, which are liable to damage, could be lower than that of the lamp bulb, as the secondary winding could step up.

The compressed-air generator is another method by which higher candle-power can be obtained, but the cost and the complications is against its adoption for general face lighting.

The Modern Miners' Lamp. The Battery.

Having now briefly explored the available avenues for lighting power, it appears conclusive that although the modern portable electric lamp has an extremely low overall thermal efficiency, it is the best practical means of mine lighting known to-day. There are two distinct types of secondary cells—the lead-acid cell and the newer, but not new, alkaline cell.

The alkaline cell at first sight appeals to the engineer. It is very strong mechanically, housed in a stout steel container it carries no acid and its electrodes are steel cages which are sound in construction. Long standing uncharged does not affect its efficiency. But it suffers from several disadvantages when used in a miners' lamp. The voltage of a single alkaline cell is low—1.3 volts, and therefore two cells must be used in series to give 2.6 volts.

The discharge curve is steep. The bulb is overrun at the beginning of the shift, and in consequence its life is shortened; or, alternatively, the bulb is operating at a low efficiency at the end of the shift. Attempts to change this characteristic have so far failed.

The caustic electrolyte will become oxidised unless kept from contact with the atmosphere. Although the caustic solution will not attack steel, it readily eats away brass and aluminium and must be kept away from these metals. The absence of acid is a doubtful advantage, particularly in a cap lamp, where leakage of the caustic electrolyte can be very painful.

The first cost is high, approximately 3 to 4 times that of a lead-acid cell, and therefore a problematic life of 4-5 years is a doubtful proposition against a certain one year from the plates of a lead-acid cell.

The lead-acid cell is the most reliable and efficient means of "storing" electrical energy. The lead electrodes are heavy, but when the overall weight of the cell is compared with the alkaline cell, it compares very favourably, as the following figures show:

CHARACTERISTICS OF LEAD-ACID AND ALKALINE CELLS.

	Ampere hrs./lb.	*Watt hrs./lb.*	*Watt hrs. cu. in.*	*% voltage variation from mean.*
Lead-Acid Cell (Free Acid)	3.6	7.2	.72	+ 13.2 — 8.6
Solid Electrolyte	3.5	6.8	.70	+ 12.8 — 7.7
Alkaline Cell (British)	3.4	8.2	.82	+ 13.8 — 26.8
Alkaline Cell (German)	2.8	6.5	.74	+ 12.1 — 22.4

With regard to the relative merits of "free acid," and solid electrolyte, there is no doubt that theoretically "free acid" is definitely preferable. No added matter can improve the performance of the cell and the actual active acid content of the cell is reduced by any addition.

A solid electrolyte would not be considered for a stationary battery, where overall electrical efficiency is of the utmost importance. But in a cell for a miners' lamp, different conditions obtain. The actual efficiency in terms of input to output is not of serious importance, nor is the internal resistance of the cell.

What is important is the efficiency in terms of pit service—the ability of the cell to stand up to hard work and require little attention, and the effect of the cell on other components. Here Jellac, the solid electrolyte, definitely does stand out. There is no leakage, a condition practically impossible with free acid, for acid creeps and penetrates minute cracks and somehow defies the most elaborate traps. The corrosive action of acid on contacts is responsible for much trouble with flickering lights, and also for heavy costs for spare parts. A further point in favour of the solid electrolyte is that the absence of spilling allows the topping up to be performed regularly at a pre-determined time. The swilling action of the acid on the plates is also removed. It should be noted that these advantages are all definitely applicable in a cell which is portable and subjected to rough usage.

The Bulb.

The manufacture of small electric light bulbs is an art. The same materials are universally used, but bulb performances vary greatly. Tungsten is used for the filament, supported and connected to steel feet, which are in turn connected to platinum (or substitute) leads to carry the current through the glass and then by copper leads to the cap.

The length and diameter of the tungsten filament determine the "efficiency" or rating of the bulb. By efficiency is meant the watts required for one candle-power, no notice being taken of the life. The filament of a bulb of low watts per candle-power operates at a higher temperature than that of a bulb of high watts per candle-power. The rate of filament evaporation is greater, the blackening of the glass more rapid, and the life of the bulb shorter.

The actual life of a bulb on stationary duty can be predetermined to close limits, but the relation between the bench life and the life in the pit is not easily determined. Conditions of usage underground vary greatly, and unless experiments are undertaken on a large scale, results can be misleading. Recently, for the first time, a large scale investigation into the relationship between the rating, the bench life, and the life in the pit of miners' lamp bulbs of different rating has been undertaken.

The work was carried out by a Sectional Committee of the British Electrical Standards Association. The tremendous amount of data proved extremely illuminating and in many ways surprising. There is more than sufficient information to provide matter for a technical paper, and it would be unfair at this stage to comment on the findings. Experience has shown that the life of a bulb in the pit often exceeds the bench life. The difference may be accounted for by the fact that bench life tests are carried out at a constant pressure of two volts. Under working conditions the average voltage is 1.95 volts. The bulb is therefore operating in the mine at a lower rating and the life, from the standpoint of filament evaporation will be longer.

Actual tests on similar bulbs at 2 volts and 1.95 volts showed that the life of the 1.95 volt bulbs is almost twice that of the bulbs operating at 2 volts. Against this, the usage in the pit will be responsible for many mechanical breakages. A bulb of very low rating which would last, say, 2000 hours on bench test, would be broken before that time in the pit. The most efficient bulb would be one in which the bench life at the average working voltage was exactly the same as the limiting life due to mechanical breakage.

There are, of course, many variations in the life of the bulb due to differences in manufacture. The method of connecting the filament to the feet, the efficiency of the seal in the bulb foot, and, what is most important, the degree of vacuum obtained and maintained.

The manufacture of bulbs is a highly skilled art demanding constant care with all the numerous operations, and specialised equipment of an intricate nature.

Lamp Design.

The design of the lamp itself presents many prolems, most of which are solved by long experience in the pit. The type of joints, the provision of safety devices, the use of prismatic glasses, are all points which have great bearing on the ultimate true efficiency of the lamp and the cost of maintenance.

A word about the cap lamp: this certainly gives greatly increased illumination, up to 10 times that of a hand lamp, and it is now rapidly finding favour in many districts—quite apart from Scotland, the home of the cap lamp.

Floodlighting by portable lamps of the so-called Bull's-eye type is also being investigated. In this connection it should be noted that a much more even intensity is obtained using 4 volt wide-angle beam lamps than by half the number of 8 volt lamps.

Having now considered briefly the available means of electric lighting, and also more briefly still the present types of electric safety lamps, it will be agreed that the portable electric safety lamp is the best means available to-day for mine lighting, and that the modern electric safety lamp embodies all that modern science and experience has been able to give up to the present.

At the same time, there is great scope for improvement. New methods must be investigated. Too much notice must not be taken of past work and of precedent, for as Mr. A. P. Herbert says: "as Lord Mildew said in *Bottle v. the Port of London Authority*, 'There is no precedent for anything until it is done "for the first time"'".

Discussion.

Mr. WHITEHOUSE (in the Chair) thanked Mr. Lyon for his paper and said he hoped members would ask question on any points they were not quite clear about. He, himself, did not favour the use of Jellac in cells: he thought it was only a makeshift way of dealing with the situation. Further, the use of free acid was the thing to-day, as it was now possible to make cells which were unspillable; also, the increased length of life of the plates due to the use of free acid was worth consideration. An average life of between 15 and 18 months was obtained by use of acid against an average of 8 or 9 months with Jellac. He also asked Mr. Lyon how was it that there was such a large difference in the performance of two-volt bulbs. There did not appear to be any fixed standard with the various makes.

Mr. JONES asked what process was used in the forming of lead plates, as he thought much depended on that. Also, could not gas-filled bulbs be used to get better lighting.

Mr. STAFFORD said he really thought the question of free acid versus Jellac depended much on the skill with which the lamps were handled. Much could be done by attention to the mixing of Jellac, also to see that the right composition was used. He had known the use of iron files in cell re-plating have an injurious effect on the cells, but he did not think the question of spilling had been quite got over.

Mr. MANN asked Mr. Lyon if he did not think it would be cheaper to have all cells repaired and replated by the firm who supplied them, as he thought they were in a better position to deal with the matter.

Mr. BUNNEY did not think cap lamps a good proposition for work in thick seams, and considered they were awkward when it came to walking distances in the pit with them.

Mr. RIGBY said he would have liked to hear about the Gas Detector lamp, as he considered it ought to be possible to detect gas without having to use oil lamps.

Mr. MORRIS said anything that could be done to improve the light at the coal face was worth consideration, but he did not consider the transformer scheme set out by Mr. Lyon was practical, as the using of cables at the coal face was a big proposition. He, Mr. Morris, was inclined to think the use of compressed air lamps had much in its favour if the first cost was less than it was at present. He was rather surprised, according to Mr. Lyon's figures, at the relative efficiency of Jellac cells against those with free acid. He thought the discrepancy would have been much more in favour of free acid. Although personally he favoured the use of Jellac, as he considered taking all points into consideration it was the best thing to use, he quite understood that a plate lasted longer and was more efficient with the use of acid; but there was bound to be a certain amount of leakage after the cells had been in use any length of time. He thought Nickel Cadium cells with Alkaline solution had much in their favour and when they became more efficient weight for weight they would be a serious rival to lead acid cells. With regard to the point made by Mr. Lyon that the lighting from cap lamps was 10 times as efficient as the ordinary lamps, Mr. Morris said he should like Mr. Lyon to explain how he arrived at this figure.

Mr. LYON (in reply).—In reply to Mr. Whitehouse, Mr. Lyon said that he could not agree with the figures given for the length of life of plates. A recent large scale test at three different collieries had shown that a life of 12 months with the negative plates and 15 to 18 months with positive plates could be obtained when using Jellac. With free acid the negative plate had a longer life and the positive a shorter life. There was little to choose between costs in each case. The real crux of the question was the performance of an "unspillable" cell after service in the pit. Sooner or later the free acid cells leaked.

With regard to the variation in the performance of bulbs, it should be noted that a variation of 1 millimeter in fixing the filament of a two volt bulb was a 10% error, but with high voltage bulbs the same variation would mean an error of 0.1%.

The usual process of plate formation was outlined in response to Mr. Jones' query, and it was explained that gas-filling showed no advantage in a two volt bulb, owing to the shortness of the filament. The advantage at four volts was doubtful, but it was appreciable at 6 volts.

Mr. Mann's proposition regarding cells being sent back to the makers for replating, was interesting, but the question of cost would go against it. Unless new material was used, an experienced lampman should be able to carry out a repair as well as the manufacturer.

Mr. Bunney's contention regarding cap lamps in thick seams was held by many who were accustomed to hand lamps, but in many districts, with thick seams, men had in time grown to like the cap lamp, when they had become accustomed to the change.

The Gas-Detecting Lamp referred to by Mr. Rigby was put forward experimentally some four years ago. It consisted of an electric lamp, usually of the Bulls Eye type, surmounted by a small oil lamp, the flame of which could be lit electrically and controlled from the lamp top. The flame was protected by double gauzes, and the intake was near the top of the lamp. The electric lamp was used for general inspection work and switched off when a gas test was made, the oil flame being lit, turned down, and the cap examined. The flame was then extinguished and the electric lamp lit. The present form of lamp gives very good readings, and is in daily service in numerous pits. It has the advantage of being positive in action, and the action can be seen and not remain inoperative without the user being aware of it.

Mr. Morris had commented on the transformer core connecting scheme. This was first an original idea put forward for discussion. There were many objections to it, and to other schems for floodlightng.

With regard to compressed air lamps, to light a face with these would prove an expensive proposition, although for special duties this type of lamp was giving good service here and in Germany.

On the question of Jellac and acid cells, the whole question should be considered from every point of view. As Mr. Morris pointed out, a certain amount of leakage occurred in time. This gave trouble in the lamproom, and the slight advantage in efficiency was soon outweighed in practice.

In reply to Mr. Morris on the cap lamp: as the light was collected into one area, this gave an increase to at least 4 c.p. As the light was nearer the work, the actual illumination was greatly increased. For example, assume a hand lamp of 1 c.p. placed 4 ft. from the face, and compare this with a cap lamp of 4 c.p. on a man's head, say, 2 ft. 6 ins. from the face. The illumination would be as $\frac{1}{4^2}$ is to $\frac{4}{2.5^2}$, that is, as 0.0625 is to 0.64, or slightly over 10 to 1 in favour of the cap lamp.

LONDON BRANCH.

Design and Construction of High Tension Joints.*

Discussion.

Mr. A. C. SPARKS (Branch President) said that as clients of his firm had erected what he believed to be the first 33,000 volt line in this country, on their advice, they had been closely in touch with the experience gained since that time. As the author had dealt so largely with 33,000 volt work, he was sorry to note that there was no reference in the paper to joint boxes at terminating points where insulators were used; as, whilst the paper brought out a number of points arising in the design of boxes, it only dealt with what were relatively the easier types of joints.

He hoped Mr. Grover would give the meeting the benefit of his experience of terminating point boxes, with special reference to the connection between the insulator and the box, the arrangement of bringing out the conductors through the insulators, and compound expansion; unless these points were carefully studied all the safeguards taken in the design of the boxes Mr. Grover had mentioned were easily lost.

Mr. GROVER, replying to the Branch President, said that with 3-core cable boxes, conductor expansion effects did not usually come into account. Each box had a sort of dome at the top to accommodate the compound expansion.

It must also be remembered that the cores in the cable were twisted, which permitted of a certain amount of elasticity, and expansion troubles had not been very great in three-core cables up to working pressures of 11,000 volts. With 33,000 volt cables, however, the conditions were quite different, and it was usual now-a-days to trifurcate the three cores below ground. The difficulties through expansion troubles upsetting the sealing of the conductor and insulator had been found to be very real, and modern designs made provision for that by fitting a flexible connection between the cable conductor and the main connector of the terminal box and an expansion chamber to accommodate the varying volume of the filling compound.

A terminal bell had much greater temperature extremes to contend with than had the ordinary cable. The temperature could vary from several degrees below zero in winter up to 120 to 130 degs. F. in the summer, so that one had not only to contend with the expansion of the exposed cable running up the tower, but also the expansion of the porcelain itself.

With regard to the sealing of the insulator into the base, he illustrated a section of a typical cast-iron base and pointed out that very special attention was devoted to the binding of the insulator to the cast-iron shell. Usually, he said, the base of the insulator was rough and the inside of the cast-iron fittings grooved, and between the two there was a cement having the same coefficient of expansion as the porcelain. This last matter was very important, because in the earlier days, when any kind of cement was used, it was found that it would probably expand on freeizng, and troubles would occur. The quantity of water which could enter, he added, was amazing, because there was a continual breathing action going on. A box would heat and cool periodically—at least once in 24 hours—and when it cooled down it sucked in air; the moisture in the air was condensed inside; heating occurred again and that process was repeated time after time, and in the course of a couple of months, though the crack might be minute, two or three ounces of water could accumulate inside the box.

Mr. LOCKWOOD asked for more information about expansion in straight joints. The old form of Vernier expansion joint, he said, was designed to take care of the expansion of the copper alone, but he asked whether a joint had yet been placed on the market which would take care of the expansion of the copper and the lead also.

Mr. GROVER replied that various types of expansion joints had been evolved but they introduced greater evils than they had set out to cure because of the great difficulty of keeping such joints in proper alignment. Expansion generally along the cables had been supposed to aggravate the deterioration of earlier types of 33,000 volt cables because of the different rate of movement of the copper and the lead, which probably resulted in the occurrence of air or vacuous spaces; that matter had not been determined definitely but with the cable thoroughly impregnated the difficulty did not arise. The variation in length as between the copper and the lead was not so great with the high tension as with the low tension cables, by virtue of the higher thermal resistance of the high tension cable and the different coefficients of expansion of copper and lead.

If there was likely to be any subsidence along the line of a cable which might impose excessive strain upon the joints, it was general to lay the cable in a serpentine form. This enabled one to use a standard type of joint and there was very little fear of it getting out of position. If the cable was laid on a gradient, and the pull of the cable was likely to be considerable, it was often the practice to anchor the cable or joint by earth anchors, of which there were different forms available.

Mr. E. E. PICKETT asked if there were any objections to folding back the armouring over the glands after jointing. He had adopted that practice in connection with the lower voltage cables because he had found that unless he had done so the joints pulled out when a fall of roof occurred below ground.

Mr. GROVER said that there was no objection to the practice, electrically, so far as he was aware, but it did not make such a neat looking job as when the armouring wires were cut off neatly.

* See *The Mining Electrical Engineer*, May, 1930, p. 411.

Mr. E. N. CHRISTMAS asked if the braided joint was still protected by patents, and what Mr. Grover considered to be the best type of medium for a joint. Anyone with experience of jointing would appreciate the difficulties that might arise as the result of the use of a slip joint with simply a metal connector, and he asked if the braided type of joint would not be better if it were likely to be subjected to considerable tensile stresses.

Discussing the filling of a lead sheath, he said it had become the practice to use a semifluid compound. It had been stated that, when the cable expanded, the compound disappeared, and he asked whether or not it came back. It appeared to him that it could only disappear along the cable, and if it did not come back, what happened to the inside of the lead sheath?

Mr. GROVER said that if the braid joint were in use as an expansion joint he did not think it was now covered by a royalty, though he could not be sure about that. In the braided type of joint to which he had referred, the ends of the conductor were butted together, and copper braids were laid over. The ends were tapered off with a knife, and the whole was bound over with, say, a 20 gauge copper wire. The whole was then sweated solid. There was no flexibility about the joint, but it was the equivalent of glueing together two serrated surfaces rather than two plain surfaces; there was greater adhesion. One disadvantage was that it took longer to construct than did the slip joint, and unless the jointer was very careful he might leave sharp points of solder.

Mr. CHRISTMAS said that was the point he wanted to make. By binding down the tape one made a much closer joint and squeezed out any solder which should not be there, whereas in an ordinary slip joint one was likely to have solder between the cable and the ferrule. Any foreign matter in the solder would get between the cable and the inside of the connector. If one squeezed it by means of a clamp, would not the clamp tend to cool the solder too quickly? On the other hand, when tape was used, the tape bedded well down with the binding wire and formed a strong joint, and he asked if Mr. Grover would not consider that that type of joint, even though its construction might take a little longer than that of the ferrule connection, would be the better.

Mr. GROVER illustrated the two types of joint by means of sketches, and pointed out that the braid joint had not the same geometrical precision as had the ferrule joint; usually it was of greater diameter. Most of the insulation up to the level of the cable core was done by wrapping with comparatively inelastic materials, and with the ferrule joint there was only a small space to fill up before the true cylindrical form was obtained. The braid type of joint was somewhat stronger mechanically than the ferrule joint, but there were other considerations, and so far as he knew the two types were in equal favour, but with the ferrule joint one had a perfectly smooth cylindrical surface.

Mr. CHRISTMAS said his point was that with the binding wire one did impress the braid well into the cable, and there was no risk of solder getting between the cable and the connector. He supposed Mr. Grover would agree that the nearer one got the connector to the cable, the better.

Mr. GROVER said he had already stated that the braided joint had greater mechanical strength than the ferrule joint, but the ferrule could be squeezed down very tightly. Usually a well-made soldered joint of either type was adequate.

Mr. CHRISTMAS.—You do not consider the braid has a big advantage over the split back?

Mr. GROVER said he did not, unless the joint were to be subjected to more than the normal strain. With regard to compound, he said it was usually the practice, with 33,000 volt cables, to provide expansion chambers, in which the level of the compound rose and fell as the temperature varied. He illustrated a form of three-core joint containing a common lead sleeve arranged eccentrically. In a single-core cable joint the cable was very much more compact, he added, and expansion troubles were not so acute. In that case the only channel along which the compound could flow was in the conductor, and the impregnation process filled that with compound, but in the three-core cable there were big spaces which formed considerable breathing channels.

Mr. ARTHUR E. DREW said it was gratifying to learn that in this age of mechanisation we were still so largely dependent upon the skill and experience of the jointer. Many of our skilled crafts were dying out, but the cable jointer appeared to be holding his own, and on his experience the success of a joint depended. The problem of dampness was still acute, as it always was, but he was not certain, from his own experience, that perspiration was quite so deadly as Mr. Grover had indicated. In one case of which he had some knowledge there was trouble thought to be due to dampness, and various means were employed to overcome it. At that time blow-lamps were used for soldering the joints, and it was thought that condensation occurred when the flame impinged upon the cold copper and the moisture was driven up into the insulation during heating. Sweating with molten holder was therefore resorted to and the trouble disappeared. A statement in the paper which had rather surprised him was that the jointer's mate was allowed to handle a thermometer; the only thing that the jointer's mates he knew could do with a thermometer was to break it. The heating of compounds was still a problem, and apparently it was impossible to find a compound without volatile constituents. It had occurred to him, therefore, that some better method than applying direct heat to the compound might be used. For many years there had been on the market domestic cooking utensils in which there was a water jacket provided with a lightly loaded valve so as to increase the steam pressure in the container and produce a higher temperature than that of boiling water. It appeared to him that a somewhat similar vessel with a graduated valve might be of assistance to jointers, particularly those engaged in colliery work, where the difficulties were greater than those met with above ground. The author stated that when joints were made below ground the compound was heated above ground and taken down the shaft in a heat-insulated bucket; at the same time the author described an ingenious device for electrically soldering the joint, and that suggested an electrically heated vessel for heating the compound, but apparently such apparatus was not used.

Discussing the problem of ionisation of air in the compound filling, Mr. Drew said that remarkably little seemed to be understood about it. He had come across cases recently in which experienced designers of high tension gear had overlooked the fact that an air pocket resulted in a distinct weakness in the design. He did not know what happened to ionised air when it was compressed, but he imagined that the air pockets must be subjected to a great deal of pressure when the compound expanded, and that many cable joint failures might have been due to that cause.

Mr. GROVER, commenting on Mr. Drew's reference to the jointer's mate being entrusted with a thermometer, said that with the march of progress the jointers and jointers' mates had to accommodate themselves to the new conditions. They must be taught to use thermometers, and although he admitted that their use of thermometers was rather costly, the results had justified it, because very expensive materials could be ruined by overheating. A material could be changed to something quite different from what it was previously as the result of driving off the lighter volatile constituents. Most of the compounds for the 33,000 volt cables were very carefully graded to give the best results.

Mr. Drew's suggestion with regard to the use of a water-jacketed vessel for heating compounds was a very useful one, and there were certainly possibilities in that direction. As to the criticism of the system by which the compound was heated above ground and taken down the shaft afterwards, he said that in fact the actual equipment used did provide for the electrical heating of the compound. An air-jacketed vessel, although expensive, would retain its heat for quite a long time, and gave good results in practice.

With regard to ionisation, he believed Mr. Drew was interested from the design point of view, and therefore, would be gratified if given a clue to the mechanism of cable failure. A single-core cable, for example, might be made perfectly air-free between the layers of the dielectric, but there was always a microscopic quantity of air entrapped in the fibres of the paper and in the oil which might have become aerated somewhat in its circulation through the pipes. One might assume that the cable, as first made, was more or less homogeneous. Its dielectric loss, plotted against voltage, at a given temperature, gave a curve of the form shewn in the sketch, Fig. 1. If the cable were heated to 70 or 80 degs. C. it expanded as a whole, and the lead, being non-elastic, did not follow the contraction of the dielectric when cooling, so that a space was formed. If one measured the dielectric loss after the first heat cycle, i.e., after the cable had expanded and had been allowed to cool again to its original temperature, a curve was obtained a little above the previous curve. If this process were repeated several times the curve would be a little higher each time, but after an indefinite number of heat cycles there was very little increase. The difference between the initial loss and the final loss, however, was very considerable. It meant that the insulation had become "pappy". The minute quantities of air in the materials might be driven out as the result of stress, but what was more likely was that the loosening of the materials permitted gaseous spaces, which would be in a state of ionisation, so that there was a cumulative growth of gaseous spaces which gradually brought about breakdown at the working voltage. As to the effect of compression on gaseous spaces Mr. Grover said there was an instrument called a compressed air voltmeter. The breakdown strength of air followed a very definite law, with static pressure. Under high pressure, i.e., when the cable was hot, there was a static pressure in it. The dielectric strength of the gaseous spaces was higher than when the cable was cold, and for that reason cable failures tended to occur either when the cable was cold or cooling.

KENT SUB-BRANCH.

The Selection of Motors for Mining Work.

M. G. R. ELLIOTT.

(*Paper read* 1*st February*, 1930.)

"Choosing the right motor for the job" becomes a more difficult problem for the mining electrical engineer every day. In the first place the tendency in collieries, as in most other industries, is to replace manual labour with machinery and whenever possible electric driving is resorted to. Secondly, all round the collieries subsidiary plants are springing up either for dealing with the raw coal after it is won from the earth, or for new processes for which cheap coal is an essential factor. As each "side-show" is added, the mining electrical engineer is expected to come along at the right moment with the right motor for the job.

To meet this increasing and multifarious demand, motor manufacturers are constantly developing and adapting their motors, and it is imperative that the mining engineer shall make himself familiar with these developments, so that he may know where to obtain the motor best suited for the job and insist on having it.

Some very elementary matter is dealt with in this paper as it is the author's wish to explain in the simplest possible manner the difference between the various types of motors employed in collieries and the reason for selecting a particular type for a given duty.

Supply System.

Direct current is rapidly disappearing in collieries, the usual supply being three-phase, 50 cycles, alternating current to comply with the standard supply systems in this country. It is common practice to adopt 3300 volts as the standard voltage for high tension motors as it is now possible to construct a thoroughly reliable motor of, say, 80 B.h.p. and upwards, wound for this voltage. Often the grade of insulation is specified to be suitable for 6600 volts as an additional safeguard, little extra cost being involved.

For smaller motors and those working in situations where H.T. is not practicable, low tension voltages up to 600 volts are used. This is somewhat higher than the standard industrial voltage of 415 volts in order to keep down the section of cables for long runs.

Furthermore, as lighting circuits in collieries are invariably distinct from power circuits, there is no question of running lighting circuits from one of the three phases to neutral.

H.T. or L.T.

The question whether a given motor shall be wound for high or low tension depends on the size of the motor the situation and the duty. Motors of less than 80 b.h.p. are seldom wound for high tension for colliery duty. Below this size they are comparatively expensive as is also the switchgear. Above this size the question is settled by comparing the saving effected in the cost of the smaller section high tension cables with the extra cost of high tension motor and switchgear.

Generally speaking there is a strong case for the H.T. motor in sizes exceeding 100 b.h.p. anywhere in a colliery in view of the long runs of cable; moreover the feeling is rapidly disappearing that for a duty where freedom from breakdown is essential the motor should be wound for low tension, as confidence increases in the reliability of modern high tension motors.

Protection.

The question of protection of the motor is not affected by the voltage of the windings. 50 b.h.p. is about the economic limit for total enclosure in any case and high tension motors can be made drip proof, pipe ventilated or totally enclosed with or without external cooling.

Types of motor.

The important question of the voltage having been settled the next question is the right type of motor for a particular drive. It is obvious that in the early days of the application of electricity to colliery machinery, particularly underground machinery, designers could not foresee the very arduous and special conditions under which such machinery would have to operate and as a result the plant used at that time was very little different from the plant then in use for ordinary commercial purposes.

It was only by dearly-bought experience that the peculiarities of the duty were realised and at the present day motors and switchgear are available perfectly adapted for the work.

Induction and Synchronous motor.

In collieries using alternating current there are two principal type of motor in common use, viz., straightforward induction motors with "squirrel cage" or "wound" rotors and synchronous motors of the "salient pole" or "Induction" type.

Special Types.

With the numerous elaborations of these types, such as "cascade," "A.C. commutator," and "compensated induction" motors, etc., it is impossible to do more than remark in this paper that each type has its particular uses and advantages. For colliery duty, however, there are three points of first importance to be remembered in selecting motors, viz., absolute reliability, simplicity and interchangeability. Therefore the fewer special types of motor about a colliery the better for the peace of mind of the engineer.

Characteristics of Induction Motors.

Returning to the two types of motor first mentioned, it is necessary to appreciate their characteristics to be able to decide which to use for a particular drive. Dealing with induction motors, the squirrel cage motor would at first sight appear to be ideal for all constant speed drives.

It is the simplest and, at the same time the soundest of all motors mechanically, but until recent years was ruled out for the majority of drives on account of its low starting torque and high starting current.

Torque.

A motor when running on a steady load demanding its full output is exerting a continuous force or effort tending to turn the motor shaft. This "turning force" or "torque" is called the "full load" torque.

When current is switched on to the motor at rest a turning force is exerted at the motor shaft. The motor being about to start, this turning effort is called the "starting" torque and is expressed as a percentage of the full load torque.

The starting torque and, incidentally, the starting current of an induction motor, whether squirrel cage or slipring, depends upon the impedance of the rotor circuit. The impedance depends upon the resistance of the rotor circuit, the self induction of the rotor circuit, and the method of connecting the rotor conductors together.

Fig. 1 shews how the resistance in the rotor circuit affects the torque of the motor. Notice first of all that the resistance does not affect either the maximum torque or the full load torque developed by the motor but only the speed at which they are developed.

Curve "A" is a typical "speed-torque" curve of an induction motor with a low rotor resistance. The motor runs on full load at a speed within 5 per cent. of synchronous speed.

If more than full load is applied to the motor it will continue to run until it is developing approximately twice full load torque, giving out double its rated horse power with very little loss in speed. When the load exceeds this amount the motor stops.

This motor with full volts applied to the stator develops nearly full load torque at the start, but the current taken by the motor at start is approximately seven times full load current.

Now it this motor be a large one and have a squirrel cage rotor, it might be necessary to keep down the starting current by reducing the voltage applied to the stator until the motor had run up to speed. This has a bad effect upon the starting torque which varies as the square of the voltage, e.g., if the voltage is halved, the torque falls to one quarter. On the other hand, if the motor has a slipring rotor, an external resistance can be connected in series with the rotor winding, thereby increasing the starting torque and reducing the starting current. As the motor speeds up this external resistance can be cut out in steps so that under load the motor runs efficiently with very little slip and small energy loss in the rotor circuit.

Curves "B" and "C" shew the effect of increasing the rotor resistance. The "maximum" and "full load" torques are still obtained but at lower speeds.

Varying the self induction of the rotor circuit has a similar effect upon the torque of the induction motor, and this is made use of in the modern design of squirrel cage motor. By making the squirrel cage winding highly inductive, the starting torque is increased and the starting current reduced. At the same time the resistance of the rotor winding may be kept low. This, as is seen in Fig. 1, results in the motor running with very little slip. Consequently, at full speed the frequency of the rotor current is very low and the choking effect of the highly inductive rotor winding disappears. The rotor losses at full speed are therefore small and the motor efficient.

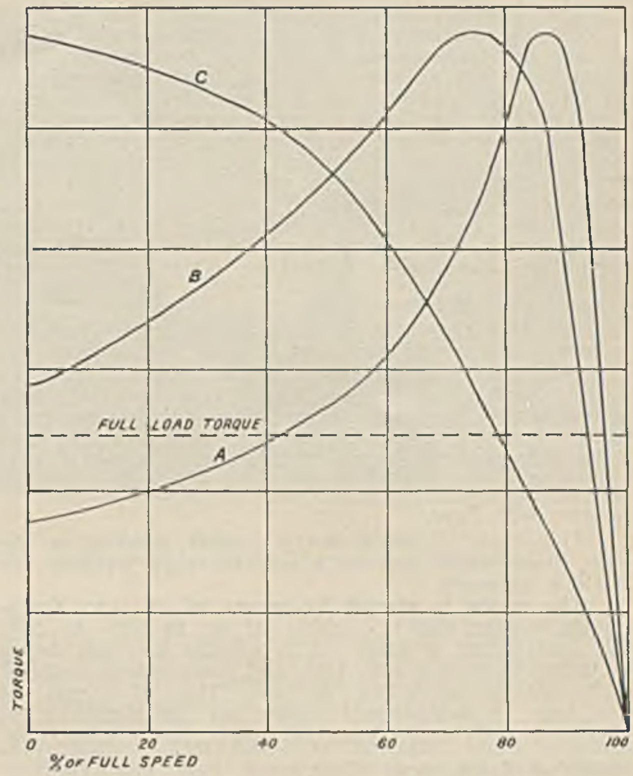


Fig. 1.—Curves of Torque and Speed with varying Rotor Resistance.

It is here that the method of connecting the rotor conductors comes into account. Part of the winding with low resistance is embedded deep in the rotor core where the choking effect is maximum with the rotor stationary and little current is passed. The remainder of the winding is connected in parallel with it, but close to the surface of the core and has a high resistance.

With the slipring motor a certain amount of speed variation can be obtained by varying the external resistance in the rotor circuit, the actual speed at which the motor runs with a given resistance in circuit depending upon the load on the motor. This is unsatisfactory in cases where the speed is required to remain constant below full speed with a varying load.

Squirrel cage motors however can be manufactured to run at two or more definite fixed speeds independent of the load. The stator is wound with a corresponding number of separate windings or, in the case of three or more speeds, one winding may be reconnected to give two speeds. The speed is varied by changing the winding of the stator, which can be effected with very simple switchgear.

Different types of machinery vary enormously as regards the starting and running-up torque they require. Neglecting friction, such machinery as haulages and cranes demand constant torque at all speeds and the motors driving them must exert at least full load torque at start. On the other hand, fans and centrifugal pumps, again neglecting losses, require a much lower starting effort, the torque varying as the square of the speed. These are therefore obvious drives for squirrel cage motors.

Such drives, however, as ram pumps and compressors starting with open valves and ball mills present difficulties owing to the variation in starting conditions and each drive has to be treated on its merits. Slipring motors are often used because the starting torque can be controlled and applied gradually, but squirrel cage motors can be used where the conditions are fully appreciated.

For instance, a squirrel cage motor, designed to develop the maximum anticipated starting torque might damage the transmission if the drive happened to start light, but a similar motor designed to develop moderate starting torque can be used in conjunction with a centrifugal clutch. The clutch allows the motor to start light and can be set to take up the drive gradually when the motor attains the speed at which it develops its maximum torque. Both squirrel cage and slipring motors have however, one disadvantage; if operating on light load or designed to run at low speed they work at a low power factor, thus loading up the supply cables and generating plant with "idle" or "wattless" current.

Synchronous Motors.

For this reason it is advisable to install sufficient motors of the synchronous type in every colliery, whether generating its own current or purchasing it from an outside source, to keep the power factor of the whole installation as near unity as possible. Of the two types of Synchronous motor—Salient pole and induction type—the former is similar in construction to a salient pole alternator.

Salient Pole Type.

This type of motor has a damper winding in the pole shoes which acts as a squirrel cage winding for starting purposes.

The motor is started by means of an auto Transformer starter and is capable of up to 30% to 35% full load torque at start. It is suitable for such drives as motor Generator sets, fans, and compressors equipped with suitable unloading devices. The advantages of this type of synchronous motor are its simplicity of operation and large range of power factor correction.

Induction Synchronous Type.

The induction type synchronous motor has the usual induction motor type of stator winding with a concentrically wound rotor with a single two- or three-phase winding.

The motor starts up like an ordinary slipring induction motor with resistance in the rotor circuit. Direct current, supplied by an exciter, is imposed upon the rotor windings as the motor approaches full speed causing the motor to pull into synchronism.

The advantages of this type of motor are its high starting torque and heavy overload capacity.

Power Factor Correction.

By increasing the amount of direct current excitation either type of synchronous motor can be made to take a leading current from the mains. Suitable arrangements can be made to balance the lagging current taken by the induction motors in the colliery, the whole plant thus being run at or near unity P.F. which means that all the current flowing in the generating plant and main cables is useful current and both generator and cables are worked to their maximum capacity.

MINE VENTILATING FANS.

The mine ventilating fan is of such vital importance in its dual function of ensuring a sufficiency of pure cool air and removing any possible accumulation of gas that the first consideration for the motor to drive it is reliability and immunity from breakdown. This has been a strong excuse for retaining steam drives for many mine ventilating fans but the electrically driven fan with its steady load has a beneficial effect on the load factor and is ideal for power factor correction—a matter of particular importance to a colliery purchasing electrical energy from an outside source.

Horse Power.

Settlement of the motor horse power does not follow any definite rules as the quantity of air sufficient for one mine may be quite inadequate for another even if the extent of the workings in the two mines is approximately the same.

The load obviously varies over long periods as conditions underground alter. In a new colliery a comparatively small fan and motor may be installed at first, later to become standby to a larger unit and for week-end use. Or on the other hand a full sized fan sufficient for the ultimate expected load may be installed right away.

Speed Variation.

It is necessary to decide first of all whether fan speed variation is required over short or only long periods. If only over long periods a constant speed motor can be employed with indirect drive, preferably by ropes, the pulley ratio being changed as the speed is required to be increased.

A synchronous motor should undoubtedly be employed because of simple power factor control irrespective of load. Fig. 2 shows a typical layout of a mine ventilating fan driven by a 570 b.h.p., 375 r.p.m., self-starting synchronous motor, 550 k.v.a, 0.85 p.f., 3300 volts, 50 cycles, three-phase.

The induction type synchronous motor is usually preferred since its better starting characteristics enable a heavy fan to be run up to speed in a minimum of time.

For larger sizes the motor should have three bearings arranged for ample movement on the slide rails to take up slack in the ropes and allow for subsequent changing of the pulleys.

The motor speed will be governed by the fan speed and should be as high as possible, the aim being to arrange for a rope speed of 4000 to 5000 feet per minute.

In congested situations, the exciter of the synchronous motor may be belt or chain driven or even separately driven, and in dirty situations both motor and exciter may be pipe ventilated, the cooling air being supplied through an air filter.

Ropes are superior to belts or gears (sometimes employed) owing to the former's greater flexibility which assists in absorbing fluctuations in load.

Speed Variation.

If speed variations over short periods is essential, in cases of emergency or for week-end running, a problem arises needing careful consideration, because with alternating current motors it is difficult to achieve a combination of absolute reliability and efficiency.

Synchronous motors at present are practically only used for constant speed drives, though it is interesting to note in passing that for electric ship propulsion this type of motor is used as a variable speed motor when docking and so it may in due course come into more common use on land for variable speed drives where, for the bulk of the time, the motor operates at full synchronous speed.

For the variable speed fan it is therefore usual to employ a slipring motor, and to improve its efficiency at low speeds many extremely ingenious drives have been evolved. The improvement is, however offset by the elaborate nature of the plant and its high first cost.

Multi-Speed Squirrel Cage.

For motors up to 300 b.h.p. these elaborate drives are not worth considering and there is nothing better than a two- or three-speed squirrel cage motor or a slipring motor with rotor control.

The former is worthy of consideration where the fixed speeds obtainable are sufficient.

For simplicity and reliability the motor should have two or more separate and distinct stator windings. The rotor is of standard S.C.R. construction.

The switchgear may be arranged for "Direct" "Star Delta" or "Auto Transformers" starting on any or all speeds and it is operated by a single handle.

For indirect drives up to 300 h.p. it is possible to choose a combination of reasonably high speed and both the efficiency and power factor are good at all speeds. Where this motor does not afford sufficient flexibility of speed control the alternative is a slipring motor.

For larger motors the resistance losses in the controller are serious. For example: A 1200 h.p. fan is driven by a slipring motor, input 880 k.w., 5000 volts, 50 periods, three-phase. Speed varying from 292 r.p.m. down to 202 r.p.m. At the bottom speed the motor input is 410 k.w., and with resistance regulation the power factor has fallen from 0.82 to 0.67, and the efficiency from 93 per cent. to 62 per cent.

There are a number of ways of saving these excessive losses, and although they all necessitate elaboration of the drive, the saving more than justifies the increased first cost and it is possible to arrange matters so that in emergency the main motor can be operated alone at full speed.

All these modifications involve the employment of additional machines coupled in the rotor circuit of the main motor in place of the regulating resistance and designed to turn the energy of the rotor circuit, which would have been lost, to useful account.

Typical examples are the Scherbius motor control and the rotary converter, both of which are used as a rule to drive an asynchronous generator feeding back into the mains. Occasional use has also been made of a.c. commutator motors and cascade motors.

It would appear necessary, however, to make out a very strong case for speed variation over short intervals to justify installing anything in preference to a synchronous motor for a mine ventilating fan drive.

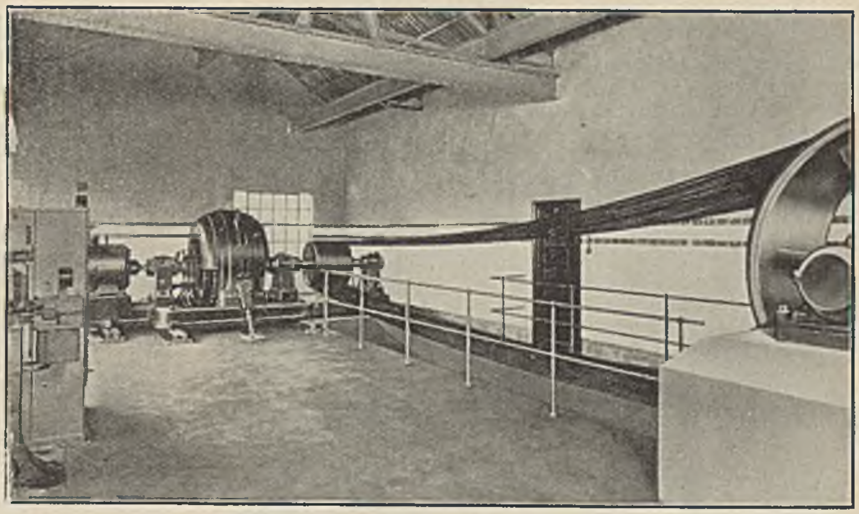


Fig. 2.—A 570 *h.p. Mines Fan Installation. Self-starting synchronous motor,* 375 *r.p.m.,* 3,300 *volts.*

AIR COMPRESSORS.

Compressors are of two types, the turbo blower and the reciprocating compressor. Reciprocating compressors may be driven either by belt or direct coupled motor. The torque is practically constant and the load on the driving motor can also be kept practically constant if a receiver is installed between the compressor and the pipe system. This receiver will take care of small load fluctuations. Very large fluctuations call for some method of regulation.

Speed of Compressors.

The speed of reciprocating compressors has been much increased of recent years. Previously, in order to damp down cyclic irregularity, inseparable from the piston type of machine, if the motor was direct coupled it had to be of special design with very heavy rotor. With the raising of the speed it is sufficient to employ a comparatively small flywheel between the motor and compressor. With direct current a shunt wound motor is often considered suitable but a certain amount of compounding is advisable. With alternating current, the choice lies between a synchronous motor and the plain induction motor.

Generally speaking, in the larger sizes there is a strong case for the synchronous induction motor, and it is interesting to note that British practice is here well ahead of American practice where salient pole type synchronous motors are still used in spite of their inferior starting characteristics. The induction type synchronous motor, first perfected in this country, has now been copied by every European country manufacturing electrical equipment.

Double Ended Drive.

Recently a double ended motor driven compressor has been introduced, the motor being mounted between two separate compressor units. A compressor of this type with a capacity of 6,100 cu. ft. per minute at 80 lbs. per sq. in. has been installed at Horden Collieries, the speed being 260 r.p.m. For this capacity the arrangement is less expensive, takes up less room, gives a more even turning movement, and in emergency permits of one unit being disconnected for inspection or repair.

Turbo compressors must of necessity run at high speed. Even in very large sizes the best speed is approximately 3000 r.p.m. As, however, turbo compressors are only used where very large amounts of air are required it is usual to have a centralised air supply system analogous to an electric central station, working in conjunction with a centralised boiler system. The turbo compressors are therefore generally driven by steam turbines. Unlike the reciprocating compressor, an electrically driven turbo compressor is the exception rather than the rule.

Where a motor is used it is generally coupled through a double helical gearing, and its speed is either 1500 or 3000 r.p.m.

At these speeds the power factor and efficiency of an induction motor are both over 90% and there is therefore no strong case for the synchronous motor.

As no air receiver is used with a turbo blower all load fluctuations are imposed on the motor. This alone rules out either type of synchronous motor on account of phase swinging and its constant excitation may cause violent fluctuations in the power factor.

Although a slipring motor is generally employed there is no reason why a squirrel cage motor should not be used, in spite of the size, the duty being similar to that of a centrifugal pump which will be dealt with later.

Regulation.

With regard to the regulating of a reciprocating compressor this may either be done by stopping and starting the motor as the pressure rises and falls in the receiver, or the motor can run continuously and the output of the compressor be varied. Which system shall be adopted is determined by the "load factor" of the compressor. The nearer this is 100% the stronger the case for the continuously running motor. If the load factor is low continuous running would give too long a period of light load, the intermittent system then being best.

Automatic Control.

An interesting example of a compressor driven by automatically started and stopped synchronous motor has recently been installed in H.M. Dockyard, Portsmouth. The compressor is intended largely for night duty and will normally only start up two or three times during the night. In cases of emergency it is required to start twelve times an hour. The motor, 500 b.h.p., 250 r.p.m., is of the synchronous induction type to facilitate rapid acceleration. The stator is wound for 6600 volts, three-phase, 50 cycles. The air compressor is automatically unloaded at start and remains so until the motor is up to speed and synchronised, which takes 20 seconds.

The starting and stopping is controlled by a pressure operated switch operating at 80 lbs. and 100 lbs. per sq. in. respectively. This is of course an obvious case for automatic starting and stopping and the use of the synchronous motor is interesting.

The regulation of the turbo compressor is more difficult. Although its characteristics resemble a fan the large size of the motor makes the cost of such an equipment as a Scherbius controlled induction motor almost prohibitive. It is usual, therefore to employ some system of regulation whereby the suction is throttled by means of a surging gear.

Portable Compressors.

Before leaving the subject of air compressors, mention must be made of portable compressors, the use of which is so well appreciated. These should be driven by a squirrel cage motor and it should be remembered that the Mining Regulations are now being amended, stipulating that all motors, as well as starters, on *portable* machinery in coal mines must be of flame-proof construction.

MINE PUMPS.

Pumping, in common with ventilating, is one of the most vital problems which the mining engineer has to solve, and no matter what stoppages or mishaps may occur with the rest of the plant, it is assential that there shall be no interruption in these two services. For driving underground pumps electrical power is ideal and has practically no real competitor nowadays. Since first installed there has been more progress in electrical pumping than any other application of electricity.

Speeds.

The use of electrical drive for ram pumps has undoubtedly had the effect of improving the design of this type of pump to enable it to run at higher speeds. Even so the pump speed rarely exceeds 150 r.p.m., and it is often as low as 50 r.p.m. for large three-throw ram pumps.

This necessitates the use of some form of reduction gearing between the motor and pump to enable a motor of reasonable speed to be used. The recent perfection in machine-cut gears enables large ratios to be used, with the result that single-gear reductions can be employed with the advantage of smaller overall dimensions.

It is not intended to enter into the relative merits of ram and centrifugal pumps in this paper; it will be sufficient to note that the latter type, although 10 per cent. to 15 per cent. less efficient in large units, scores heavily on the question of first cost, maintenance and space occupied: whilst the turbine pump is invading the previously accepted domain of the ram pump in dealing with very high heads.

Another important advantage of the centrifugal pump, from the electrical as well as from the hydraulic point of view, is the even delivery, there being no danger of fluctuations in the water stream, a situation liable to arise with ram pumps through valve trouble, and calling for special precautions.

For driving centrifugal pumps the motors will almost invariably be wound for four or two poles. Owing to their high speed the performance of induction motors for this duty is so good that there is no call for synchronous type motors.

In an excellent book, published last year,* to which reference has been made in preparing this paper, the Author submits that squirrel cage rotor motors are suitable for this duty in sizes up to 150 b.h.p. For larger sizes he rules this type of motor out on the score of the unreliability of the usual auto-transformer starter.

The experience of the Kent Collieries is no doubt that squirrel cage rotor motors with auto-transformer starters, when suitably designed for the duty, can be used most effectively in much larger units. As a matter of interest it is to be noted that two such equipments are now in course of construction for power stations circulating water pumps of over 1000 h.p. each. Fig. 3 shews a typical 100 h.p. squirrel cage motor pumping set as installed in the pit.

It is usual to wind the motors for high tension and they should at least be drip-proof. In certain circumstances the motors may have to be pipe-ventilated, the cooling air being tapped from the main air current by means of a by-pass.

Sinking pumps are now almost invariably centrifugal, and the motors of the totally enclosed S.C.R. type started by auto-transformer from the surface.

ELECTRIC WINDING AND HAULAGE.

It is impossible to do more than make a passing reference in this paper to these two subjects and the motors suitable for them. Electric winding is growing in popularity and is of particular interest to collieries purchasing electrical energy from an outside source.

Direct current motors and induction motors are usual for winding, though cascade motors and poly-phase commutator motors have been used. Where a direct current motor is used in a colliery which has only an A.C. supply the Ward Leonard System of control is ideal. With induction motor drive speed control is obtained by the insertion of resistance in the rotor circuit, supplied by a water-cooled liquid controller.

For haulages, whether "endless rope," "main and tail," or "direct," it is usual to use induction motors. These may have squirrel cage rotors for small units, particularly small endless rope sets where the motor can be started up light; and for small direct haulages with epicyclic gears, since the brake on this type of gear enables the load to be picked up gradually.

Synchronous induction motors may be used under certain conditions for constant speed drives, their capacity for withstanding severe overloads being worthy of note, as previously mentioned.

Generally speaking for all but small haulages slip-ring induction motors are preferred. They should be designed for a pull out torque of 2½ times normal full load torque since momentary overloads approaching this may so easily occur.

It is usually worth while fitting short circuiting gear, at any rate; brush lifting being optional as even if the motor is purchased for a direct or main and tail haulage, sooner or later the drive will almost certainly be superseded and the motor may next be required for an endless haulage. There is also the important question of interchangeability to be considered.

The primary drive may be by belt or ropes requiring a three or four bearing motor. Other haulage motors in the colliery will be all gear drives employing two bearing motors.

In a new colliery it may be decided early to standardise on haulage motors of 50 h.p., 100 h.p., and 200 h.p. at 725 r.p.m. It is therefore worth the small extra cost when purchasing a motor with extended shaft for belt or rope pulley to use a motor with standard shaft extension flexibly coupled to a short shaft extension and to carry the pulley mounted in two independent pedestal bearings.

Probably few other drives in a colliery are so liable to change as haulages, as it is impossible to predict requirements at a later date when the workings develop. Interchangeability of haulage motors is therefore of paramount importance.

* H. Cotton. "Electricity Applied to Mining."

The calculation of horse power for main haulages is complicated. It is almost always necessary to err on the safe side, as the dislocation caused by a motor refusing to start when the load has come to rest in bad position outweighs the loss in efficiency due to running a motor normally too large for the job. Here again, standardisation of the motors comes to the fore. It is often good practice to put in a haulage the mechanical parts of which are capable of sustaining the very maximum load ever anticipated, a small motor being employed at first arranged for easy change to a larger motor at a later date.

Controllers may be either of the drum type with separately mounted resistances or liquid controllers. In the case of the former it is advantageous to purchase a reversing controller in every case, whether the drive is reversing or not. Generally this entails no extra cost in the controller, and the reverse fingers are available for an incidental reversal or, in the event of damage to the forward fingers, the reverse fingers can quickly be adapted for the forward drive, keeping the haulage in use until such time as it is convenient to overhaul the controller.

Liquid controllers are becoming increasingly popular for large and medium haulages. With these the speed control is necessarily smoother than with the drum type, an important point with main and tail haulages and direct haulages as it eliminates a good deal of the lashing of the rope which takes place at each step due to the sudden changes in starting current and so cuts down the strain and wear of the rope.

A further advantage is that the resistance of the electrolyte can be controlled very easily and consequently can be adjusted to suit any given starting or speed regulating duty, always provided that the tank is large enough to dissipate the heat produced. It is therefore particularly suitable where a large haulage is working for some time on light duty. The arrangements for cooling the electrolyte are similar to, but more simple than those employed for liquid controllers used with winding motors, the haulage motor being smaller and working on a lighter duty cycle.

As regards protection of the motor they should always be drip proof, with provision for easy conversion to pipe ventilation if necessary a matter specially catered for on certain makes of motor with adaptable end covers.

OTHER COLLIERY DRIVES.

It is impossible in this paper to deal with the many other drives which have to be contended with in collieries. Power station auxiliaries, screenig and cleaning plants and the many new by-product plants all present their several problems. Experience proves, however, that it pays to stick to the simpler types of motor of standard design and interchangeable as far as possible.

Induction motor design has improved materially of late years in the matter of protection against injurious matter in the atmosphere or situation in which motors are called upon to work. At one time it was thought imperative to make all motors totally enclosed which had to work in dirty situations. This certainly prevented a lot of injurious matter from entering the motor and affecting the windings, but sometimes faults occurred in spite of these precautions due to the fact that the motor was completely enclosed. A totally enclosed motor "breathes" owing to variations in temperature, and under certain conditions moisture and injurious gases enter the motor in, perhaps, minute quantities, but being unables to escape again gradually accumulate and in time attack the windings and cause breakdown.

Recent improvements therefore have been made in the protection of the windings themselves. Induction motors for instance, are made with completely sealed stator windings, dust, dirt and moisture proof. The squirrel cage rotor being uninsulated and of extremely robust construction is also proof against all injurious matter. In addition, ball and roller bearings are used completely enclosed and magazine lubricated, the driving and bearing being fitted with a special dust excluder. For many dirty situations, such a motor need not be totally enclosed. It is sufficient to make it "enclosed ventilated" or "drip proof" with the advantages of smaller size, lower first cost, and better service.

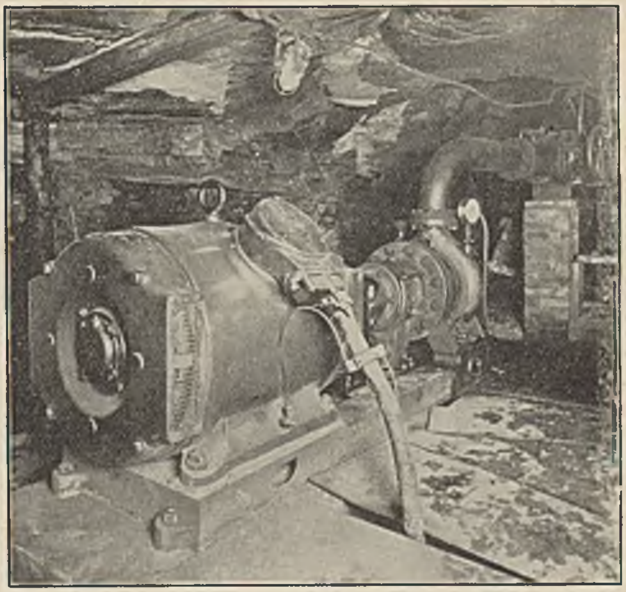


Fig. 3.—A 100 h.p. Maxtorque Motor driving a Pump.

There are situations, however, where total enclosure is essential. Motors which have to work out in the open exposed to severe weather conditions, abrasive dust and acid gases, must be completely enclosed. Standard motors are now being manufactured admirably adapted to withstand such conditions. As the first motors of this type were built for gas works they are known as "gas-works" motors, though of course they are equally suitable for dirty situations in any other plant.

The standard commercial "totally enclosed" motor with sheet metal bands and plates over all openings is quite suitable for saw-mills, flour mills and the like where it is simply necessary to prevent fine particles of foreign matter from entering the motor. The "gas-works" motor, however, has no sheet metal covers. Instead, the enclosure of the motor is of solid cast iron construction, any necessary openings being covered with flat cast iron plates with broad machined joints similar to flameproof construction. The terminal box is specially constructed, the leads from the motor windings being brought up through insulators in the solid base of the box, sealed in so that even if the terminal box cover is removed, there is no opening through into the motor. The cover is also of cast iron as described. Bearings are ball and roller type with dust excluders.

For totally enclosed motors of larger size than about 15 b.h.p., at 1000 r.p.m., considerable economy is effected by a system of radiator cooling. By this means a much smaller frame can be used, the overall dimensions of the complete motor and radiator being less than the ordinary totally enclosed motor. Moreover, totally enclosed motors can be built on this system in much larger units than is otherwise practicable.

This paper would not be complete without some mention being made of flameproof motors. The British Standard definition of a flame-proof enclosure (B.S.S. No 229) reads: "A flame-proof enclosure (including explosion proof) for electrical apparatus is one which will withstand, without injury, any explosion that may occur in practice within it under the conditions of operation, within the rating of the apparatus enclosed by it (and recognised overloads, if any, associated therewith), and will prevent the transmission of flame such as will ignite any inflamable mixture which may be present in the surrounding atmosphere."

Motors are built in totally enclosed flame-proof and explosion proof casings, but this is only possible for units not exceeding 50 k.w. output. With alternating current, however, squirrel cage motors may be used, sparking then being impossible so long as the rotor is constructed in such a way that the bars will not come loose; or slipring motors may be used, the sliprings being enclosed in a flame-proof enclosure. This does not affect the rating of the motor, and adds little to the cost. All slipring motors used below ground in a colliery should be fitted with flame-proof slipring covers.

SUMMARY.

(*a*) Use standard motors wherever practicable, always making special features of a drive mechanical and exterior to the motor, thus keeping motors interchangeable, reducing outlay on spares and facilitating maintenance.

(*b*) Employ synchronous motors in sufficient numbers to keep the power factor of the whole installation near unity.

(*c*) Install drip proof motors wherever possible with properly protected windings as they can be used under the widest diversity of conditions: particularly is this so with squirrel cage rotors.

(*d*) Employ high tension motors when in large units for reasons of economy.

Discussion.

Mr. L. W. BARNEY said he could fully agree with Mr. Elliott's remarks regarding the selection of motors and their effect on the power factor of the system concerned, as it was only as a system grew that the effect of putting the wrong type of motor in the wrong place really began to make itself felt. In the early days of the colliery with which Mr. Barney was until recently connected certain people thought he was a little power factor mad as he had installed synchronous type motors in places where they were rare; now that the system had grown to a fairly large size a glance at the power factor meter on the main power house switchboard shewed that there had been method in his madness.

An engineer responsible for the layout of a large system where a number of motors are going to be used should take a sort of aeroplane view of the job and look quite a long way ahead, and not just sit down and order motors regardless of what was sure to happen in a few years. In some cases a motor of the synchronous type may in the first instance appear more expensive than an induction motor, but it could often be proved that the saving in copper for cables due to the better power factor of the synchronous type would meet the extra cost of this type of motor, quite apart from the better regulation of the alternator at high power factor and the greater actual load that it would be able to carry without overheating.

A small point in connection with motors, more particularly those for underground use, which even the best makers sometimes fail to give satisfaction in design is the terminal box and its cable gland. Many makers send out a motor fitted with a cable box and gland that might just do for an ordinary industrial job but which is quite unsuited for mining work where continuity between the armour and the motor is most essential.

Mr. Barney said he would like to have Mr. Elliott's opinion of ball and roller bearings, whether he considered they were now so far developed that they could safely be used for all duties and speeds even up to the highest; some engineers retain the idea that for high speeds they are not safe and that for a gear drive they may give trouble. Mr. Barney's own opinion was that the ball bearing machine has so many advantages over the machine with a plain bearing that in practically every case it should be used, and that the small possible troubles of the ball bearing type were as nothing to the known defects of the plain bearing. He considered that a ball bearing machine must have a reliable make of ball race, etc., and further, each ball race must be suited to the drive in question and that the motor maker should be given full details of each drive and given a free hand as to bearings. Probably a lot of the trouble one sometimes hears of is due to bearings being fitted by makers without the necessary experience of this type, or to an unsuitable type being used, possibly the maker being quite in the dark as to what his motor is going to drive.

The paper deals with motors, but when selecting a motor nearly as much thought should be given to the selection of starting gear, as the selection of proper starting gear is of as much importance as the motor itself. Many makers put forward a good motor which is sometimes quite spoilt by poor or unsuitable starting gear; some engineers would appear to encourage this, having the idea that as the starter is only sometimes used there is no need to spend much money on it. Generally speaking, air-break starters should only be used on the surface for small motors started by skilled or semi-skilled men; for other work the reliability of the oil type starter will pay for itself in the long run.

Mr. COOPER asked whether, assuming a definite lift in power factor is sought, it is more economical to obtain this by synchronous machinery, or whether it would be cheaper by condensers, or if there was some economic limit for condensers above which it would be more efficient to instal synchronous motors.

He also asked whether, in the case of a self-starting synchronous motor and some condition having arisen causing the machine to fall out of step, would the machine continue to function as an induction motor, and could one expect it to pull back into step and run as a synchronous motor ?

Mr. Cooper also asked whether Mr. Elliott recommended a synchronous or plain induction motor for a job running constantly but subject to widely varying loads, the power factor being corrected by other means if an induction motor was used.

He further asked would it not be possible, when designing synchronous induction motors, to have the rotor voltage considerably higher than that which was usually employed, so that a corresponding decrease was effected in rotor current, in order to effect an economy in rotor copper.

Another question put by Mr. Cooper was: when a motor is started by means of a starter which broadly speaking causes the motor to start up in a series of jerks, would the end turns, if not rigidly supported, be inclined to bend over and eventually touch one another, or even the rotor, causing transient flashovers where the insulation was at all weak ?

Mr. Cooper, with regard to the question of a high torque squirrel cage motor, suggested that Mr. Elliott might be able to give some idea of the relative percentage difference in cost between an ordinary squirrel cage motor and a high torque machine. He also asked: if a synchronous motor got out of step and ran as an induction motor, against what percentage of full load torque would it pull back into synchronism ?

Mr. RUSSELL asked, regarding the bearings for high speed heavy duty machines, whether the question of lubrication was more important with ball and roller bearings than with plain bearings, and was it necessary in the case of the former to use a grease gun as a means of lubrication ? He also asked: in the case of a synchronous motor running out of step as an induction motor, would it continue to do so until conditions reverted to normal, and would it then take up its former duty as a synchronous machine ? Would this also apply to large machines ?

Mr. FORD.—Would Mr. Elliott recommend an induction motor with the high torque rotor, such as he had explained, for service with a mine fan ? Could Mr.

Elliott give any idea as to the cause of the rotor bars of a squirrel cage rotor breaking off at the end, practically across the section. In some cases they broke off where welded on the short circuiting ring; was it due to hardness of the copper due to welding during construction?

Mr. HOWARD.—With regard to the remarks on electrical driving of ram pumps, and the claim that centrifugal pumps were cutting them out, could Mr. Elliott say what was the comparative cost of maintenance of the two types of pump and the comparative reliability of running? Referring to the gasworks motors, Mr. Howard would like to have more details of the type of dust-proof seal used on the driving end bearing.

Mr. FRANKLIN.—How does the gasworks motor compare as regards price and dimensions with the ordinary motor? What is the largest sized motor roller bearings are employed on? Would Mr. Elliott explain why, when a certain type of slipring motor was started up there was considerable flickering and surging all over the system. He had in mind machines ranging from 110 h.p. to 300 h.p.

Mr. LOWE, referring to the regenerative set of which Mr. Elliott spoke, said, why use an asynchronous generator for feeding back into the mains rather than a synchronous one, which on the face of things would appear to be the correct machine to use? In the case of a machine having the coils only completely sealed in preference to a machine of total enclosure, would not internal breathing in these sealed coils take place in the same way as the author had said would take place in a totally enclosed machine?

With reference to the trouble of which Mr. Franklin had spoken, Mr. Lowe thought he knew of another certain colliery which also experienced this flickering, as on a Supply System fed by this colliery it was possible to tell the time when certain pump motors were started up.

Mr. WOOD said that it was sometimes advisable to have terminal boxes on each side of the motor; would Mr. Elliott say whether this depended on the specification of the customer.

Mr. POLLARD asked whether it was becoming the practice to use a.c. motors for crane work apart from colliery work.

Mr. ELLIOTT, in reply.—With regard to Mr. Barney's remarks as to ball and roller bearings, he thought it had been pretty well proved that ball and roller bearings could be used irrespective of the speed of the motor. They would stand up to all normal work such as gear conditions, etc., as well as plain bearings, provided they were large enough and correctly fitted; but for any special drive the makers of the ball and roller bearings should be consulted. The experience of the leading manufacturers of ball and roller bearings enabled them to give definite advice as to the most suitable type of bearing. Trouble with ball and roller bearings seldom brought a motor to a dead stop. Almost invariably plenty of warning was given by the bearing becoming noisy. The opposite was often the case with plain bearings.

With regard to starting gear, of course it was fatal to buy a good motor and a cheap switch. A good switch was as essential as a good motor.

In reply to Mr. Cooper's question as to which is the more economical—a synchronous induction motor or a condenser—that question must be settled by the particular facts of the case, and depended on the circumstances of the job. In some cases one was more economical than the other, but the fact remained that people do buy synchronous motors and ran them light as synchronous condensers intending eventually to run them on load; a real economy in the long run. There was also the fact that with a synchronous motor used for the improvement of power factor, useful work is done in addition, whereas with static condensers power factor improvement only is achieved with the disadvantage of useful floor space being occupied.

With regard to the question of a synchronous motor running out of step as an induction motor, of course usually that only happened for a short time, but the fact remained that it would run as an induction motor until the load was relieved and the motor returned to synchronism again.

In answer to Mr. Russell, the question of lubrication of high speed heavy duty motor bearings was important whatever type of bearing is used. A grease gun should not be used for motors fitted with ball and roller bearings. Actually on a high speed motor anything over 1000 revs. the bearing cap should not be more than half-filled with grease. An excess of the latter caused churning and overheating of the balls and rollers; also the grease may melt and run out along the shaft.

In reply to Mr. Cooper's question of using a synchronous induction or plain slipring motor for constant running duty with widely varying load. If the job is of first-class importance, Mr. Elliott would undoubtedly recommend the simpler type of motor to be used, and the power factor correction to be obtained by using synchronous motors on drives where conditions are more stable.

In reply to Mr. Ford: as far as a fan is concerned, the starting duty being light it was unnecessary to use a high torque squirrel cage motor. Squirrel cage motors for driving fans need develop comparatively low starting torque provided they develop sufficient running up torque, the fan torque increasing approximately as the square of the speed. A mine fan was such an ideal drive for a synchronous motor, however, that it was unlikely that a constant speed squirrel cage motor would ever be considered for this drive.

Mr. Elliott believed the fracture of the rotor bars, referred to by Mr. Ford, was due to crystallisation of the copper set up by vibration.

In reply to the question by Mr. Howard, he thought it was a question for the pump maker; from a motor point of view Mr. Elliott would prefer the centrifugal pump.

The dust-proof seal of the gasworks motor could take several forms, the usual being that of a circular plate secured on to the motor shaft by means of a set screw close to the bearing. The idea of this shield plate being that only the dust falling in the minute space between the shield and the outer bearing cap could possibly enter the bearing. Another method was to bolt a cap on to the bearing cover and line this with an insertion of felt pressing on to the motor shaft, but this form was not so effective.

As far as size is concerned the gasworks motor was the same as an ordinary totally enclosed motor; and as regards cost, the average cost over an ordinary commercial motor was about 10% to 15%.

In reply to Mr. Cooper, one must bear in mind that even with a synchronous motor with the rotor designed for running at low voltage, when starting the motor up, a very high voltage indeed was impressed on the rotor. Increasing the excitation voltage would entail more rotor turns of smaller section with lower current to give correct rotor ampere turns. The increase turns would mean higher impressed voltage when the motor was started. It would, therefore, be seen that under these conditions a saving in copper could not very well be effected. It was obviously also a point of good design to keep the voltage of windings on revolving parts as low as possible.

In reply to Mr. Franklin, Mr. Elliott could not say definitely, but roller bearings had been used on motors up to at least 1000 h.p.

The end turns of large motors were securely braced to withstand any tendency to bending.

In reply to Mr. Lowe: an asynchronous generator is similar to a squirrel cage induction motor with stator connected to the line and rotor driven above synchronous speed in its normal direction of rotation as a motor. The amount of power returned to the line depended on the speed of the rotor. Increasing the speed of rotor of the asynchronous generator decreased the speed of the main motor. A synchronous generator—or alternator—would be unsuitable for this duty.

With regard to the question of protected or drip proof motors compared with totally enclosed motors: with the drip proof type ventilation was taking place, and it was difficult for moisture in the atmosphere to accumulate in the motor as often occurred with totally enclosed motors. If the winding were properly impregnated, practically all air was excluded from the coils and the interstices between the turns were filled with varnish: consequently the coils could not breathe. In a totally enclosed motor, if water accumulated, the bottom coils, though sealed, in time became sodden and the insulators impaired.

The extra cost of the "Boucherot" rotor is little, approximately 10% above that of the standard squirrel cage rotor.

A customer could have two terminal boxes fitted, if specified, at an extra charge. A way out of the difficulty with a motor with single terminal box would be to reverse the end covers of the motor which were generally made interchangeable for the purpose of bringing the terminal box to the required side.

In reply to the third question by Mr. Franklin, the disturbance on the supply system would seem to have been caused either by a bad contact, heating up of the electrode of the starter, or the torque reaching such a figure that the machine was on a point of pulling out of step.

In reply to Mr. Russell: the motor does actually come back into synchronism. The motor would drop out of step, i.e., run slower, and immediately the load was relieved the motor would automatically pull back into synchronism. This would also apply to large machines. If the speed of the motor should fall below that at which it developed its maximum torque it could not pull back into synchronism, but would shut down completely. The percentage depends on what pull-out torque the motor was designed for, but provided the machine was on the side of the torque curve approaching the full speed torque line for which the motor was designed the machine would pull back into step, even though the full load torque be well exceeded.

LONDON BRANCH.

Notes on the Maintenance of Flame-proof Enclosures for Electrical Apparatus.

H. RAINFORD.*

(*Paper read* 1*st April*, 1930.)

Introduction.

The advantages of the use of electrical power in coal mines are of real economic importance, and they are such as should not be surrendered excepting where considerations of safety present overwhelming difficulties. The main risk resulting from the use of electricity underground is that of "open sparking," and whilst this risk has been minimised by the use of flameproof enclosures, the responsibility resting upon the user of such enclosures has not yet been fully realised.

The principles of the design of flameproof enclosures and pressure relief devices are given in a paper† read by Professor I. C. F. Statham before the Warwickshire and South Staffordshire Branch; and these notes are therefore intended primarily for the user of flameproof electrical apparatus rather than for the designer who, with the experience gained from the research work on flame-proof enclosures, and from the testing of such enclosures, has had an advantage over the user. The user has perhaps been somewhat neglected in this respect and in consequence has not thoroughly grasped the extent to which his collaboration is necessary if the danger of "open sparking" is to be reduced. The term "user" is employed to cover not only the purchaser of the apparatus but also the electrical engineer or electrician responsible for its installation and the miner who operates the apparatus in the course of his work.

For reference purposes the definitions of relevant terms such as "open sparking" and "flame-proof enclosure" are given in an appendix to this paper and it will suffice at the moment to state briefly the object of flame-proof enclosure.

The object of flame-proof enclosure is to prevent the ignition of an external explosive atmosphere, i.e., in coal mines, fire-damp air mixtures, either directly from electric arcing or sparking within the enclosure, or indirectly from the ignition of an explosive atmosphere therein, whether introduced from outside or produced within the enclosure.

In connection with nomenclature it may be mentioned that the use of the term "total enclosure" with respect to mining apparatus has in the past been misleading. The term has a definite meaning, particularly for motors, but it does not mean flame-proof enclosure. It is suggested that a combination of the two terms would meet the case, a unit being referred to as a totally enclosed flame-proof enclosure or, alternatively, as an unvented flame-proof enclosure. Similarly, an enclosure which is provided with definite venting arrangements can be referred to as a vented flame-proof enclosure. Such a distinction would enable users to distinguish between the two types of enclosures.

Testing of Flame-proof Enclosures.

In 1926 the British Engineering Standards Association issued its standard specification for flame-proof enclosures for electrical apparatus for use in mines and other places where an explosive atmosphere may be encountered. This specification has been revised and is now known as the B.S.S. No. 229, 1929.

The specification sets forth particulars as to the method of testing to be adopted and the form of certificate to be issued by the Testing Authority. The specification defines only the performance required from a flame-proof enclosure and the special features of design and construction will be specified in the British Standard Specifications dealing with particular types of flameproof apparatus. The requisite specifications for air-break switches, air-break circuit breakers, and for motors (excluding motors embodied in coalcutters, conveyors etc.,) have been drafted and will be available in the near future.

Maintenance of Flame-proof Enclosures.

It should not be necessary to stress the point that all mining engineers and those responsible for the installation and maintenance of electrical apparatus should be conversant with the risks introduced by the installation of electricity in mines.

Obviously the best design for a flame-proof enclosure is one which will prove safe when tested under the standard specification, and which, in addition, can be easily maintained in its original condition by men who have been carefully instructed in this respect.

If any justification is needed for a paper dealing with this subject, it is only necessary to refer to the annual reports of H.M. Electrical Inspector of Mines. These reports, over a number of recent years, indicate that a large proportion of accidents due to electrical machinery were preventable. The term "accident" is in certain instances inadmissible, since a number of the occurrences have been so obviously due to carelessness and ignorance as to remove them from the category of accidents.

In this connection the following information, abstracted from the Report of H.M. Electrical Inspector of Mines for the year 1928 will be of interest. In Tables I and II an analysis is given of the fatal and non-fatal accidents, over a number of years, classified according to the nature of the equipment involved.

* Testing Officer, Mining Department, University of Sheffield.

† *The Mining Electrical Engineer*, 1928, Vol. 8, p. 378.

TABLE I.

Total number of fatal accidents during the years 1919 to 1928 inclusive, classified according to the equipment involved.

Switchgear and fuses	30
Flexible cables and plugs	27
Overhead lines, bare or insulated	15
Lighting accessories	9
Motors and transformers...	3
Coalcutting machines	3
Total	87

TABLE II.

Total number of non-fatal accidents during the years 1924 to 1928 inclusive, classified as in Table I.

Switchgear	118
Trailing cables and plugs	89
Armoured cables	13
Overhead lines and unarmoured cables	14
Dynamos and motors	17
Lighting accessories	4
Bell signal systems	1
Total	256

Such information should prove of great value since it clearly indicates the directions in which efforts to reduce accidents can be made.

In Table III an analysis is made of non-fatal accidents according to the contributory cause.

TABLE III.

Non-fatal accidents, classified according to contributory cause.

Accidents attributed to	1924	1925	1926	1927	1928	Totals
(a) Defects of design, or misapplication...	5	9	13	13	10	50
(b) Faults of Maintenance	19	17	5	10	15	66
(c) Misuse or negligence	29	21	16	22	24	112
(d) Unforseeable ...	4	7	3	8	6	28
Totals ...	57	54	37	53	55	256

This table indicates that the majority of these accidents were preventable and, furthermore, that nearly one-half of the total were due to misuse or negligence, a fact which shows that much remains to be accomplished before the maintenance of mining electrical equipment can be considered as satisfactory.

It may be argued that the annual accident rate is small in view of the steady increase in the amount of electrical power used, but the fact remains that other opportunities of dangerous conditions have occurred through faulty design or lack of proper maintenance, which have not resulted in accidents because of the non-coincidence of the other factor, namely the presence of an explosive atmosphere.

Features of design requiring special attention.

Sufficient evidence has been advanced to establish a case which requires consideration, and attention is therefore directed to those features in the design of flame-proof enclosures which require special and frequent attention.

Pressure Relief Devices.

With regard to pressure relief devices it can be stated at the outset that their use on apparatus at or near the coal face is not to be recommended. Apparatus to be used in these places must necessarily be of robust design to withstand rough usage, and also it is desirable to exclude dust from them as far as possible. In addition, these situations are generally such that proper inspection of the devices is impracticable, thus increasing the risk of the apparatus being used in an unsafe condition.

For larger units away from the coal face, venting devices may be used with advantage, but it is essential that the electricians and the men operating the gear should be familiar both with the design and the object of such devices. To cite only one instance of the lack of knowledge in this respect:

At a recent demonstration given by the author, models of venting devices were shown and one member of the audience (a colliery electrician of some years' standing) stated that he had seen one particular type of device on several units but until that evening he had not understood the reason for its use.

The fundamental principle of pressure relief devices is that the flame and hot gases produced by an internal explosion are cooled by contact with metal surfaces and by expansion; the apertures, or gaps, provided by the devices being so dimensioned that a certain amount of release of pressure is obtained, whilst the flame from the internal explosion is prevented from passing to the external atmosphere.

The maximum size of aperture, or width of gap, allowed under the present requirements is 0.02 ins. and it is essential that the men should understand that in no circumstances should this width of gap be exceeded. Without this knowledge the miner can hardly be blamed for not appreciating that, as a gap is definitely provided, a little more gap won't do any harm. Whilst the colliery managements cannot be expected to provide every man with a set of "feelers," the colliery electricians at least should have facilities for the correct maintenance of the devices.

In general, pressure relief devices should not have loose components, i.e., such devices should be separate units assembled ready for bolting to a casing. Any device which can be disassembled *in situ*. is a potential source of danger owing to the risk of its being re-assembled minus some of the component parts. In particular, loose spacing washers should be avoided in order to prevent two spacers being used where one only should normally be inserted.

Unbottomed Holes.

The presence of holes which have been drilled through the walls of enclosures constitutes a real hazard in electrical mining gear. So long as the bolts or screws are in position no danger exists, but the omission of a single bolt or screw leaves an aperture which is almost invariably large enough to allow of the passage of flame, thereby rendering the enclosure non-flame-proof. This defect is one of the commonest causes of accidents due to ignition of fire-damp, in several instances the fault not being in the loss of one bolt, but in the wholesale omission of bolts due to carelessness and lack of knowledge of the danger resulting from such omisions. The number of fatal and non-fatal accidents, reported by H.M. Electrical Inspector as being due to ignition of fire-damp caused by such omission of bolts, clearly indicates that this feature of maintenance is still not sufficiently appreciated.

This factor is essentially one of design and the defect is gradually being eliminated in the design stage. The only real safe guard is in the entire absence of such unbottomed holes and the specifications now require that—if removable bolts, studs or screws are provided for the attachment of any component parts of a flame-proof enclosure, or for the attachment thereto of any external or internal fittings, the holes for the reception of such removable bolts, studs or screws shall not pass through the walls of the flame-proof enclosure.

There is one practical difficulty in connection with "bottomed" holes and that is the possibility of the holes becoming choked with coal dust or dirt, with the result that the cover or fitting is not securely attached. Here again is an instructional point and the men should be made to realise that, if a cover is taken off, the bolt holes should be cleared before an attempt is made to replace the cover. In this respect a safeguard is obtained if covers and fittings can only be removed by authorised persons. This point is dealt with under the appropriate heading.

An alternative to bottomed holes is to employ studs screwed into the casing, the studs being rivetted or welded in position to prevent removal. If, however, a stud is broken off the occurrence may not be reported and there is again the danger of a cover not being securely attached.

All equipment recently certified complies with the requirement as to bottomed holes but there must be a large number of units at present in use which are a potential source of danger owing to unbottomed holes. If possible, existing designs which err in this respect should be taken in hand and the bolts and set-screws should be replaced by studs rivetted into the bolt holes. The only alternative is to make the men realise the danger due to unbottomed holes—a difficult task.

Cable Entry.

The direct entry of cables into flame-proof enclosures is not permissible under the present requirements, the acceptable construction being that which comprises the use of insulated terminal stems projecting through the flame-proof enclosure, so that the external cables terminate outside the enclosure.

This method will not, however, be found in a larger number of units at present in use and every care should be taken, when apparatus is being connected, to ensure that the point of cable entry is sealed in a proper manner. Cable glands should be packed correctly and any packing which shows signs of deterioration should at once be replaced.

An even more important point is in connection with cable replacements. A cable, even if used only temporarily, should be of the same size as the original cable. It will be obvious that, if a smaller cable is fitted, a passage will be left through the gland rendering the enclosure unsafe. In the report of H.M. Electrical Inspector of Mines for 1928 will be found a note concerning the cable attachment to the starting-switch of a coalcutting machine. On examination of the apparatus, after an ignition of fire-damp, it was found that a cable passed through an unbushed hole in the wall of the switch box leaving an annular gap around the cable. The original design included a bush for this aperture, the bush having apparently been lost and no attempt made to replace it.

The use of compound filling *in situ* for the purpose of sealing a flame-proof enclosure is not now permitted, but in certain types of apparatus in use some such sealing is necessary. It is doubtful whether this sealing by compound is always carried out, and every endeavour should be made to ensure that this important feature of maintenance is not overlooked, however difficult the problem of conveying and inserting the molten compound.

As a final point in connection with cable entry, it may be mentioned that a standard specification for plug and socket connectors has been issued and their more general use is to be recommended, particularly with trailing cables.

Unauthorised Interference.

The safety of electrical apparatus can be enhanced by the use of some form of interlocking to prevent the possibility of misuse or meddling. In this connection manufacturers are giving every assistance, and when new equipment is being ordered advantage should be taken of such interlocked gear being available. In general, interlocking provides a safeguard against apparatus being operated when incorrectly assembled. Thus, a switch can be interlocked so that it cannot be operated unless the cover is correctly secured in position. An interlock can be provided between switch operating gear and a plug and socket connector so that the plug cannot be withdrawn without first tripping the switch.

The shrouding of bolt-heads and the use of bolts with specially shaped heads also tend to prevent easy access by unauthorised persons. In some countries such forms of interlocking are compulsory, but whilst that is not the case in this country, their adoption is becoming general.

It is not possible to legislate against the man who is determined to get a piece of apparatus, but it is possible to take precautions against the purely thoughtless or careless individual, and to this end interlocked gear should be installed wherever possible . With regard to apparatus in use which is not interlocked in any way, the opening of such apparatus should be limited to authorised persons. In many instances a locking bar and/or a padlock would affect this in quite a simple manner.

Air-break and Oil-immersed Gear.

It is not within the scope of this paper to discuss the relative advantages and disadvantages of air-break and oil-immersed gear. For apparatus to be used in the vicinity of the coal face, the balance is probably in favour of air-break gear.

From the user's point of view the important factor to be remembered is that the oil can only be regarded as a second line of defence and that oil-immersed gear should not be accepted for use underground unless an external flame-proof enclosure is provided. Every care should be taken to keep the oil at the normal indicated level. In the report for 1928, previously referred to, will be found an account of an ignition of fire-damp caused by a defective oil switch. Not only was the switch casing non-flame-proof in design, but the frame had apparently been erected out of alignment, with the result that the effective head of oil over the switch contacts was reduced, while the quantity of oil was insufficient to provide the full designed head even when correctly mounted.

General.

Under this heading may be placed several other features of maintenance which require constant attention. Mishandling of machinery is one of these features and as an example an instance can be cited of a coal-cutter with a chain haulage gear where the chain had been allowed to work off the guide wheels, with the result that a hole was cut through the flame-proof enclosure.

Careful and frequent inspection should be made of the methods adopted for securing covers and fittings in position, and any tendency for screws and bolts to work loose should be checked. Bolts and nuts will be found to fit badly, as a result of wear and vibration and these should at once be replenished.

Repair *in situ*, although it may result in the saving of time, should only be considered as a temporary measure and electrical apparatus, particularly coal face machinery, should be periodically brought out for examination if it is to be maintained in a safe condition.

The provision of better lighting underground must undoubtedly result in better maintenance of the electrical equipment and any developments in connection with coal face lighting will be awaited with interest. In the meantime every endeavour should be made to take advantage of the improved hand lamps which are now available.

Summary.

To sum up, it is clear that the human element enters very largely into the causes of electrical accidents and that the maintenance of flame-proof enclosures for electrical apparatus involves two main factors, namely, instruction and inspection.

It is obvious that the electrician and mechanic must become familiar with the essential features of design and should receive instruction as to the particular defects which constitute danger. The actual operators of the apparatus should also be given sufficient instruction to enable them to recognise dangerous defects and to understand the dangers which may arise from mishandling of the apparatus they are using.

Colliery managements should realise that the duties of maintenance and inspection can only be entrusted to persons who have been suitably instructed both as to the general principles of flame-proof enclosure and with regard to the particular features of the equipment that is in their charge. Only when they have received this instruction and have given proof of their knowledge should they be termed competent persons, under the rule in which the term "authorised person" is used.

To this end, lectures and demonstrations have been given at the Sheffield University Testing Station, to electricians and operators. The method of instruction has been to give a short lecture on the features of maintenance, followed by a demonstration showing how, although a unit may be quite safe when properly assembled, the unit may be easily rendered unsafe by the omission of a bolt or by interference with a pressure relief device. The resultant ignition of the explosive atmosphere surrounding the apparatus drives home, as no other form of instruction can, the danger arising out of faulty maintenance. These demonstrations have proved to be of great value and their extension is to be recommended.

The annual reports of H.M. Electrical Inspector of Mines should also serve for instructional purposes and there appears to be no reason why copies of the reports should not be supplied by the managements to the men responsible for the maintenance of the electrical plant. Certainly the purchase price of the reports is not prohibitive. The accounts of accidents, and the explanation of the likely causes thereof, should materially assist the men to realise the necessity for careful work.

The increasing use of mining electrical apparatus requires a corresponding increase in the knowledge of the personnel and in the co-operation of the management with respect to their outlook towards the problem of maintenance.

The safe use of mining electrical apparatus cannot be entirely assured by legislation and inspection. It can only be obtained by a combination of increased knowledge, experience, and interest on the part of all concerned in the industry.

APPENDIX.

General Regulation No. 127, para. V., states:—

"Where there may be risk of igniting gas, coal dust or other inflammable material, all parts shall be so protected as to prevent open sparking."

"Open Sparking" is defined in General Regulation No. 118 as: "The sparking which, owing to lack of adequate provision for preventing the ignition of inflammable gas, external to apparatus would ignite such inflammable gas."

The wording of the British Standard Specification No. 229, 1929, is as follows:—

"A flame-proof enclosure (including explosion-proof) for electrical apparatus is one which will withstand without injury, any explosion that may occur in practice within it under the conditions of operation within the rating of the apparatus enclosed by it (and recognised overloads if any associated therewith) and will prevent the transmission of flame, such as will ignite any inflammable mixture which may be present in the surrounding atmosphere."

Two qualifying notes are appended to the specification. The first note states that in the absence of any statement to the contrary, it is assumed that explosions of methane-air mixtures only are contemplated. The second note draws attention to the danger of a short circuit within the enclosure and points out that this should be guarded against as far as possible by good design. In addition the protection of the circuit should be such that the highest recognised overload for the apparatus is not exceeded.

[The paper was amplified by many interesting and informative lantern slides.]

SOUTH WALES BRANCH.

The Annual General Meeting of the South Wales Branch, for the year ending March 31st, 1930, was held at Porthcawl on May 17th, and was largely attended by members from all parts of the district. As on previous occasions, there was a good attendance of ladies and the party partook of tea at the Esplanade Hotel, Mr. W. W. Hannah presiding.

Mr. H. J. NORTON, the Hon. Sec., in his Annual Report stated that although the Branch was easily maintaining its position as the largest in the country, there was a small decrease in membership. This was due to members being struck off the books on account of non-payment of their subscriptions. At March 31st, 1929, the membership was 396; 42 new members were enrolled throughout the year; the total number of members at March 31st, 1930, was 387, consisting of four patron members, 271 members, 79 associates, and 33 students. The Branch had been fortunate in obtaining the consent of Mr. W. D. Woolley, General Manager of The Tredegar Iron & Coal Co., Ltd., to become a patron member. Seven candidates had sat for the Association Certificates, the successes including one First Class and four Second Class Certificates. During the year eight General Meetings were held, the standard of the papers read being well maintained. Two papers were read which were eligible for the Association Prizes, specially granted to members or their subordinates who sign the Log Book.

A very successful visit was made to Oakdale Colliery and members were afterwards entertained to tea by The Tredegar Company. A visit was also paid to the works of The Electrical Construction Company at Wolverhampton, the party being entertained to lunch on arrival and tea after viewing the works. The Engineering Exhibition at Cardiff was well attended by members who accepted the invitation of The South Wales Institute of Engineers.

The Gold Medal for the best paper by any member read before any Branch again came to South Wales and was awarded to Mr. S. B. Haslam for his paper "Modern methods of firing steam boilers with special reference to pulverised fuel."

The Branch Prize of £2 2s. 0d. was awarded to Mr. F. E. Pring for his paper "Electric Coal Cutters in Low Seams" Various Sub-Committees had met. The B.E.S.A. Sub-Committee had considered a number of draft specifications in connection with colliery plant and valuable suggestions made. A new Sub-Committee had been formed called the Propaganda Sub-Committee with the view to increasing interest in the Association. The relations of the Branch with Kindred Associations continued to be very cordial.

The Secretary also emphasised the importance of sitting for the Association Certificates which were of increasing value to the Mining Electrical Engineer. He was frequently asked for the names of suitable members for important positions, the stipulation being that the candidate must hold the Association's First Class Certificate.

The Report was adopted on the proposition of Major E. I. David, seconded by Mr. Dawson Thomas.

In the absence of the Hon. Treasurer, Mr. A. C. MacWhirter, the Secretary presented the accounts for the year; they were adopted on the proposition of Mr. S. T. Richards, seconded by Mr. H. W. Shilbach.

Mr. T. B. STANAWAY (Hon. Sec. Western Sub-Branch) thanked the members for their confidence in appointing him as Secretary of the Western Sub-Branch. He realised that there was a lot of uphill work to do and they had decided to make an intensive canvas of all the collieries with the object of securing as many available members as possible. They had had a very successful year, holding seven ordinary meetings with an average attendance of 40% of the members. The Annual Dinner had also been most successful. The Papers given were of a high standard and had proved of great benefit to the Association and the members generally. The Report was adopted on the proposition of Mr. Theodore Stretton, seconded by Mr. W. A. Hutchings.

Sir Arthur Whitten Brown, K.B.E. was appointed Branch President and Major W. Roberts and Mr. H. W. Shilbach vice Branch Presidents for the year.

The ballot for four Members of Council resulted in favour of :—

S. Dwyer, Cardiff;
J. Jones, Abertillery;
R. E. Michael, Crumlin;
H. Williams, Rhondda.

Proposing a vote of thanks to the retiring Branch President, Major E. Ivor David said that he had expected great things from Mr. Hannah, who had a family record to live up to, and that he had not been disappointed. The year was a very bad one as far as unemployment and a low standard of wages were concerned but in spite of this, the membership of the Branch had only fallen by 9, and they confidently expected that the results of the campaign of the Western Sub-Branch would soon convert that small decrease into an increase. Mr. Hannah had a record of which they were all very proud. His attendance at meetings was 100%, which proved that his election was a good one; in addition he had done much excellent work outside for the Association.

Mr. Idris Jones seconded the vote of thanks which was warmly carried. Mr. Hannah suitably responded.

The Hon. Secretary, Hon. Treasurer, and the Press were also cordially thanked for their work and cooperation during the year.

AYRSHIRE SUB-BRANCH.

Short Circuits to Earth on Electrical Machinery Underground.

ALEXANDER McPHAIL.

(*Paper read 29th March,* 1930.)

Revolving on its own axis and making a complete revolution every twenty-four hours and also a complete revolution round the Sun every year, is a planet of the solar system termed the Earth. It is one of the electrons of that solar system and has a negative polarity. The sun being positive attracts all the electrons in its group, but as each electron is of the same polarity they will all repel each other, thus forming circles round the sun, or proton, and each cirle has seven electrons or a divide of seven. All circles are so arranged in every group as to form a ball. The total number of electrons in each group is 2520 (a wonderful number, because it is the least common multiple of all the prime numbers) all arranged by a natural law, in proper division. As an illustration, take a number of sewing needles and cut half an inch off the point of each, then magnetise all the points "South": next take a small piece of cork and pass one point through it so that it will float on water with point up: do the same with about 100 needles. Next, suspend a bar magnet with the "North" end down about six inches above the water. If we put in the water one needle it will stand below the magnet.

The several sketches in Fig. 1 show the arrangement of the needles. Now suppose the needles are electrons, and the magnet is the proton. The arrangement when complete with circles is what is called the Atom. Each electron is held from its neighbour by magnetic flux (like poles repel) and all are attracted to the proton (the Sun).

This constitutes a very limited description of the Law of Electricity, nevertheless it may serve to convey an idea of how the Atom is built up. The electron has the same relation to electricity as a knot on a piece of string has to the string. It is made of string but it is not string, it is a knot. Such is the arrangement of every group, and the groups arrange themselves in the same way. If we take the copper cable, or any other kind of conductor, we find the smallest particle is the Molecule. Examining further we find that every different kind of cable has a different number of atoms to the Molecule. Our arrangement now is:

The Cable, built up of Molecules;
The Molecule, built up from Atoms;
The Atom, built up from Electrons;
The Electron, built from Ether (or magnetic flux).

Every electron in the cable or conductor is revolving, just the same as are the planets of the soler system. Every group round its proton, the same as every group of planets round its sun.

There are also shooting stars or free electrons. These are tramp electrons, or electrons for which there is no place in the atom. The more of these tramps, the better the conductor of electricity, and the fewer of these tramps the better the insulator of electricity.

Electricity is said to be very quick, but the author believes it is very slow. If we take a pipe from a pump for say, two miles, then start the pump, it will be a long time before the water will reach the end of the pipe, but if the pipe be full of water when we start the pump, the water will flow out of the pipe at once. It is just the same with electricity. The cable is full of electrons. If fifty curling stones are all lying on the ice in a straight line, each separate from the the other, if we throw another stone and strike the last, we will find the stone at the other end will be repelled, but the one thrown will remain beside the person who threw it. If we carry on throwing stones, the first one we threw will eventually leave the ice. It is just the same with the electrons in the cable: we have set up a state and when that state is set up, the tramp electrons have heard that there is a "job" for them and they rush for the other end of the wood. In doing so, they strike the electrons in the atom and knock them off, each tramp taking its place, the one knocked off now becomes a tramp and so on as long as this state continues. This is electricity, or the primary side of it. The secondary side is the magnetic flux. There cannot be flux without electricity, nor electricity without flux.

Such a description will give us some idea of what we are working with and also how we may prevent it running to earth. If an electrical system is to be run in safety its law must be understood. In the early days of electricity it was seen that the potential to earth of the system would oscillate about a point, this point being at earth potential, above it, or below it—depending upon whether the system as a whole was electrostatically charged—and, in addition, that point would depend upon the leakage to earth of the cables of the system. If the system be completely insulated it may happen that no part of it would be at earth potential.

In Fig. 2 the positive cable is shown above earth potential and the negative below earth potential. This always happens in completely insulated systems. If the mid-voltage point of d.c. systems be earthed then we get the same result as shown in Fig. 3. With the neutral point of a three-phase system insulated there is equal danger from shock to anyone coming accidentally into contact with one pole of the system. The effect of capacity is to keep the neutral point at earth potential, hence the reason why he would receive the same shock. If for any reason the leakage current from any one cable of a three-phase system is much in excess of that from the other two, the axis of rotation of the triangle will not be at earth potential, but at some other point according to the amount of leakage.

All joints made on any part of a system should have proper conductivity, both cores and earth, and also if fuses are used at motors they must all be put in, when renewed, in the proper way: if any one of them is left slack it may upset the whole system. To prevent this, trip switches should be used, in fact every three-

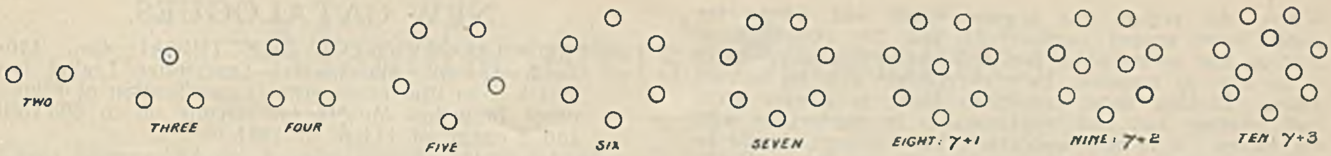


Fig. 1.

phase system ought to be fitted with trip switches so as to do away with the erratic human element as much as possible, which gives a better balanced system.

All the above ought to be observed for proper running. The conductivity of all earth cables should be kept as efficient as possible.

The author has known of cables tested for conductivity when the results showed the resistance of the cores to be so high from bad jointing that it was quite easy to get a good earth conductivity in comparison with the resistance of the cores of the cable. Cables should be tested for earth conductivity in relation to a full length of cable without any joints in the cores. If this rule be obterved many short circuits to earth will be prevented.

A great number of short circuits to earth are caused by careless attendants switching on motors with the starters on, and also by switching off motors when improper starting apparatus is used. These faults are caused by high voltages from induced forces, from the coils of the motors used. These puncture the weak parts in other motors or cables.

Short circuits to earth are always dangerous unless proper earths are installed. As many earth plates should be put in as will reduce the earth resistance to the lowest possible point always remembering that earth plates are like lamps in parallel, the more in circuit the lower the resistance to earth.

To prevent short circuits to earth, the insulation should be kept at the highest possible efficiency, and should be examined every day. All coils in motors should be well insulated when put in, and also cables passing through holes in any frame or box.

Switches should have a protecting insulation inside the box to prevent an arc from the switch or fuses shorting to the side of the box. This is one of the greatest sources of troubles the author knows of and he has definitely traced about 90 per cent. of punctures to these boxes. All switches, fuses and starter boxes should be lined with some insulating material that will not burn and which can be readily removed for cleaning: also insulation barrier should be placed between starter fingers to prevent the insulating bushes from being burned. These linings and barriers can be arranged quite easily, and they should be inserted before installing any electrical apparatus; it will save time, expense, and worry. The cost is very little to prevent so much damage and waste of material.

Discussion.

THE CHAIRMAN (Mr. T. M. McGlashan) said that considering th escope of the subject Mr. McPhail had succeeded in presenting the salient points of it in a very interesting and helpful way. From past experience members of the Branch knew how valuable were Mr. McPhail's contributions. His observations were based on wide experience and knowledge of electrical plant working under very trying conditions underground and they were almost invariably reliable. Mr. McPhail had given them a scientific and practical survey of the problems of the short circuit to earth and had shown the great importance and necessity of using common sense in subjecting electrical plant to regular examination and and overhaul. Breakdowns arising from small causes might result, if not in the wreckage of the machine, at least in very extensive and expensive repairs. Neglect to keep a small part of a machine in proper adjustment was often the primary cause of breakdowns, causing serious stoppages and impairing the usefulness and life of the machine.

Mr. McPhail's reminder and explanation of the fundamental electrical laws was far from being amiss. The human element rather delighted in taking risks by trying to upset the balance of natural laws; we were inclined to put forward and substitute our own theories. The younger members especially were none the worse for being reminded again of the inexorable elements with which the electrician had to deal.

One of the points in Mr. McPhail's paper that was well worthy of careful consideration, was the one concerning mid-voltage point in connection with a.c. and d.c. circuits in relation to earth potential. That was important because if they tried to handle an apparatus contrary to these laws they were looking for trouble and would puncture the installation to earth. He was sure he spoke for all the members when he said they hoped Mr. McPhail would enlarge on other aspects of this important subject next session.

Mr. GARVEN thanked Mr. McPhail for his very practical paper. Personally he had found it extremely interesting, because from his own experience he was able to confirm many of Mr. McPhail's contentions. Talking of earth plates, Mr. McPhail said that one must have a great number of them in parallel before one got a perfect earth connection. At the time that earth plates were made compulsory in mines—about the time when armouring cable was also made compulsory—Mr. Garven remembered getting a pipe in the ground and connecting the earth to it. (It was the concentric system which was in use). At another point half-a-mile away he connected to another pipe. The bottom of the pipe was well under water-level in the ground, and in order to test the "earth," 500 volts pressure through earth was connected to the two pipes but the current passing was only 20 amperes on test, which proved that the two pipes, one at each end of the line, did not make an efficient earth. Mr. McPhail had gone into this whole matter very thoroughly, and he, (Mr. Garven) had gained a good deal of information from the paper which he did not possess before.

Mr. P. McGEOUGH said he would like to ask Mr. McPhail, what about the neutral point on a threephase system. Mr. McPhail had said it was much safer to have a neutral point on a three-phase system. His own experience was that when working on a three-phase system, the neutral point of which was not earthed, and a short circuit to earth occurred, there were not any more detrimental effects than when the three-phase system was earthed.

Mr. McPHAIL.—Where the neutral point is not earthed and a short circuit to earth occurs there follow the conditions which have been demonstrated. If the short circuit was only partial and the potential had been raised by 100 volts nearer earth point the result would be that neutral point was revolving at some other point, not at a potential. Thus, if the earth plates are not able to take away the amount of current that is being thrown through that leakage resistance, then the potential of the armouring and the casings of the motors would be raised up to, say, 100 volts. As in Mr. McGeough's experience that did not happen, it meant that his system had a very good earth: that was the thing that saved it.

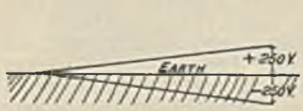


Fig. 2.

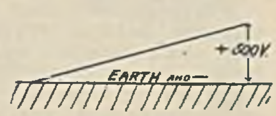


Fig. 3.

Where the system has a good earth and where the joints have proper conductivity and the resistance is kept as low as possible, and also the resistance to earth is as low as possible, then everything will be carried away. Lacking these conditions there is danger from bad jointing and bad workmanship in connection with the cables. It is very important that jointings should be well done because men's lives depend on them. If the electrician would only pause to consider that he would in most instances pay more attention to jointings than was commonly done. The electrician is often to blame because the person above him cannot make a personal examination in every case but must depend upon his working electrician; so the responsibility really rests on the electrician. Even where the neutral point is earthed there may be the same conditions, because if the jointing is not well done that point will not be revolving at earth potential but somewhere above or below as the case may be. The jointing in the armouring is depended upon for the return, and if that jointing is not well done the pressure may be raised above earth just the same. So there is danger in both cases, but more especially in the one that is not earthed. The one with the neutral point earthed is the less dangerous because there is the chance of the pressure forcing something through and cutting the potential of the armouring and the motors down.

Mr. W. H. COLVIN said this question of the earthing of the neutral raised a very important point in his own practice. There was something new and quite informative to him in what he might call the undependability of earth. He had seen in practice where there had been a big fault to earth on one of the phases of a three-phase system and no fuses acting, yet there was no question raised about the earth plates. To him it was a very instructive point, this one about the undependability of Mother Earth and that there was no safety in referring to natural earth plates.

Mr. McPHAIL said he had tested a considerable number of parts of the earth in Ayrshire and in districts in Lanarkshire, and to him there was great difficulty in finding a suitable earth. The reason apparently was that one may get into an earth pocket. Take the Western seaboard here, for instance; there we get sand and there is practically no earth whatever. Where the situation is damp, some of the waters may contain a great amount of lime and very little iron, so that water is no good and in such places it would require a great number of earth plates to bring things down to the conditions required by the Act. That is just one of the reasons why the neutral point should be earthed, and also the mid-voltage point on a d.c. system, because men's lives depend on that.

Mr. GARVEN said he could give an instance of where on a three-phase system it was necessary to have the neutral point earthed. Taking a system in this locality of 415 volts between phases, 240 volts between phase and neutral, in the event of No. 1 phase developing a fault to earth and there being a fault to earth in a switch, where a connection to earth can be obtained by someone standing and switching on, then the person switching on would be connected by the hand to No. 2 phase, through his foot to earth and No. 1 phase, and he would receive a shock of 415 volts instead of the 240 volts he would receive if the neutral had been earthed.

EDISON SWAN AND METRO-VICK SALES.

NEW TRADE ARRANGEMENT

Arrangements have been made whereby the wiring supplies, lighting engineering and radio business of Metro-Vick Supplies will be taken over and carried on by the Edison Swan Electric Co., Ltd., at their present addresses. "Cosmos" lamps will not be included in this arrangement, but will be marketed by the Lamp Sales Department of Metropolitan Vickers Electrical Co., Ltd.

NEW CATALOGUES.

METROPOLITAN-VICKERS ELECTRICAL Co., Ltd., Trafford Park, Manchester.—Descriptive Leaflet No. 39/1-1 is an illustrated general specification of Flameproof Induction Motors for circuits up to 600 volts and a range of 1½ h.p. to 140 h.p.

CROMPTON PARKINSON Ltd., Guiseley, Leeds.—Recent illustrated specifications include: A 504, A.C. Switchboards of the flat back type; A 402, Transformers; A 200, S.C. Induction Motors; A 608, Instrument Current Transformers of the ring type; A 603, The "A.C." Test.

GENERAL ELECTRIC Co., Ltd., Magnet House, Kingsway, London, W.C. 2.—The Installation Leaflet No. 22 gives interesting and useful details of the Kiosk Substations installed in Leicester.

Publication No. P 5411 is a forty-page description of the Hams Hall Generating Station of the Birmingham Corporation. It is a reprint, complete with illustrations and inset plate diagrams, of the several notices which appeared in *Engineering* during November and December last.

W. T. GLOVER & Co., Ltd., Trafford Park, Manchester. —The valuable paper by Messrs. W. Elsden-Dew and H. Denehy read recently before the South African Institute of Electrical Engineers has been reprinted in attractive form and issued by Messrs. Glovers who made the 20 k.v. mining cables described. Every progressive mining electrical man will wish to have this publication.

HEYES & Co., Ltd., Water-Heyes Electrical Works, Wigan.—"The Wigan Review" for May contains interesting notes on Historical Wigan; Prismatic Fittings at Hams Hall Power Station; Flameproof Circuit Breakers, etc.

GENERAL ELECTRIC Co., Ltd., Magnet House, Kingsway, London, W.C. 2.—Liquid Controllers and Oil Immersed Stator Reversing Contactors are dealt with in the Technical Description No. 282. It is indicated that there is need for smaller sizes of controllers, namely of 50 h.p. and 75 h.p. capacity, and these sizes have therefore been developed. The 50 h.p. size works without the addition of cooling water. Other particular features of these controllers are: welded steel construction has been adopted as far as possible, thus ensuring not only strength but reduction in weight, thereby facilitating installation underground.

A door has been provided on the controller by means of which the pots can be quickly removed when necessary; furthermore the removal can be effected without disturbing the operating gear or the cooling tubes; this means that headroom can be reduced to a minimum. Electrode pots are totally submerged in the electrolyte, and therefore remain at a like temperarture both inside and out; this overcomes the question of cracking due to uneven expansion.

The question of renewal of contacts on the reverser has received particular attention and can be performed by one man in half-an-hour.

MIDLAND ELECTRIC MANUFACTURING Co., Ltd., Barford Street, Birmingham.—"Safeguarding the Small Electric Motor" is the title of an illustrated price list describing motor starter gear for small squirrel cage motors.

W. T. HENLEY'S TELEGRAPH WORKS Co., Ltd., Holborn Viaduct, E.C. 1.—The pocket folder quotes the new reduced prices for "Henley" Tape.

GENT & Co., Ltd., Faraday Works, Leicester.—Book 5, Section 1e is a complete catalogue of the "Pul-Syn-Etic" system of electric impulse clocks and time discipline apparatus. Prices, dimensions, and general specifications of a large range are included.

Book 2, Section 1b is devoted to the large range of telephone apparatus and accessories manufactured by this Company.

Manufacturers' Specialities.

The New Dock Lighting System at the Port of London.

The average man has but little idea of the immensity of London as a seaport. The Port of London Authority controls five groups of Docks in the Port of London, and the tidal portion of the River Thames—69 miles long—and possesses a total dock area of some 3688 acres, with a water area of approximately 722 acres. The total lineal quayage, including the Surrey Canal, is about 45 miles in length. Warehousing accommodation is provided for over one million tons of merchandise. Some six hundred and fifty cranes, the largest of which has a lifting capacity of approximately 150 tons, are used for handling the merchandise. There are also ten graving docks, with accommodation for some of the largest ships afloat. The shipping, entering and leaving the port in the course of one year, is recorded as well over fifty million net tons register. The Royal Albert and King George V. Docks, situated a distance of 40 miles from the seaward limit of the port, can accommodate vessels with a draught of 36 ft. Quay accommodation is provided for ten miles of shipping in these two docks alone. Such accommodation, although permitting the handling of over twenty-five million tons of merchandise brought into the port annually, of a value exceeding seven hundred million pounds, has not, however, proved adequate, and recourse is constantly being made to extensions and improvements. These extensions and improvements during the past twenty years have cost over fifteen million pounds.

One notable improvement now being effected is in regard to the artificial lighting of this great dock area. The illumination of large open-air spaces is a problem which faces many of the heavier industries and the care and study given to such a system of lighting as has been here adopted will be appreciated by those responsible for colliery surface works and railway sidings.

Fig. 1.—Daylight view shewing Lighting Units: Tilbury Landing Stage.

A special type of fitting, Fig. 3, was devised by the General Electric Company incorporating certain well-known distribution characteristics found successful in the lighting of important land thoroughfares, but with modifications rendering them suitable for the needs of dock lighting. This lighting unit is capable of providing the requisite distribution when operating at an approximate height of 30 feet, with a spacing of from 100 to 110 feet, with a distribution peak intensity at some 65 to the vertical, and a cut-off closely approximating to the same angle. Incorporated in this unit is a silvered glass reflector of mathematically determined contour which permits the requirements being attained when a 500-watt Osram zig-zag filament lamp is used. The fitting was designed in accordance with zonal flux methods, to give a light distribution of such a character that, with two fittings installed at the appropriate spacing, horizontal illumination values of uniform characteristics would as nearly as possible be produced.

The original tests with this fitting proved of considerable interest, as it was found that, by positioning the light source at a predetermined point in relation to the bottom edge of the reflector, an angle of cut-off could be obtained at 71, with a 65 angle of peak intensity. In these tests it was found that, owing to the minuteness of the lamp filament used, it was impossible to obtain an abrupt cut-off at the point of maximum intensity, and that, therefore, in its application to dock lighting it might prove preferable to compromise by adopting slightly different angles. Further experiments were made, but the reduction in maximum intensity occasioned by altering the housing in relation to the light source involved a loss of intensity which precluded the results of such experiments being adopted in the design of the unit.

The type of lantern adopted is constructed throughout of heavy gauge copper, with a malleable iron bridge piece, substantial steel strengthening straps, a single piece "Gecoray" interior reflector and a porcelain lampholder, the unit being equipped with a 500 watt

Fig. 2.—Night view shewing resultant illumination.

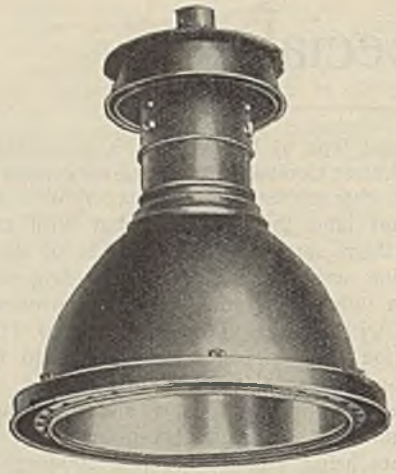


Fig. 3.—G.E.C. specially designed P.L.A. Type Dock Lighting Lantern as installed at the Port of London.

Osram zig-zag filament gasfilled lamp. The patented G.E.C. ventilated top is an important feature in this lantern, and one which has proved of outstanding success under sustained conditions of rough usage, and under varying climatic conditions. The mechanical construction of the unit in every detail, including screws, bolts, nuts, etc., is of an unusually strong and durable character. As an engineering production it is sound and robust, while its precision and efficiency as a giver of light is amply evidenced by polar curve records, taken from actual photometric readings of candle-power intensities.

What an advance in illumination achievement this represents may perhaps be gauged from the fact that, at the Port of London, with the same current consumption, it has been found possible to secure upwards of 40 per cent. greater intensity at the angle of maximum emission than has hitherto proved possible in earlier types of fittings. This gain of maximum candle-power further results in a pronounced increase in the minimum horizontal illumination at ground level at the mid-span position, i.e., the point which is equidistant between any two lanterns and added to this increased illumination at ground level there is ample illumination on the vertical surfaces of vessels lying alongside. With all these advantages—the advantages of a definite angle of cut-off contributing to safer navigation by reason of the complete elimination of objectionable and dangerous glare, as well as an increase in lighting intensity in both vertical and horizontal planes at no extra cost for current consumption—we think it can be claimed, without fear of contradiction, that this is a system of dock lighting that is not only remarkably efficient in character, but one which will continue to operate efficiently indefinitely, subject, of course, to ordinary maintenance care.

At Tilbury the same system of dock lighting as that installed at the West India Docks has been adopted for the magnificent new entrance and lock communicating with the immense docks. The lighting of this section of the Port of London is equally as meritorious as that at West India Docks, and may in some respects be regarded as of even greater importance in view of the fact that the new entrance was constructed for the express purpose of catering for the world's largest ships on all tides by day or night. At Tilbury the total dock area of 90 acres includes the Tidal Basin. The new lock, recently completed, is one of the largest in the world. It is 1100 feet long and 110 feet wide, with a depth of 45 feet 6 inches below Trinity highwater. At the entrance to the new lock and the lock itself the special system of lighting, to which reference has been made, is now in operation. By its aid many of the largest vessels afloat are able to enter or leave with perfect safety.

The extensions and improvements effected in the lighting of the Port of London, to which reference has been made, should have the effect in due course of bringing about very considerable advantages not only to the Port, but also to the City of London. The advent of an efficient and safe form of artificial illumination has made it possible to cope with double the amount of shipping previously handled, owing to all-night activities being now a practical proposition.

To Messrs. Rendel, Palmer & Tritton, the P.L.A. Engineering Department, the Chief Electrical Engineer, Mr. D. G. Davies, and Messrs. Electrical Installations Ltd., with whom the G.E.C. acted in close collaboration in the design of the Port of London's new system of lighting and its installation, unstinted praise is due on the successful issue of one of the most noteworthy undertakings in illuminating engineering yet embarked upon in this country.

The new P.L.A. Floating Landing Stage at Tilbury, the official opening of which was performed by the Prime Minister on May 16th, removes from the Port of London a long standing reproach. Prior to the erection of this new structure passengers had to proceed to and from their vessels by means of tenders or proceed to the docks to join or leave the boats. This new landing stage furnishes such facilities for the landing of ships' passengers that it now places Tilbury on a level with other ports which in the past have proved more popular than London to ocean travellers. The largest vessels using the port can berth at any level of the tide and at any hour of the day or night.

The new floating stage consists of a platform 1142 feet long by 80 feet wide, and is constructed of heavy steel girders with a timber deck. It projects some 370 feet into the river, and was designed by Sir F. Palmer, C.I.E., Consulting Engineer to the P.L.A., the contractors being The Cleveland Bridge and Engineering Co., Ltd. Sir Robert McAlpine & Sons were responsible for the embankment and other works connected with the shore portion.

The lighting of the new stage is likely to prove one of the most important factors in its success as it permits of all-night activities. The scheme was evolved as a result of collaboration between the Electrical Department of the P.L.A. and the Illuminating Engineering Department of the G.E.C., the actual installation being carried out by Messrs. Harland & Woolf. The system of illumination is similar to those employed for the dock lighting as described.

The striking advance that is being made in illuminating engineering is without doubt destined to open up new and far-reaching ways and means for trade expansion, both in this country and overseas, and it is very significant that the G.E.C. continues to blaze the trail in many of these great lighting enterprises.