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EDITED BY E. DINSDALE PHILLIPS.

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Our Standard Page.

Some twelve months ago the Engineering Section of the Incorporated Society of British Advertisers tackled the formidable problem of persuading advertisers and publishers that the Standardisation of Page Dimensions in British trade and technical journals was an urgent economic necessity. Figures provided by certain large engineering firms shewed that no less than about fifteen per cent. of the expenditure on trade journal advertisements was incurred for process blocks, artists' designs and lay-out displays. The multiplicity of shapes and sizes of pages necessitated special blocks and drawings for the repetition of one particular advertisement in a number of journals, often three or four times over when once would have served had a standard page, or a standard ratio of page dimensions, been common.

From the advertiser's point of view the case is so completely advantageous as to be beyond argument: but the publisher is placed in a different position. It is not a simple thing and it is expensive for a publisher to alter the shape and size of his journal. On the face of it the suggested reform could only be generally accepted by all interested parties as good and much to be desired. As in all cases of reform, prejudice and custom would have to be sacrificed and money spent by those who were so unfortunate as not already to be working on the lines which were to become standard. However these matters were discussed and debated at several conferences and eventually settled last January at a joint meeting representing the Incorporated Society of British Advertisers, the Periodical Trade Press and Weekly Newspaper Proprietors' Association, and Independent Publishers. It was resolved that the Advertisement Page size of 10 inches by 7 inches be the accepted standard of printed area.

From the very beginning when the action towards standardisation was first suggested we have viewed it with favour and been entirely in agreement with the economical principle which would remove the cause of palpable great waste. We found ourselves as one of the unlucky journals which happen not to be in line with the standard and, since belief in principle is not much good without action, we have decided to toe the line and bear our share in the cause and cost of progress. For it will mean considerable expense and some disturbance of routine to serve this journal in the new and larger standard page form. The change will be introduced with the July issue, that being the first part of a new volume.

We have shewn that the advertiser stands to gain by the change. On our part we accept with confidence the argument, put forward for the conversion of the publisher, that the money saved in this way by the avoidance of wastage will be available for the purchase of additional advertising space. An increased revenue would set off our conversion costs and, such is the effect of real progress, it would enable us to give our friends more and better service, and generally enhance the scope and opportunity of this journal in its work.

Electrical Porcelain.

On the fifteenth of this month, with due ceremonial, was opened the research laboratory which is the latest addition to the new works near Stourport of the Steatite and Porcelain products Limited. The inexorable calendar defers the publication of a technical description until next month, but we may briefly refer now to certain peculiar points of general interest concerning these works. Set in the upper valley of the River Severn amidst the charming countryside, here the ancient art of the potter, continuing ever on through all the ages of man, now serves his newest need in this the electrical era.

It would indeed be difficult to mention offhand an equally good example of ultra-modernity in manufacturing industry. Where else could one find the lesson of progress so irresistibly driven home as in this place of compelling comparisons ranging from the hand worked lump of common clay to the grand crash of man-made lighting? For here still spins the old-old potters' wheel before the muscular bare-armed potter as he moulds with deft fingers the yielding mass: his craft requires only a few shillings' worth of mechanism but a wealth of manipulative skill. Alongside are rows of automatic presses of which alone the dies are worth hundreds of pounds; dainty girls in overalls manipulate them. The wheel and the press—each makes things the other cannot: but there are far more presses than wheels and the things made by the one are counted in the millions of machine repetition whilst there are merely dozens of the products of the craftman's labour.

These works to a remarkable degree exemplify the blending of science and industry. The one million volt electrical insulator is, after all, only a piece of pottery: but it is a creation of chemical, mechanical and physical science. The meticulous observation of scientific truths is apparent throughout: even the atmosphere had to be clean and pure—hence the works were placed in rural sheltered vale. The mechanics' shop provides tools of the finest accuracy and permanence; the chemists ensure purity and uniformity of materials; the physics experts test, gauge, supervise and devise all through the processes in regard to electrical, mechanical and temperature effects and usages. It is interesting to note further in this connection of science and industry that only by the co-operation of German interests, which hitherto led the world in this field, has it been possible to provide Britain with this valuable national property. The catholicity of science and the mutual dependence of nations will surely be one of the wholesome lessons spread by the grid over the land to all who know the origin of the insulators, of which some £200,000 worth have already issued from these works.

Forceful and encouraging too is the impression of the far reaching benefit of a new industry planted in virgin soil. The Electrical Power Company assisted in the acquisition of the works' site, and now provides the whole of the works power services. The Railway Company has built a new station close to the works: the first passenger train to arrive at Burlish Halt, as the new station is called, was the special " diner " which brought a party of guests direct from Paddington for the inaugural ceremony of the fifteenth. Workpeople had to come in from other places. Many miners were drawn from the ranks of the unemployed in South Wales and Durham: it was stipulated that these men should be married and have two children. They have proved to be extremely apt in their new work, and not forgetful of the paternal qualification, as is evident in the model village which has had to be built and which had to be provided with an enclosed recreation ground for the youngsters. The housing estate is an essential part of the Company's establishment; it is planned in keeping with the rural charm, even the smallest houses have two living rooms, three bedrooms and a bathroom, and the rents to the workpeople are very low.

It had been arranged that Lord Melchett should " open " the research laboratory, but at the last moment he found it not possible to get away from the House of Lords and the Coal Mines Bill. However, he sent a long letter paying tribute to those responsible for bringing the scheme to fruition; he outlined the principles upon which the business had been established and dealt with its aims and objects. In his absence the chair at luncheon was taken by Dr. Clayton. The principle speakers were Sir Philip Nash, Chairman of Metropolitan-Vickers Electrical Company; Sir John Brooke, one of the Electricity Commissioners; Sir Edward Crowe, of the Department of Overseas Trade; Mr. L. Thurner and Mr. C. S. Garland, Managing Director of Steatite and Porcelain Products Ltd. From this list it will be gathered that the interests and prospects of the new industry were covered in all phases. Points emphasised were that this country is most greatly concerned to-day with the transmission and distribution of electricity, with the development of export trade, and with the reduction of unemployment. Obviously, in all these respects, the new works has a great and permanently effective part to play.

Wake Up!

At the risk of boring some of our good readers, we must again refer to the A.M.E.E. Annual Convention. Our apologetic excuse for reiteration is that there are some very estimable folk who do require to be urged and reminded even to get up and catch the train. This paragraph is in effect another knock at the door of those who have deferred writing to Mr. Cowie of the London Branch for tickets and other talismans to bring them to the auspicious foregathering of their fellow members of the Association in London on June 24th. Acceptance is now an urgent matter, and as the time draws nearer so does the programme offer yet more delectable fare. Plainly this year's Annual is to be one of the best ever.

Standard Specification for Mining Motors and Generators.

The British Engineering Standards Association has just issued a British Standard Specification for Electric Motors and Generators for Mines. The Specification applies to machines of one brake horse power and upwards per 1000 r.p.m., having windings insulated with Class A material, and wound for voltages not exceeding 7000 volts. The Specification has been drawn up to comply with the General Electric Regulations made under the Coal Mines Act and in its preparation due regard has been paid to the explanatory notes made in Mines and Quarries, Form No. 11. The Specification does not apply to turbo type machines, rotary converters, motors for traction purposes, i.e., motors mounted on vehicles for their propulsion, nor does it apply to motors embodied in coalcutters, drills and conveyors, for which another Specification will be prepared. Two classes of machines are provided for by the Specification, those for use in locations where flameproofness is not required, and those for use in locations where General Regulations 127 (v.) and 132 of the Coal Mines Act are applicable.

Colliery Power Plant: Condenser Vacuum.

EDWARD INGHAM, A.M.I.Mech.E.

EVERY colliery engineer realises the importance of maintaining a good vacuum in the condenser of a reciprocating steam engine or a turbine. A slight reduction of vacuum means a serious waste of steam or coal; indeed a reduction of only 1 lb. per square inch may mean, in the case of a large engine, a monetary loss of £2 or £3 per week. It is not therefore surprising that the engineer-in-charge who wishes to obtain the best results keeps a constant eye on the vacuum gauge; which, if reliable, constitutes one of the pointers towards economical working.

Now, there is good reason for believing that vacuum gauge readings are in a great many cases not by any means to be depended upon. If the readings are to be trustworthy, not only must the gauge be of satisfactory design and construction, but the engineer must have clear notions as to the real meaning of vacuum, and the manner in which it is measured.

Unfortunately, it is a fact that many working engineers, and not a few technically-trained men, are not perfectly clear on the principles involved, and as so much depends upon a right knowledge of these principles, we proceed with an explanation of them.

The atmospheric pressure, which is due to the weight of the atmosphere pressing down on the surface of the earth, is 14.74 lbs. or, say, 15 lbs. per square inch under normal conditions, but it varies from day to day according to the amount of water vapour in the air.

If now, a glass tube about one yard long, open at one end, be filled with mercury, and if the open end be then closed and immersed in a bowl containing mercury, the tube standing vertical, it will be found that the mercury in the tube falls below the upper end of the tube, and stands at a height of about 30 inches, (according to the weather conditions) above the surface of the mercury in the bowl. This column of mercury, called the "barometric column," is supported by the pressure of the atmosphere. It will be seen that two inches of mercury corresponds approximately with 1 lb. per square inch of pressure. The space above the mercury in the tube is devoid of all pressure, and is literally an empty space, or a vacuum.

A mercurial vacuum gauge is similar to the barometric tube just described, but its upper end, instead of being closed, is open and connected with the condenser. In the accompanying diagram, A represents the barometric tube, and B the vacuum gauge.

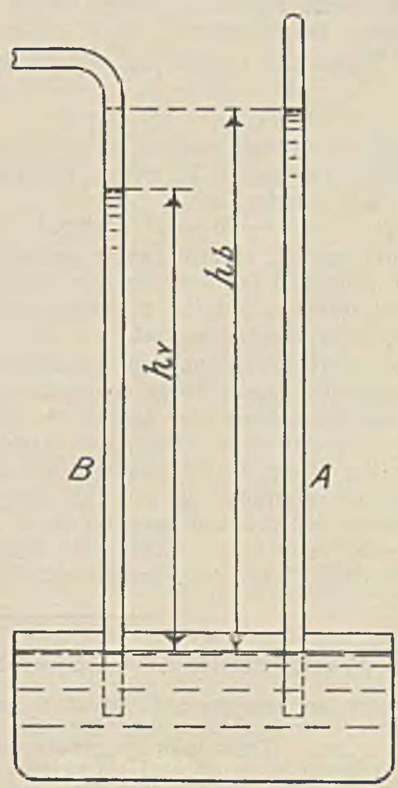
Suppose for the moment that the weather conditions are normal. Then the mercury in A will stand at a height of 30 inches above the level of the mercury in the bowl; and, if there is a perfect vacuum in the condenser, the mercury in B will stand at the same height. If, however, there is a pressure of say 3 lbs. per square inch in the condenser, corresponding to 6 inches of mercury, the effective pressure supporting the mercury column in B will be: 15 — 3 = 12 lbs. per square inch, equivalent to 24 inches of mercury, so that the mercury column will stand at a height of 24 inches above the level of the mercury in the bowl; in other words, the vacuum gauge shows that there is a vacuum of 24 inches of mercury in the condenser.

Suppose next the pressure of the atmosphere falls. Then the barometric column will fall, and so also will the vacuum gauge column. But the pressure in the condenser does not alter because the atmospheric pressure alters. Thus we see that although the condenser pressure may remain constant, the vacuum gauge will give variable readings if the atmospheric pressure varies. Clearly, the vacuum gauge readings mean nothing definite unless they are corrected to give the real vacuum under a standard atmospheric pressure of 30 inches of mercury.

If we denote the actual vacuum gauge reading by h_v, then if the atmospheric pressure is 30 inches of mercury, and the condenser pressure 3 lbs. per square inch or 6 inches of mercury,

$$h_v + 6 = 30,$$
$$\text{and } h_v = 30 - 6 = 24.$$

Suppose now the atmospheric pressure falls to 29 inches. This does not affect the pressure in the condenser,



which will still be 6 inches of mercury, and therefore,

$$h_v + 6 = 29,$$

$$\text{and } h_v = 29 - 6 = 23.$$

Thus, although there is no change in the condenser pressure or vacuum, the vacuum gauge reading alters from 24 to 23 inches of mercury when the atmospheric pressure falls from 30 inches to 29 inches, from which it would appear that a fall in the atmospheric pressure of one inch of mercury has impaired the vacuum by a like amount, although actually it has no effect whatever on the vacuum. The necessity for taking the barometric pressure into account when dealing with vacuum gauge readings will be obvious.

The gauge readings may be easily corrected to standard by subtracting the actual barometric pressure (whether below or above 30) from 30 and adding the difference to the actual reading of the gauge. The reason for this will be understood from the following consideration:

Let h_c be the correct reading of the vacuum gauge to suit the standard atmosphere of 30 inches of mercury, and let h_b be the reading of the barometer, h_v being the actual gauge reading.

On referring to the figure, we see that

$$30 - h_c = h_b - h_v,$$

$$\text{and } - h_c = h_b - h_v - 30,$$

$$\text{or } h_c = 30 - h_b + h_v.$$

Thus the correct reading is equal to 30 minus the actual barometric pressure plus the actual vacuum gauge reading.

For example, if the barometric pressure is 30 inches of mercury,

$$h_c = 30 - 30 + h_v,$$

$$\text{that is, } h_c = h_v,$$

so that the gauge reading is correct when the atmospheric pressure is 30 inches.

If the barometric reading is, say, 29 inches, then

$$h_c = 30 - 29 + h_v,$$

$$= 1 + h_v.$$

Thus, if the vacuum reading is say 26 inches when the barometric reading is 29 inches, the vacuum reading corrected to standard is

$$h_c = 1 + 26 = 27 \text{ inches.}$$

In actual practice, vacuum gauges are usually similar to pressure gauges of the Bourdon type, being graduated in inches of mercury, but the principle is the same as that of the glass gauge described.

Serious errors in vacuum gauge readings sometimes occur through the gauges being connected up with the condenser, or the exhaust pipe leading thereto, by small improperly arranged pipes. Thus, it is a common practice to fix the gauge on the engine house wall in the most convenient position, and run the connecting pipes upwards for a distance and then across to the top of the condenser, or to the exhaust pipe from the low-pressure cylinder. With this arrangement, water of condensation will collect in the pipes above the vacuum gauge, so that there is a head of water above the gauge, which may seriously affect the gauge reading. A head of water of 2.3 feet is equivalent to a pressure of 1 lb. per square inch or 2 inches of mercury, so that if there is a head of water of, say, 2.3 feet, the gauge would give a reading which is 2 inches less than the true reading corresponding to the vacuum in the condenser. It is therefore important to avoid as far as possible having connecting pipes in which any considerable quantity of water of condensation can collect above the gauge. The best plan is to connect the gauge direct to the top of the condenser or to the exhaust pipe, rather than fix it to the engine house wall.

The attainment of a high condenser vacuum requires an ample supply of condensing water, efficient condensing plant and pumps, and perfect air tightness at all parts of the condensing system. Given these, it is possible with a reciprocating steam engine to maintain a vacuum of about 27 inches of mercury. It is not as a rule worth while with reciprocating plant to aim at a higher vacuum than 27 or 28 inches at the most, because the initial cost of the condensing plant required to produce very high vacua is not warranted by the savings of steam effected. The case is different with a turbine plant, for the turbine can take fuller advantage of a very high vacuum than can the reciprocating engine. Consequently, it is usual to instal very elaborate condensing plant with a turbine, and a vacuum of 29 inches or even more is commonly maintained.

When the vacuum in any type of plant is not what it should be, every effort should be made to find out the cause. If of course the supply of condensing water is restricted, or if the condenser and the pumps are not properly designed and in good condition, the best results cannot be expected. More often than not, the cause of impaired vacuum is leakage of air into the condensing system. Consequently it is advisable to make a practice of going over all parts where leakage is possible with a lighted candle or lamp, the flame of which will be drawn inwards by the rush of air at any leaky place. Not infrequently, in the case of reciprocating engines, considerable leakage of air occurs at the piston rod and tail rod glands of the low-pressure or condensing cylinder.

Other causes of defective vacuum are restricted exhaust passages, leaky valves and pistons, improper design or setting of the valves, etc. If the valve setting is such that the exhaust is late, the steam cannot escape freely, and a high back pressure and poor vacuum are the consequences. The same trouble results from restricted exhaust passages.

When investigating causes of poor vacuum, the engineer-in-charge will often find the application of the indicator a valuable help towards a solution of the trouble.

The Weathering of Copper-Steel.

Steel with an admixture of about 0.2 per cent. of copper offers considerable saving for use in weather exposed structures. Tests with copper-steel sleepers extending over seven years showed appreciable advantages. It has been estimated that copper-steel has from twice to 2½ times the life of ordinary steel; it has been proved that where copper-free steel had lost 70 per cent. to 90 per cent. of its thickness, copper-steel, under identical conditions, had only 4 per cent. wastage. It is noteworthy that for the Central England Electricity Scheme transmission towers have been constructed of copper-bearing steel.

Proceedings of the Association of Mining Electrical Engineers.

SOUTH WALES BRANCH.

Electrical Measuring Instruments.*

Discussion.

Mr. W. A. HUTCHINGS congratulated Mr. Morgan on the excellent paper. The full understanding of electrical instruments was a part of the mining electrical work which was often neglected. They were in everyday use and with the different types available, it behoved all mining electricians to study them.

Mr. Hutchings said he was hoping that when Mr. Morgan suggested reading this paper he would say a little about the troubles cropping up in regard to meter connections. It was all very fine to place a meter on the switchboard but it was useless unless properly connected. Perhaps someone would come forward one of these days and write a paper on the connections of electrical instruments and the difficulties to be met in that direction.

He would like to emphasise one important point with regard to meters, not directly in connection with this paper. He considered that more care should be taken of the insulation of meters, i.e. where the connections are made for bringing the wires to the meters. Very often in collieries they had to experience breaking down to earth, and he believed that if a little more attention were paid to the insulation at meter connections it would be found well worth while as a means of reducing those failures.

Mr. J. B. J. HIGHAM.—In the section "Electro-Magnetic Instruments"—sub-section "Moving Iron Type," the author had stated that the coil is wound on a non-magnetic metal bobbin: it must be remembered, however, that the bobbin should not form a closed circuit and hence should be split longitudinally, otherwise it would be unsuitable for a.c. measurements. With regard to instrument scales, there was always the tendency to look for an instrument with an evenly divided scale. It was interesting to note that a scale which is open at the commencement and closed toward the end gives greater observational accuracy. A constant observational error in the reading of a logarithmic scale will give the same percentage error throughout: an incorrect zero adjustment gives the same percentage error on logarithmic scales.

There was just one other point; in dealing with frequency indicators of the vibrating reed type, the author had mentioned that the frequency of the reed is the same as that of the supply. As a matter of fact, the reed has a natural frequency equal to twice the frequency of the supply to which it responds.

Mr. JAMES F. SMITH.—The author has dealt with every form of indicating electrical meter likely to be met with by the colliery electrical engineer, and the paper filled a decided gap in the Proceedings of the Association. He, Mr. Smith, had some time ago been required to write a treatise on electrical measuring instruments, relays, etc., and he had met with great difficulty because he found that there was apparently less published material dealing with electrical measuring instruments than with almost any other electrical subject.

Mr. Smith said Mr. Morgan had not left much to be said but he thought the opening statement could well be enlarged. Measurement, and through measurement control has reached a higher degree of accuracy in electrical work than in any other branch of applied science. There are a number of fundamental measurements which must be made before the efficient operation of a colliery power plant can be assured, outstanding examples of which are steam flow, compressed air flow, water, coal, and electricity. A meter that will compute the flow of electrical power with a high degree of accuracy can be obtained for a matter of a few pounds, or even shillings for the simpler types. On the other hand a meter to integrate steam or compressed air flow will probably cost from £80 to £150 with quite appreciable subsequent maintenance costs and having, moreover, a far lower standard of accuracy than electrical meters. The value to the engineer of the accuracy, cheapness, reliability, and ease with which electrical characteristics can be measured can hardly be overestimated.

With reference to current transformers, it might be well if Mr. Morgan added the usual note of warning in his text to the effect that the secondary coil of a current transformer should be short-circuited before any attempt is made either to break or make connection with an ammeter. Remembering that the secondary side of a current transformer is wound with a large number of turns, the induced voltage created on breaking the secondary circuit can be dangerous.

He was glad that Mr. Morgan had so carefully explained the principle of the induction instrument as, while the use of this type of instrument is extremely rare in colliery work, the principles involved in its design are similar to those of many other forms of instruments, e.g., power factor indicators, synchronoscopes relays, etc.

With reference to the electro-static voltmeter, while this has a very limited application to colliery work it has the advantage that it passes no current and it is thus of special use for testing insulation by the rate of fall of charge method. It is, however, more an instrument for the laboratory than for general mining service. It might be well to remember however that a number of forms of leakage indicators are really electrostatic voltmeters.

Mr. Smith said that he, personally, held the opinion that the moving iron instrument was particularly suited for mining work. As Mr. Morgan had said, the frequent statement that its scale is too open at the lower readings and cramped at the higher readings was not really correct, as moving iron instruments could now be obtained with a scale almost as evenly divided as a moving-coil permanent-magnet instrument. It was also a cheap and reasonably accurate instrument; very reliable and far more robust with its simple movement than other types with hair-spring control, delicately balanced armatures, etc. Further it would stand vibration quite well and had a very great advantage in that it was suitable for both a.c. and d.c. measurement of current and voltage.

Mr. W. HUGHES said that with the repulsion type of meter, it sometimes happened that the pointer under certain conditions tended to move in the counter clockwise direction: would Mr. Morgan please explain the cause of the reverse movement?

Mr. ROWLAND H. MORGAN (in reply).—Several speakers suggested that treatment of allied subjects such

*See *The Mining Electrical Engineer*, Feb. 1930, p. 296; Mar. 1930, p. 333; Apl. 1930, p. 395.

as the measurement of power, the design of instruments, electricity meters, etc. would be of service. While agreeing with the remarks, Mr. Morgan had found it impossible to extend his subject on this occasion due to the necessity of confining the paper to a length commensurate with usual contributions.

Regarding the insulation of instruments, mentioned by Mr. Hutchings, tests which normally should be adequate are called for in the British Engineering Standards Specification on such instruments. An instrument conforming with the requirements therein laid down should not be generally susceptible to insulation breakdown; but for instruments operating under abnormal conditions, say where moisture is likely to be met, it would be desirable that the terminal insulation at least should be such that it is impervious to the particular abnormality existing.

As indicated by Mr. Higham, it is desirable that the metal bobbin should be split longitudinally in instruments used for a.c. measurements, to prevent the circulation of eddy currents and the resulting introduction of errors. Not only should the bobbin tube be split but also the end-plates and furthermore the splits of the tube and end-plates should coincide.

The observations on the logarithmic scale were interesting. The arrangement of scale readings was almost unlimited and could, by appropriate and good design of the instrument, be made to have an almost negligible error.

Referring to the vibrating reed frequency indicator, as each cycle of the alternating current promotes two distinct magnetic impulses, the natural frequency of the reed, to correspond to a certain periodicity of the supply, must be twice that of the certain supply frequency. This feature is sometimes made use of to double the range of reed type frequency indicators. A constant magnetic field equal in strength to the maximum field produced by the alternating supply is superposed as and when desired upon the alternating field. This results in the reeds responding to double the frequency as the reed now only receives half the impulses it would otherwise obtain. This additional field may be produced by a permanent magnet, by an electro-magnet energised by direct current, or by providing the main operating magnet with an additional winding connected to a direct current supply.

It was well that the danger associated with the collapse of the de-magnetising effect of the secondary winding following a break of the secondary circuit had been pointed out by Mr. Smith. Again, if a current transformer were to be energised with an open secondary there was a possibility of increased saturation of the core giving an altered phase angle and ratio: thus, on re-use of the transformer, an error may be introduced as the exciting current required is now different.

The electrostatic type of instrument is more readily adaptable than is generally appreciated. Not only is the principle extensively made use of in the form of leakage indicators, but it is, for example, used very successfully as an ohmmeter, being unaffected by external fields, robust, light, and accurate.

In reply to the question by Mr. Hughes: it was evident that an accidental internal disarrangement of the relative position of fixed to moving iron was not responsible, for then the instrument would, as long as the disarrangement was maintained, be permanently tending to read in the reverse direction. Referring to Fig. 1, should the secondary of the current transformer be earthed on one side and one terminal of the ammeter also earthed, the instrument would be short circuited out if the earthed lead of the transformer secondary was connected to the insulated terminal of the instrument and the earthed terminal of the instrument connected to the insulated terminal of the transformer secondary, and no deflection of the ammeter would result until the leads were changed over. No other explanation was apparent as the ammeter is a repulsion soft iron type and no peculiar influence, such as electrostatic effect for example, would be likely to be corrected by changing over the leads.

NORTH OF ENGLAND BRANCH.

The Effect of Change of Frequency.

Major R. T. EDWARDS.

(*Paper read 11th January*, 1930.)

We on the North East Coast are likely to be involved in the near future in the changing over of the existing public supply systems from a 40 cycle supply to a 50 cycle supply to bring this area into line with the standard frequency now adopted over the rest of the country, and it will be of interest to consider briefly the effect that the new frequency of 50 cycles will have on existing plant designed for working on 40 cycles and, where the result is considered such as to make the apparatus unsuitable, what modification will be necessary.

This paper cannot attempt to enter into a discussion of those very contentious subjects, the right or wrong of the grid system and its child the standard frequency, nor can any suggested methods of overcoming difficulties stated in it be taken as a guide to the policies likely to be adopted by any authority carrying out the change-over, as no doubt every case will have to be considered on its merits and considerations here can only be general.

Before considering the effect of the new frequency on plant, let us briefly run over the policy outlined by the Electricity Act and the reasons why a change of frequency is considered necessary, and why we are likely to be called upon to convert our plant to suit a 50 cycles supply.

The Electricity Supply Act of 1926 has as its main objective the improvement of supply and the reduction in cost of electricity in the United Kingdom, which is to be achieved by reducing the number of inefficient small generating stations, each with its 100 per cent. or more of standby plant, and replacing them by a comparatively small number of highly efficient super stations, working with as large a load factor as possible. For these large stations to take full advantage of the diversity of load over the whole country and to work with a minimum of generating plant and yet provide adequate standby for emergencies, it is essential to interconnect them.

Interconnection between power stations working on different frequencies entails the runnig continuously of frequency changers, or similar rotationg plant, with of course considerable losses in conversion, which would more than offset the advantages gained, so that it is vital that all the power stations and plant to be connected to this main grid system shall be at the same frequency, if advantage is to be obtained from the principle.

At the time when the Act came into being, approximately 75 per cent. of the units generated in the United Kingdom were on a three-phase supply at 50 cycles: of the remaining 25 per cent. the majority were generated at 25 and 40 cycles, three-phase, with a small percentage made up of single and two-phase a.c. and some d.c.

Owing to the preponderance of 50 cycle plant in the country, when called upon to decide on the system of supply, the Central Electricity Board—whose duty it is to supply electricity to authorised undertakers, in accordance with the provisions of the Act, and who are therefore responsible for the interconnections—selected three-phase alternating current at 50 cycles.

Section No. 9 of the Electricity Supply Act provides for the change of frequency of authorised undertakers where such is required to effect the standardisation. The Central Board is empowered to instruct the undertakers to carry out such change when required, the necessary monies being advanced by the Board, free of interest. The Board will obtain this money by borrowing; the interest and sinking fund charges on this to be repaid each year to the Board by the Electricity Commissioners who will apportion the charge among authorised undertakers etc. throughout the country and not on the undertakings to be charged over only. In this way, the cost of the conversion of the minority to the frequency of the majority will be borne by the Electricity Undertakings as a whole and this will obviate the possibility of certain undertakings being unfairly loaded with heavy financial responsibilities due to their having developed on what is now considered a non-standard frequency.

The whole of the system of Newcastle Electric Supply Co. and its subsidiary Companies, is at present working at 40 cycles, as is also the Newcastle & District Electric Lighting Co., and provision is made for the converting of these systems to 50 cycles in the North East England Electricity Scheme 1929, prepared by the Electricity Commissioners, and published in June last year, which has yet to be confirmed.*

Other non-standard frequencies at present being changed over are the Glasgow Corporation, Clyde Valley Electric Power Co., and Birmingham Corporation, all on 25 cycles.

HOW THE CHANGE AFFECTS EXISTING PLANTS AND APPARATUS.

In the majority of cases, when a change-over takes place where plant has to be changed or modified, the time available in which to do this work is very limited and may in some bad cases only amount to a few hours and this reason alone will have a very great bearing on the actual modifications made, as in these cases time will be more important than cost. As previously stated, each case will have to be considered on its own merits, and this should be borne in mind.

Generating Plant.

For a change from 40 to 50 cycles, all plant will be required either to run 25 per cent. faster, or, where this is impracticable, be altered at the generator or prime mover end to suit some other speed which is suitable for the modified machine. In the case of small turbine-driven alternator sets, it may be possible to convert the turbines to suit the increased speed by replacing the existing spindles, diaphragms, and governor drives with others designed for the new duty.

Large turbines will in nearly every case need to be replaced, as they are unsuitable for running at a higher speed. The majority of alternator stators working on 40 cycles will be suitable for the higher frequency, but it will be necessary to replace or modify the rotors and exciters to produce a weaker field. The mechanical strength of the rotating parts when subjected to a 25 per cent. increased speed must be considered.

Steam, gas and oil engine driven alternator sets are usually slow speed machines, and the engines are unsuitable for any considerable increase in speed, so that the alternators will either have to be re-wound to suit the present speeds or replaced if this is not practicable—a reduction in engine speed must be avoided if possible, as this will most probably result in a lower rating.

It is as well to point out that with the exception of speeds of 600, 300, 200 r.p.m., etc., the synchronous speeds of 40 and 50 cycles do not agree. For an existing speed of 2400 on 40 cycles, we have a choice of 3000 or 1500 r.p.m.; for 1200 r.p.m. we have 1500 or 1000 r.p.m.; for 800 r.p.m., 1000 or 750 r.p.m.; and so on. This becomes most important when motor problems are to be considered.

Power House Auxiliaries.

Any auxiliary plant such as fans, pumps, stoker drives, etc., which are motor driven, will of course be affected by the change in frequency of supply. These will be considered under the general heading of motors.

* Confirmed by scheme adopted by Central Electricity Board 24/1/30, after this paper was read.

Auxiliaries which are steam driven, will not be affected except where the plant has been re-designed and the duty of the auxiliaries is changed.

Transformers.

Forty-cycle transformers when working on a 50-cycle supply, are affected as follows :

1. The k.v.a. rating remains practically unchanged.
2. Iron losses will be reduced by some 10% to 15%, depending upon the constants of the transformer.
3. Copper loss will shew a slight increase, particularly on transformers having a high winding current, i.e., 500 amps. and upwards, but this increase will be more than offset by the reduced iron loss.
4. Reactance will be increased by approximately 20% for the same k.v.a. rating.
5. Regulation will show a slight increase for unity power factor loads, and an increase amounting to 20% at the worst power factor. This arises from the fact that while at unity power factor, reactance of the transformer affects the regulation but slightly, after the power factor decreases with a lagging current, the reactance component of the regulation becomes more and more important until, in an average transformer, it becomes preponderant at a power factor lower than 0.95.

Summing it all up, it will be seen that the transformer on 50 cycles will have a slightly better efficiency, and a slightly increased voltage drop. Transformers in general, both step-up and step-down, will require little or no modification when working on the new frequency. But it is possible that where the regulation is particularly important on low power factor, it may be necessary to reduce the k.v.a. rating and instal extra transformers to carry the load. In certain cases where transformers are doing special duty or where the control of other plant depends upon very definite characteristics of the transformer, such as rotary converters, electric furnaces, etc., considerable modification or even replacement may be necessary.

Rotary Converters.

In many cases, existing 40 period rotary converters will be suitable for running on a 50 period supply. The starting motors, however, will require modification to ensure easy starting and paralleling on the bars.

As the existing 40 period rotary will run on an increased speed on 50 period supply, it is important to consider the mechanical strength of the armature and commutator. Extra binding wire to keep the windings in place will most likely be required and, in some of the older machines, it will be necessary to enquire into the strength of the commutator "V" rings.

Commutation will be the chief difficulty. On full load this will most likely be at least as bad as at present on 25 per cent. overload, and probably worse due to the increased speed.

The regulation of the machine should be O.K. provided the transformer reactance does not exceed 25 per cent. on the new frequency. Above this, the machine is liable to be unstable. It may be possible, by modifications to the transformer, to correct this reactance but it is probable that replacement by a new transformer will be the most satisfactory and possibly not the most expensive method.

The starting motor of a rotary required to be used on a higher frequency will need to be altered, either by completely rewinding or reconnecting and, in some bad cases, by replacement.

Motors.

Forty-cycle motors connected to a 50-cycle supply without alteration will be affected as follows :

1. The speed will be increased by 25 per cent.
2. The starting torque and pull-out torque will be reduced.

The speed increase is due to the fact that the so-called synchronous speed or number of revolutions per minute made by the magnetic field of the stator, is equal to the alternations per minute of the supply circuit divided by the number of pairs of poles. From this it follows that if the cycles are changed and the poles remain the same, the revolutions per minute of the field will change exactly as the frequency.

It is not so obvious why the torque is affected, so it will be as well to consider it in more detail. The flux in the motor will vary inversely with the frequency, while the speed will vary directly with the frequency. The torque on the motor varies inversely as the square of the frequency; but, due to the fact that the speed increases directly with the frequency, a reduced torque is required at the higher speed. Therefore, for an equal power output, the starting torque and pull-out torque will vary inversely with the frequency instead of inversely as the square of the frequency.

In all these considerations, it has been assumed that the voltage on the new frequency will be the same as that operating before the changeover. If, however, it could be arranged for an increase of voltage in proportion to the change in frequency, then the majority of motors would be suitable, without modification, for an increased load at the new frequency. It would, however, be necessary to ascertain that the mechanical strength and insulation are suitable for the change. Under these new conditions, when frequency, voltage, and horse power are all increased in the same proportion, a 40-cycle motor running on a 50 cycle supply could be expected to give a very similar performance to that which it had before the supply was changed. Actually, the efficiency might be improved by ½ per cent. to 1 per cent.; the power factor reduced by 1 per cent. to 2 per cent., whilst the starting torque may be reduced by approximately 20 per cent. expressed as a ratio to full load torque. Actually the output could, in many cases be rather more than that corresponding to the 25 per cent. increase in frequency, as the temperature rise will be less, due to the improved ventilation. This, of course, does not apply to totally enclosed and short-rated machines.

In the majority of motor drives, the same horse power will be required at the new frequency. In those cases where it is possible to increase the voltage and modify the drive to suit a higher motor speed, the existing 40 cycle motor can be expected to give approximately the same horse power if the voltage is increased by 12 per cent. instead of 25 per cent.; that is to say, increased by the square root of the change instead of directly as the first power. An example of this would be the operation of a 440 volt, 40 cycle motor on a 500 volt, 50 cycle supply. The square root of 50/40 is approximately 1.12; then if $1.12 \times 440 = 492$ volts to be used on 50 cycles, the magnetic density in the iron would be about 90 per cent. of its 40 cycle value, and the torque will be $90^2/100 = 81$ per cent. of the 40 cycle value. Since the speed will be 50/40 of that on 40 cycles, the resulting horse power will be $50/40 \times 81/100 = 1.01$ times its 40 cycle value, or practically the same.

Since it is unlikely that the voltage on the majority of feeders and networks supplying motors will be changed to any extent, as any considerable change would seriously involve the lighting and heating loads, also carried, consideration must now be given to the more practicable methods of executing the change-over of motor driven plant. Before considering the mechanical difficulties likely to be met, it is as well to remember that there are certain types of windings where practically the same effect as increasing the voltage can be obtained by reconnecting.

A 40 cycle motor wound with a delta connected stator can be reconnected 2 parallel star to give the same horse power at the increased speed without much difficulty. Where the delta wound motor to be reconnected is of the squirrel cage type, star-delta started, it will, of course, be necessary to replace the existing starter with either one of the auto-transformer type, or a direct starter.

Possibly the most reasonable method that suggests itself of overcoming the difficulty of increased speed with the new frequency is that of rewinding the motor to suit the nearest speed, by modifying the stator and rotor to give a new number of poles. Unfortunately this rewinding in the case of 40 to 50 cycle change presents many difficulties, mainly due to the synchronous speed of the two frequencies not agreeing. As has already been shewn, only at the speeds of 600, 300, 200, and 150 r.p.m. can a new or rewound motor be arranged to suit the same speed on 50 cycles, and we are left with a choice of two alternative speeds in every other case from which to select. For example, to replace a 2-pole motor synchronous speed of 2400 r.p.m. it is necessary to choose between 2-pole 3000 r.p.m. or 4-pole 1500 r.p.m. For 4-pole 40 cycles at 1200 r.p.m., the alternative speeds of 4-pole 1500, or 6-pole 1000 r.p.m. are possible. For 6-pole 800 r.p.m. either 6-pole 1000 r.p.m. or 8-pole 750 r.p.m., and for 10-pole 480 r.p.m., 12-pole 500 or 14-pole 428 r.p.m. As we get to lower speeds, the percentage difference between the 40-cycle and the replaced 50 cycle speeds is reduced due to the increased number of poles from which to choose. Therefore, when considering a rewind, the first thing is to decide the most suitable number of poles the motor must have after rewinding; the next is to find out whether the existing stator punchings are suitable; that is, whether the number of slots is divisable by the number of poles. Frequently it will be found that the punchings are not suitable and new iron is required. The same considerations must also be given to the rotor of a slipring motor. Squirrel cage rotors should not require modification, provided they are mechanically suitable for the new speed.

Besides the difficulties outlined above, experience has proved that when comparatively old motors are stripped for rewinding, faults, not obvious when the motor was examined assembled, are discovered. These faults probably in no way impaired the efficiency of the old machine, but when they are taken into consideration and the extra parts replaced, the rewound motor will often be found to be more expensive than a new motor designed for the new conditions. Unfortunately, the faults are not discovered until a deal of money has been spent and the only alternative is to go ahead, although the extra replacements make the rewind uneconomical.

One of the chief reasons why the rewinding of a motor is impracticable when considering change of frequency is that the actual change-over has to be carried out with as little inconvenience and service interruption to the consumer as possible, and rewinds, under ideal conditions, take time. Also, when the extra time required to remove and replace the motor, ship to and from the Works, is taken into account, rewinding will be found to be out of the question except in very special cases. The only way in which to make use of rewound motors would be to rewind for some other job altogether, and replace the motor in question with another.

The one remaining method of making plant suitable for the increased frequency is to replace the motor with a new one designed for the new conditions, and probably in the majority of cases this will be found to be the most staisfactory, taking all things into consideration.

Small motors working on steady loads that are not liable to overload, and require a small starting torque, will be quite satisfactory on the increased speed without modification. This particularly applies to small domestic motors and battery charging motor generator sets.

Whatever method is employed to make the motor right for the change of frequency, it must not be forgotten that the thing that really matters is that the plant to be driven and the work to be done should not be interfered with or the output reduced.

A 50 cycle motor cannot, in the majority of cases, be made to run at the same speed as the motor it has to replace, and it is necessary to avoid, if possible, letting that change in speed affect the duty of the plant driven. Motors driving plant by means of a belt or by ropes are comparatively simple to put right. A new pulley on the motor shaft designed to suit the present belt speed will, nine times out of ten, meet the case. There will however be a few cases where the increase in speed of the motor makes the pulley so small that it is unsuitable, and then it may be necessary to replace both driving and driven pulley.

In these cases, care must be taken to see that the belt or rope speed is not increased excessively.

Where motors are driving haulers, winders, slow speed ram pumps, etc., through gears, the necessary correction in speed will have to be made by altering the gear ratio. On smaller plant, where the motor is not mounted on a bedplate, or where the time available for shutdown is long, this correction can generally be made by the provision of a new pinion. A new pinion to suit a new motor speed will invariably mean an alteration in the position of the motor, and where the motor has to sit on a bedplate, some difficulty may be experienced in making a suitable seating. In the greater number of cases, the exact speed cannot be obtained by altering the pinion only, but the difference between the new and the old speed will generally be close enough to suit most conditions, especially small machines.

On the larger plants where usually no standby is provided, and the time available for change-over will be a minimum, the best solution of the problem is to replace both the pinion and the spur wheel of the gear with a new set designed for the new speed reduction, and (a most important point) the same shaft centres so that they can be introduced into the existing gear frame without modification to bedplate, etc. This question of alterations to bedplates and foundations becomes very important when the change-over has to be carried out against time.

One difficulty which will frequently occur is that the new motor will be different in at least one of the following dimensions from that of the existing machine, due to the improved strength of materials and improved design of modern machines:

1. Height of shaft centres above motor feet different necessitating either provision of special adapting packing plates, or, in those cases where it is greater, the lifting of the mechanical part.

2. Motor feet centres and holding-down bolt centres again requiring special adaptors to suit the existing bed.

3. Shaft diameter—modern motors have smaller shafts and where the shaft size is less than the present motor, new half couplings, pinions, etc. will be required, for in most cases time limits prevent the re-boring and bushing of the existing parts.

Motors direct coupled to pumps, air compressors and fans present problems difficult to solve unless the existing speed can be obtained with the new periodicity. The load of a fan increases as the cube of the speed, while the load of a centrifugal pump is increased by rather more than the square of the speed, the actual figure depending upon the length of pipe line and how the pump is working as compared with design conditions. This variation of load with speed is most rapid when a pump is working near its maximum manometric head, and under these conditions a small percentage increase in speed may produce a percentage increase in power ten or twelve times as great, while a decrease in speed of only two or three per cent. may cause the pump to cease delivery. It will be seen how very important it is to keep to the correct speed as closely as possible, and, should a change be necessary, how essential it is that increased horse-power be installed to make up for the increased speed, while on the other hand a reduction in speed may seriously interfere with the duty the unit has to perform.

Fans that cannot be run at their present speed by the provision of another motor will either have to be modified or changed. It is possible to modify fans where conditions suit by replacing the impeller and retaining the existing casing, but for any large change of speed, complete replacement may be necessary.

Turbo compressors have characteristics similar to fans, and the same remarks apply.

Certain centrifugal pumps, especially multi-stage, can be modified to suit a change of speed, by replacing the impellers, etc. with parts to suit the new speed, especially if the speed be increased. Less stages are required at the higher speed, and it is necessary to run dummy stages to replace those not required.

Air compressors, ram pumps, and other reciprocating engine loads increase approximately proportional to the speed but mechanical difficulties prevent any large increase. Where it is necessary to increase the speed, and the pump or compressor is mechanically suitable, a new motor of increased horse-power should be provided.

Integrating Meters.

The majority of single-phase and polyphase integrating 40-cycle meters are working on non-inductive loads and will be quite satisfactory on 50-cycle supply. For inductive load, however, the meters will require adjustment. The actual alteration required is only small but it can only be correctly carried out on a meter test board. It is possible that the majority of meters will be corrected during the regular course of overhauling and only those subjected to low power factors will be specially brought in for adjustment.

(As of interest in showing how meters are affected by change of frequency, the author passed round to the members some results obtained by tests taken on 50-cycle type "NE" and "NA" single-phase integrating wattmeters, calibrated for 50 cycles and tested on 50, 45, and 40 cycles, in Metropolitan-Vickers' Meter Test Department, together with curves plotted from the results.)

The percentage of variation is given in the results shown for all three frequencies, at full, half, and 1/20th load, non-inductive, and the curves are plotted from these results, but in order to indicate the variation to be expected with inductive loads, figures obtained with half load at 0.5 power factor current lagging are also given. For non-inductive loads it will be seen that the results are within the permissible limits of plus or minus 2 per cent., but that on inductive loads at 0.5 power factor the error varies from 5 per cent. fast to 7 per cent. fast, depending upon the type of meter. For leading currents the meters will of course indicate slower on 50 cycles to the same amount as they indicate fast on lagging currents.

Indicating Instruments.

Existing induction ammeters will give a slight increase in reading on the new frequency while induction voltmeters will show practically no change. Induction wattmeters calibrated for 40 cycles will show a slight increase in reading at unity power factor, and from 3 per cent. to 4 per cent. increase at 0.5 power factor current lagging. Existing moving iron instruments should show no change when working on the new frequency.

Switchgear and Control Gear.

Control gear etc. working on 40 cycles will be affected as follows, when working on 50 cycles. All coils which are connected across the supply voltage, such as no-volt coils and operating coils of contactors, are directly affected by the change in frequency and voltage. Where it is possible to increase the voltage in direct proportion to the frequency, the coils will be suitable without change under the new conditions.

Auto transformers can be used on the new frequency, provided the motor conditions remain the same. Current coils, such as overload coils, are dependent only on the stator current, so that provided the voltage does not change to any appreciable extent, the coils should be satisfactory under the new conditions.

Accelerating relay coils on contactor equipments are generally connected in rotor circuits, so that in the case of existing machines the new rotor data should not vary more than 10 per cent. from the original if the same coils are to be used.

Starting and speed regulating resistances are mostly connected in the rotor circuits and are therefore likely to be unsuitable unless the new rotor current is similar to the old. They should be satisfactory for motors where the new rotor current is within 5 amps. of the original design figures of the control gear.

On large control gear which is motor-operated the motor will require modification if the same speed is required. Some of the larger sizes of liquid controllers are of the weir type and have a small motor-driven pump to circulate the water. These are usually running at high speed and it will be necessary to modify both pump and motor to suit the new frequency.

As under any change of frequency scheme the majority of motors will be changed in some way, either by rewinding or reconnecting, and frequently by replacement by new, it follows that the control gear must be made suitable for the new motor conditions. This is most important when dealing with slipring motors, as both stator and rotor circuits will have to be considered.

Domestic Appliances.

A change of frequency should have no effect on the average domestic utensil, provided of course that the voltage is not changed. Lamps, kettles, irons, etc. will be quite satisfactory. Small motors used in the home are generally of the commutator type, suitable for either a.c. or d.c., and these will not be affected by the change in frequency.

Forty-cycle and 25-cycle domestic and industrial ventilation fans will need replacing, as the greatly increased load caused by running the fan at the higher speed, makes them unsuitable for the 50-cycle supply, although it is probable that the motors will be suitable for their present load on the new frequency.

Motors driving domestic washers, refrigerators, etc. which are designed for the 40 and 25 cycles supplies will in most cases have to be replaced with one built for the new frequency.

PREPARATORY WORK AND METHOD OF CARRYING OUT CHANGE-OVER.

Before the change-over of plant can take place, a tremendous amount of preparatory work will be necessary to ensure that the replacements of, or modifications to plant proceed smoothly. The consumer and the authority responsible for the change will each have opinions regarding the modifications necessary: both views will have to be considered, and the best proposition proceeded with. A spirit of co-operation between the authority responsible and the consumer should go a long way towards solving many of the difficulties likely to arise.

A supply at a frequency of 50 cycles must be available at the nearest distribution board before a start can be made on the changing over of any particular machine, and it is interesting to see how such a service may be made available without interfering with the existing supply. The 50-cycle supply will most likely be provided in one of the following ways, i.e. existing turbo alternating plant converted to suit the new frequency: new sets suitable for the new supply installed either in an existing or new station; frequency changers, or from some adjoining supply company already working on the standard frequency.

Let us assume that a 50-cycle supply is available at the generating station, and that this is connected to the set of idle or standby busbars, while the main busbars are supplying the load on 40 cycles. A ring main can now be broken at a substation and be supplied from one end with 40 cycles, and the other end with 50 cycles. At the substation, the 50-cycle incoming supply may be connected to the standby busbars while the main busbars supply the load of all plant not changed over. With a duplicate supply available at the substation, each feeder can in turn be changed over and connected to the new supply. When all the load on that substation has been converted, the ring main will be opened at the next station and the same procedure adopted. In this way, the 50-cycle supply comes round through the stations working on that frequency, and the 40-cycle supply from the other side. When all the substations on that ring are converted, both ends are connected to the 50-cycle supply and the main will again function as a ring.

Where a lot of motors are running on one feeder without a standby cable, it may be necessary to run another cable temporarily to ensure both a standard and non-standard supply being available during the time required to change the motors over.

On certain long main feeders, it may be necessary to instal reversible frequency changers at the consumer's end to ensure a duplicate supply—such changers being removed when the plant is changed over and the existing feeder is on 50 cycles.

An efficient staff of engineers will be required to ascertain what is necessary in the way of motors, control gear, tools and erection tackle for each job to be changed over, and to see that everything is correct even down to the minutest detail before the word "Go" is given. Considerable time and money can be wasted due to, say, a motor having a terminal box on the wrong side, where the existing cables won't reach round, or due to the new motor being drilled incorrectly for the existing bedplate.

Discussion.

Mr. H. J. FISHER said they were all expecting the change of frequency to take place soon and anticipated plenty of hard work, and many brain storms before the work was completed. He had already had the experience of making one change of frequency; a group of collieries to change over from 50 to 40 cycles some years ago, and now they would have to revert to 50 cycles again. There were many difficulties then, but they would be greater now, seeing that there was about five times the amount of plant to be dealt with.

The biggest difficulty when changing over, was to maintain the supply during the change, when part plant is on 40 and the rest on the 50 cycle supply. In many cases duplicate or standby feeders would have to be provided, either as a permanent or temporary measure, and in some cases, a third standby feeder provided to act as such, for either the 40 or 50 cycle supply.

When the other change was made, they connected the new supply on to the bus-bars of the permanent gear, and temporary switchgear was brought into use, and connected up to the cable terminal boxes with jumpers. Those switch-boards having duplicate feeders on two sections and provided with section switches, would be the easiest to change over, and no temporary switchgear should be needed, except perhaps one feeder switch.

Pull-out gear like the Reyrolle type, lends itself particularly to the connecting of jumpers, an end box attached to a carriage and connected to a plug-in arrangement could easily be made. Jumpers even for 6000 volts could be used with safety, having cores insulated with vulcanised rubber, cab-tyre sheathed, and flexible wire armoured. One precaution however must be taken and that was that no matter to what kind of apparatus the cable was to be connected, the ends must pass through a trifurcating box and compound filled, otherwise the cable would surely break down at the neck, where the conductors leave the cab-tyre sheathing.

Continuing, Mr. Fisher said it was necessary when considering a change-over, that each colliery should be considered on its own merits, and the change-over programme carefully planned, all the requirements tabulated, and written instructions given to those who would take part in the change. There was of course a lot of preparatory work that could be done before the actual change, and the more that was done the easier it would be to carry out the final arrangements.

Mr. Fisher said he had been given to understand that coalcutter motors would not require any change, and that only the gearing need be altered. The biggest problem at many collieries would be the change of the change of the turbine pumps, especially at those places where the standage is small. In many cases it would mean that new pump houses would have to be built and new plant installed.

Mr. S. TULIP having expressed indebtedness to Major Edwards for making such an interesting subject of the change of frequency, re-echoed his plead for co-operation between the consumer and the Electricity Commissioners. He thought there would be a readiness to co-operate if consumers could be assured that the effect of the change proposed would not involve them in any serious loss either directly or indirectly, and it was to be hoped that such assurance will be forthcoming. At present, there was a feeling among consumers that they might be called upon to face serious consequential loss.

Then there was the question of spares; with large companies this item alone might run into many thousands of pounds. Would those be taken over and replaced by the Commissioners, or would allowance be made for the full value? There was another point worth consideration; cases would arise where it would be folly merely to exchange existing plant with similar plant of the altered frequency. It might be obviously advisable to modify the existing plant, or put in plant of larger capacity resulting in increased consumption. How would such cases be regarded by the Commissioners, and would consumers be encouraged to make such improvements?

It had been suggested that motors rejected in one district might be transferred to another district, and in this way effect some economy. It did not, said Mr. Tulip, require much imagination to see that such a proposal would hardly be worth serious consideration.

Mr. S. E. GRAHAM.—Nothing has been said regarding the low tension distribution from the Supply Companies; if they distribute at 500 volts with a possibility of a further change at some future date to the national supply of 400 volts it would certainly cause a good deal of trouble to the small consumer and any new consumers thinking of coming on the Supply Company's mains would hang on, as some are doing at present, waiting to see what would eventually happen.

Mr. E. E. GROVER.—With regard to the voltage question, the suggestion has been made that the voltage be raised from 440 to 495 in order to get the same performance out of a motor at the same time that the frequency is increased from 40 cycles to 50 cycles per second. That did not get over the difficulty of the man who has 650 volts at present as that was the maximum voltage allowed by the C.M.R.A. for medium pressure. Further, that was not a standard voltage and whatever happened it was to be hoped that the British Standard Voltages that have been agreed to by Manufacturers and Users would be adhered to in future installations.

Mr. S. A. SIMON said he would like to ask Major Edwards one or two questions. Major Edwards had mentioned that 40 cycle meters would read correctly on 50 cycles if the power factor were somewhere near unity but if the power factor was low then the meter would start reading fast (which incidently might please the supply authorities, but that by the way). Mr. Simon said he presumed that eventually the meters would have to be put right and would like to know what exactly would have to be done to them. Would it mean new meters or new coils, or merely an adjustment to make them read correctly over the complete range? Similar considerations would no doubt apply to other instruments. Again, in connection with the effect of the change on transformers, he understood Major Edwards to say that with low power factor the reactance might increase 20 per cent.; he did not know whether that meant an increase by 20 per cent. or to 20 per cent. Major Edwards had said that the regulation at unity power factor remains constant but that low power factor depends upon reactance; he believed the author said that 0.95 would be the point at which reactance took charge of the regulation which then increased rapidly. That seemed a very high power factor at which the change took place and Mr. Simon would be glad if Major Edwards would clear the point.

Major EDWARDS (in reply) said the object of this paper was to give a brief idea of the effect that the application of 50 cycle supply would have on plant designed for 40 cycles, and he was in no position to answer questions regarding the policy of the authorised undertakers. He did, however, believe that everything possible would be done to make the changed-over plant a good sound engineering job and that consumers would be put to no inconvenience which could be avoided. Facilities would be given to consumers to modify and improve their layouts, and spares would be looked after, but those points would have to be arranged between the consumer and the change-over authority.

Mr. Graham had raised the interesting question of standarisation of voltage. Major Edwards said he believed himself correct in saying that it was not proposed to alter the voltage of existing distributions when the change of frequency took place. That would also answer Mr. Grover's question.

When the suggestion of increasing the voltage was put forward, it was given only as a possible solution of the pull-out torque difficulty when running a 40 cycle motor on 50 cycles, and not as a practical method of accomplishing the change-over. In the majority of cases, the method adopted will be to replace the existing motors with new ones designed to suit the new frequency and the speed required for the plant to be driven.

Mr. Simon had asked what would have to be done to existing 40-cycle intergrating wattmeters to make them suitable for the new frequency; whether they would have to be replaced with new ones or would need to have new coils fitted. Actually the modification required was an alteration of the position of the quod loop and no new parts should be necessary. Unfortunately the adjustment to suit the new frequency could only be carried out on a meter test board and checked against a standard meter. To do this, meters would have to be removed from their present locations when the change-over took place, and be replaced by others already corrected for 50 cycles. A 40 cycle meter, after re-adjustment should have the same characteristics as a meter designed for 50 cycles.

Regarding the question of transformer regulation, Major Edwards said he had not made himself clear. The reactance would be increased by 20 per cent. on 50 cycles; that is to say, if the reactance is 5 per cent. at present, it would be approximately 6 per cent. on the new frequency. The increased reactance would have the effect of increasing the regulation at all power factors, the actual percentage increase at any power factor being 20 per cent. of the percentage of reactance component in the regulation figure at that power factor.

As the reactance component varies as sine Ø at about unity power factor, it has little effect, but, as the power factor gets lower it increases rapidly until at power factors below 0.95 to 0.9 (depending upon the transformer) it becomes the largest component. The effect of this on an average transformer was that the regulation at 0.5 power factor on 50 cycles was about 13 per cent. worse, and about 16 per cent. worse at 0.5 power factor than at the corresponding power factors on 40 cycles. That was to say, for a transformer having a regulation at 0.8 power factor of 4 per cent. and at 0.5 power factor of 4.5 per cent. on 40 cycles, the figures would be approximately 4.5 per cent. and 5.2 per cent. respectively, on 50 cycles.

LONDON BRANCH.

The Design and Construction of High Tension Joints.

C. GROVER.

(*Paper read 4th February,* 1930)

Introduction.

The electrical equipment of a modern colliery in the aggregate, demands electrical energy of a bulk commensurate with the needs of a town having a population of 20,000 to 30,000 people, whilst the area over which electrical energy has to be distributed for the colliery demands the use of long feeders. Indeed, several instances may be cited of a group of collieries covering a considerable area being fed by one, two or three generating stations linked together and delivering energy to the individual collieries of the group, thus following ordinary practice for supply of electrical energy for industrial purposes.

This practice necessitates the use of transmission voltages up to 33,000 volts, and before long higher pressures will probably be used, and although overhead lines are extensively used for main transmission, cables designed for this working pressure are necessary for those parts of routes where overhead lines are not permissible.

Joints in cables must always be regarded as vulnerable points so that it is hoped that the ensuing comments on their design and construction will be of guidance to those interested in bulk transmission.

It is not possible to cover comprehensively the whole field of cable jointing with which the colliery electrical engineer is associated, as the types of cables used for low tension distribution are too numerous for individual treatment, and their design and construction does not involve the special problems relating to higher voltages. One may say that low tension joints of all classes may be reliably made by jointers of average skill, having due regard to the special circumstances under which they are often constructed as distinct from ordinary mains practices, the biggest problem in this respect being the prohibition of the use of naked lights on joints in fiery pits which precludes the ordinary means of heating materials and plumbing on site. A departure in the construction of joints in impregnated paper cables which have to be made under these conditions, is the electrical method of sweating conductors and plumbing, known as the Callender-Wilson system, full details of which are published by Messrs. Callender's Cable & Construction Co., and to which brief reference is made later. This system is applicable to high tension as well as low tension joints.

Principles of Procedure and Personnel.

The conditions under which cable joints and terminal boxes are frequently made, particularly in collieries, make it advisable to ventilate the precautionary measures which should be observed, as well as pointing out that the jointer and those assisting him should be fully skilled and properly trained in the construction of the particular type of joint. This point is mentioned because it sometimes happens that a jointer who has been accustomed only to low tension cable work is called upon to construct high tension joints, with which he proceeds on the assumption that the processes are similar, the only difference being a greater bulk of insulating materials, which can only result in failure, because precautions are necessary in high tension jointing, which need not be observed in low tension work, although a properly trained and conscientious worker should be equally careful with either class of work.

It may be assumed that all cables used for high tension working are insulated with impregnated paper and lead sheathed, except in pit shafts and below ground where waters corrosive to lead are encountered and where vulcanised bitumen sheathing is used in place of lead, but the working pressures of such cables do not usually exceed 3300 volts.

The ensuing comments, being directed mostly upon the insulation processes, will therefore apply to these classes of cables.

The proper care of insulating materials and general cleanliness are the most important points for which the jointer is individually responsible, for dampness and foreign matter are his greatest enemies. Although it is advisable to avoid opening up a cable for jointing during wet weather, the need of urging work ahead often renders the observance of this condition impossible, hence the jointer should be provided with an efficient and waterproof tent for the protection of his insulating materials, tools, and apparatus. He should also be provided with a good waterproof covering for the joint hole, which it should completely cover, and be so arranged that rain dripping from it will not fall into the hole. Where a joint hole is in sloping ground it is advisable to construct an earth dam at the higher side to deflect surface water, for the construction of a joint occupies several hours, and in the event of a sudden deluge the hole may be flooded and several yards of cable ruined before the jointer can seal up the joint, in the absence of this precaution.

In waterlogged ground or where water drains into a joint hole, an efficient sump should be dug, at the highest side of the hole, if on sloping ground, and a pump always available to keep the water down. The discharge from the pump should be lead well clear of the joint hole, and precautions taken against splashes of water falling on to the joint. However slight the tendency of water to gain in a hole, it is never advisable to make shift with baling, as a considerable risk of splashing the open joint is incurred.

The jointer's mate should be conversant with the procedure for the proper care and preparation of insulating materials, tinning and plumbing metals, as undue exposure of the opened cable due to delays through the jointer having to get out of the hole to give his personal attention to these matters is undesirable. An intelligent and efficient jointer's mate is always a potential jointer.

The insulating materials and compounds are frequently spoilt by an incompetent jointer's mate, through overheating, hence he should be provided with a thermometer and instructed in its use.

The effect of overheating on paper sleeves and linen tapes, the materials almost universally used for joint insulation, is to cause partial charring which greatly reduces their dielectric and mechanical strengths. Paper sleeves become brittle and break on application to the joint whilst linen tapes will not withstand the tension necessary for their proper application. Where such materials are treated by the jointer, the temperature of the compound should never exceed 130° C.: this is adequate to extract all moisture, which can be extracted in a few hours. Besides the risk of spoiling the materials, temperatures in excess of this may give a false impression of moisture, as the constituents of many of the resinous compounds used for the treatment of materials will begin to volatilise, which produces the frothing on the surface of the compound, which is the characteristic indication of moisture and may be confused for it.

The general tendency now is for cable manufacturers to send out their insulating materials for joints, such as paper sleeves, tapes, etc., hermetically sealed in compound in tins, these materials having been carefully dried and impregnated at their works. This procedure relieves the jointer or his mate of the onous of drying and impregnating these materials on site, resulting in a very considerable saving of time as well as affecting a better treatment.

The only heat treatment required on site is a gentle heating to soften the compound sufficiently, in which the materials are packed, and which is usually a resin oil compound, to permit their removal from the tins, for which purpose a temperature of 50° to 60° C. is adequate. This is best attained by placing the tins near the fire and turning them periodically, rather than the application of violent local heating such as by placing them on the fire or heating with a blow-lamp. Similarly, when heating compounds for filling joints, heat should be applied gently, and if the volume being heated is considerable, it should be frequently stirred as the high thermal resistivity of most resinous compounds is conducive to dangerous local overheating. The stirring should always be carried out gently: violent stirring will aerate the compound and so incur a risk of breakdown more especially where the compound is required for filling 33,000 volt joints. Indeed, for higher pressures, cable manufacturers are making a practice of de-aerating joint filling compounds at their works before packing, as the presence of air under high dielectric stress in any insulating material leads to ultimate breakdown because of the comparatively low ionisation voltage of air (19.5 k.v. per c.m.).

Cable manufacturers always send out their joint filling compounds in hermetically sealed tins, thoroughly dried before packing, so that continued heat treatment on site is unnecessary. The only heating required is that necessary to remove it from the tins or drums, and to obtain the desired viscosity for pouring, for which purpose temperatures of 110° to 120° C. suffice.

Once insulating materials have been removed from their packing, exposure to air and handling should be avoided as much as possible. The jointer should be provided with a suitable vessel in which the materials are kept immersed in joint filling or resin oil compound at a temperature of 40° to 50° C. so that they can be removed as required for application to the joint without the risk of the jointer burning his fingers. If these temperatures are exceeded, the materials are uncomfortably hot to handle and promote perspiration of the hands, obviously a most undesirable feature in a process wherein the elimination of moisture is essential. Further, containers for insulating materials and compounds should be provided with efficient lids as a protection against rain.

Foreign matter such as dust, earth and the many other impurities which may find their way to a joint made under the usual conditions, are very pregnant sources of trouble, so that too much care cannot be excersied in avoiding them. One must bear in mind the variety of conditions met in cable jointing: the cable may lay in boggy ground so that in addition to the continual accumulation of water, collapsing ground is encountered. The only thing to do is to effectively timber each side of the hole, as a fall of wet earth on the partly-made joint will cause serious trouble. During windy weather, much dust may be blowing about, which, if allowed to settle on the exposed insulation of a joint is also going to lead to trouble.

The jointer's mate should keep all tools and appliances clean, as these are apt to get fouled with earth, which may find its way on to the joint. One often sees the jointer's coke fire placed to the windward side of and very near to the joint, so that a cloud of ashes is periodically blown over the joint, and so one may proceed to mention numerous other causes leading to unclean work which a little forethought could easily avoid.

Accidents, of course, must inevitably happen; a joint may get splashed with water, or earth drop on it during construction. It should be immediately washed and basted with filling compound or other suitable compound heated to 140°-150°.

Basting as a normal process during jointing is now disfavour at the higher working pressures, because it has been found that the low viscosity of the cable and the basting compounds attained by virtue of the necessarily high temperatures leaves the dielectric with a lesser quantity of free compound after basting, and gives rise to the formation of voids between the layers of paper through the depletion of the compound as well as by expansion effects. This effect can be mitigated to a certain extent by continuing the basting process until the compound becomes fairly cool, but as by then its penetrative power is greatly reduced, it is doubtful whether the compound expelled from the inner layers of dielectric whilst the basting compound is very hot, is fully restored.

Up to 6600 volts working pressure, these considerations are of little count as the working dielectric stresses in the cable and joints are usually less than the ionising point of air, and moisture absorbed by the cable and jointing materials during the construction of the joint by exposure and handling, is readily removed by basting. Above this working pressure more stringent precautions are necessary to minimise moisture absorption, which mostly occurs during the handling of the jointing materials during application. A jointer with a marked tendency to perspire may be considered physically unsuited for this class of work and observation has shown that men differ widely in this respect.

During the construction of joints the cable cores are protected by one or two layers of impregnated linen tapes, which are only removed just prior to the application of the lead sleeve or outer casing. It is essential that these protective wrappings be applied with the same direction of lap as the cable papers to which they are applied: if this protection is applied in the reverse direction, a tendency to loosen the adjacent layers of paper occurs, resulting in the formation of air spaces

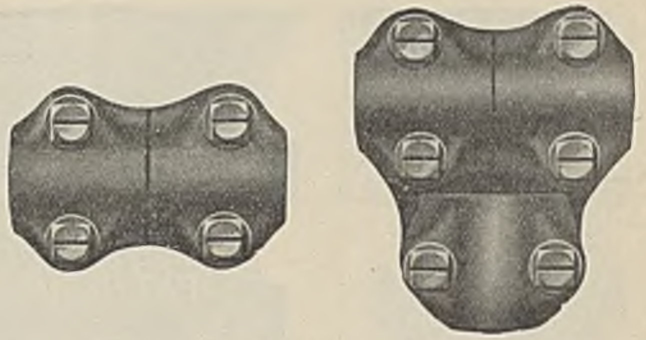


Fig. 1.—Grip Connectors for Conductors.

between these layers of paper, which is conducive to the initiation of surface spark-over. Again, when cutting the cable papers for baring the conductors, loosening of the papers in the vicinity of the cut should be avoided, which is best effected by the application of two turns of 20 S.W.G. copper wire tightly twisted immediately behind the cut. Just before the application of the lead sleeve or outer shell, these must be removed and substituted by an impregnated cotton tying: a few threads torn from a linen tape serves this purpose.

The outer layer of paper tubes slipped over the joints, which have been handled during their application to the joint, should also be removed just prior to the fitting of the lead sleeve.

When the conductor joints have been sweated, the ends of the cable core papers should be pared back for a sixteenth of an inch or so to remove charred paper and dross.

Although the foregoing comments have been made with reference to straight through joints, they apply equally to terminating boxes and tee boxes. The latter do not occur very often in H.T. cables, practically never above 11,000 volts working pressure.

Shaft and Pit Cable Joints.

The depth of shafts and the distances over which energy has to be transmitted below ground, generally limits the transmission pressure to 3300 volts. Although this is below the pressure for which specific precautions have been expounded, the exceptional conditions under which joints and terminal boxes have to be constructed call for more than ordinary care.

The prohibition of the use of naked lights has led to the evolution of designs of fittings wherein sweating and plumbing are eliminated by the use of mechanical gripping devices. Various types of gripping devices have been marketed for jointing conductors. A type which is widely used is illustrated in Fig. 1, which shows a straight through and a tee fitting. The bottom parts of these fittings are in one piece, whilst the tops are split to facilitate fitting. Set screws provide the means for firmly clamping the cable conductors. These fittings are usually tinned so that they can be sweated if possible, and this feature makes them suitable for any class of work up to, say, 3300 volts.

Vital parts of a colliery jointing box are the glands for sealing the cable into the box and the armour grip. Fig. 2 shows an efficient gland which grips the cable, yet without damaging the cable. A malleable iron casing contains a lead cone bored to suit the diameter of the lead of the cable. This is split into halves longitudinally and an outer casting with a coned interior similar to the malleable iron casing, when drawn up by the nuts, tightly grips the cable lead. The ends of the main cast iron box and the face of the malleable casting adjacent to one another, are machine faced and between them is fitted an annular tinned copper collar, so that when the gland is tightened up, this collar is firmly gripped. Each end of the box is fitted with these collars which are securely bonded together with a stout copper strip, which forms the main bond between the cable leads, via the lead cones. Tests have shown that the conductivity of this system of bonding is

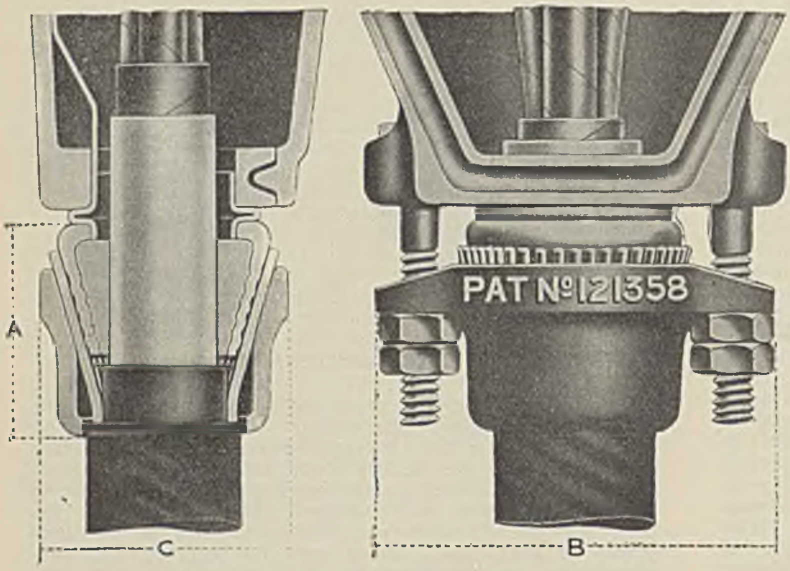


Fig. 2.—Armour Grips.

less than that of the corresponding length of armouring between the glands.

It will be noted from the illustration, Fig. 2 that the armouring wires are gripped between the malleable iron casing and the cast iron grip so that the armouring of the cable is also efficiently bonded. The necessary longitudinal strength is, moreover, imparted to the joint and cable as a whole, relieving the interior of stress.

For level runs below ground, Fig. 3 illustrates a complete straight through box incorporating the conductor joints and glands as described. Separation between the cores of the cable is effected by means of unglazed porcelain spreaders which may be immersed for a few minutes in hot resin oil to advantage, as they are slightly absorbent. The conductor joints can be insulated with resin oil insulated linen tapes, which are prepared above ground or by similar specially prepared tapes of which several varieties are available, sent out by manufacturers in sealed tins.

The shell is of cast iron, which does not produce any appreciable heating effect or loss as balanced three-phase currents always prevail. The upper half of the shell is not shown; it is fitted with two domes provided with covers for filling with compound, and these domes also form expansion chambers, providing for the varying volume of filling compound with temperature changes.

It is customary to use a fairly hard bitumen base compound for filling the shell, which serves the dual purpose of preventing the draining of the joint along the cable under the influence of high temperatures frequently met below ground, and restraining movement of the cable cores through cyclic expansion and contraction.

The filling compound is heated above ground and conveyed to the joint in a heat insulated bucket consisting of one vessel enclosed within another but separated from it by an enclosed air space.

Joints of the type illustrated in Fig. 3, if properly constructed have been proved to stand up satisfactorily to the most rigorous conditions of working They are not, however, suited to pit shaft cables which are made in one continuous length wherever possible, because their vertical position places a great strain upon the armouring which must be of adequate strength to sustain the immense weight. Shaft cables are, of course, effectively clamped every few yards to relieve the cable from as much strain as possible, but under any circumstances a joint as Fig. 3, made in a vertical position is to be avoided. Where joints are necessary it is usual to lead the cable into and out of an inbye making use of the type of jointing box shown in Fig. 4.

Fig. 3.—Straight Through Joint Box.

Copper bars supported on an insulating frame connect the conductors of the two cables by means of clamped fittings shown in Fig. 1, the sealing glands and bonding arrangements being similar to those already described. This particular design of box is provided with an opening on the side remote from the two entrant cables, so that it can be adapted for a tee-off by the addition of another sealing gland.

Both the straight through joint, Fig. 3, and the inbye box, Fig. 4, are applicable to vulcanised bitumen sheathed impregnated paper cables, a type largely used in pits where the water has corrosive effect upon lead.

The Callender-Wilson automatic electric sweating and plumbing process referred to in the introduction of this paper, is fully described by the makers of the apparatus, but a brief description is appropriate. The electric processes can only be applied where a low tension supply is available, but fittings have been devised so that the necessary heat can be obtained by blow-lamps, where permissible.

Conductor ferrules of tinned copper, the section of which is shown in Fig. 5, known as the Weak Back Ferrule, are fitted to the cable conductor, to which they are lightly gripped by a pair of gas tongs. An electrically heated U shaped muff, is clamped round the ferrule, and after current has been applied to the element for a prescribed time, the temperatures of the ferrule and the conductor enables solder to be freely run through both, with the assistance of a special non-corrosive flux. Whilst the solder is in a still plastic condition, the ferrule is firmly pinched by tightening down the clamp which fits into the top of the muff. The excess solder is afterwards wiped off, resulting in a perfectly sweated and clean joint.

The plumbing glands for lead sheathed cables are chill cast in the form shown in Fig. 6, into which a copper bonding connector is cast, the cones being made to the cable lead diameters. The main body of the gland is made of lead but the bore is lined with an alloy which has a lower fusing temperature than lead. The flange is finally clamped against the body of a cast iron box accommodating the joint. An electrically heated muff just fits against a clamping device which in turn just fits over the cone of the gland. This clamping device may be drawn towards the flange of the gland by means of the gland clamping studs. Again current is passed through the heating element for a sufficient period to melt the fusible lining of the gland, when the clamp is drawn up which pinches down the lead cone exuding the surplus fusible metal, at the same time effecting a perfect weld if the correct temperature has been attained. As all the pressure is exerted against the flange of the gland, the gland is in its final position, and on removal of the heating element and clamp, the flange is firmly bolted against the body of the joint box by a bolted clamping ring.

The time necessary for the attainment of the appropriate heats for sweating conductors and glands varies with the sizes of each, but generally these times are 7 and 15 minutes respectively. The results are very positive and effective and beyond the manipulation of the apparatus, call for no great skill, being practically foolproof, as excessive temperatures cannot be obtained. Although the apparatus and processes have been primarily

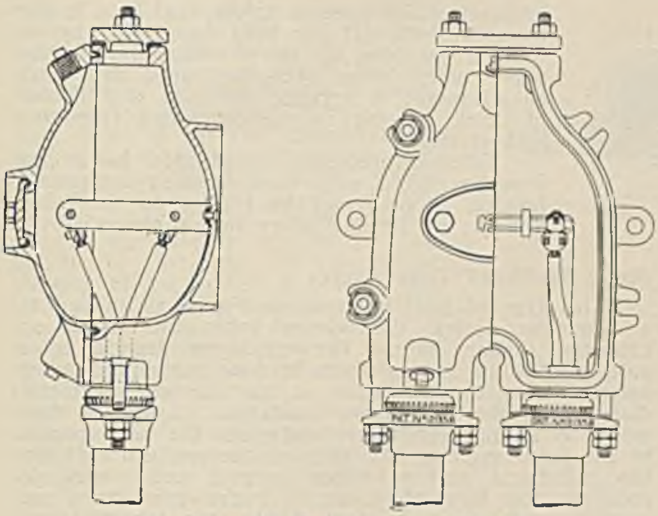


Fig. 4.—Joint Box for Shaft Cable.

Fig. 5.—Weak Back Ferrule.

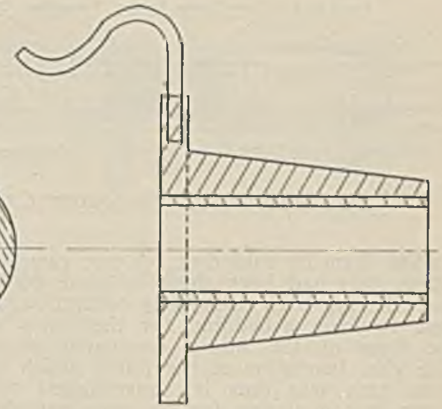


Fig. 6.—Plumbing Gland.

designed to meet colliery practices, switches being gas tight, flexible cables complying with the Mining Regulations and so forth, they are suitable for application in any situation where low tension current is available to energise the transformer which supplies low voltage current to the heating elements. Similar apparatus has been designed in which blow lamps are substituted for electrical heating elements which are also suitable for general application, with the exception stated.

Joints up to 22,000 *volts working pressure.*

Straight through joints between 2200 and 22000 volts are now constructed on more or less standard lines for surface work. By surface work, distinction against below pit installations is of course implied. The prevailing practice is to enclose joints in a plumbed lead sleeve providing external protection by a cast iron box which bonds the armours at the same time, or by means of a creosoted wooden box, a bond clamped to each armouring being provided in addition, in the latter case, or, in the case of the higher voltages, by means of a concrete box, to which reference will be made later.

Conductor joints are mostly effected by means of split ferrules made of drawn copper, frequently of the "weak back" type already described. The cable conductors are first run solid with solder from a pot of molten metal, and after applying the tinned ferrules, again run with solder, excess metal being wiped off whilst hot. A clean joint free from sharp points of solder is essential, as the latter which carelessness can easily leave, are responsible for concentrated dielectric stress which lead to failures. The "telescoped" joint made by staggering the butts in the various layers of the conductor strands is little favoured now, as they take longer to construct and a well-sweated ferrule joint has approximately a 50% greater tensile strength than a telescoped joint of equal length. This at once stands to reason as the area of the sweated surfaces which can draw apart under stress is greater in the ferrule joint.

Conductor joints are sometimes made by butting the conductors as a whole, laying four strips of flat braided copper flex about 3 ins. long over the butted conductors, and tightly binding over the braids with No. 20 s.w.g. copper wire, finally running the whole with solder. If neatly done, a bulb formation is obtained, but there does not appear to be any advantage in this form of conductor joint although it is sometimes favoured in situations where the conductors are liable to be subjected to considerable tensile stresses.

There is also the Pirelli ferrule to which reference will be made later.

It is most essential that at the higher voltages conductor joints should be smooth and free from sharp edges to preclude intensified local electric stresses. From three to four diameters of the conductor is an appropriate length for a conductor joint, and ¼ inch of bare conductor between the paper insulation of the core and the end of the joint on either side is adequate for working purposes, for all insulation removed has to be replaced by some means or other, so obviously the less removed, the better.

Great care is necessary in cutting the cores of multicore cables to ensure that each are of the same length, otherwise some will bulge more than others, resulting in dissymmetry of the joint as a whole.

Impregnated linen tapes may be safely used for pressures up to 3300 volts, but as every bit applied has to be handled, its use for higher pressures is not generally encouraged. When used, ¾ to 1 inch is an appropriate width, and it should be tightly lapped, preferably with an edge to edge lap; it is usually impregnated in a resin oil, similar to that used for impregnating the cable, although specially prepared tapes are available. Each core of the cable should be lapped to a diameter equal to 1½ times the diameter of the core insulation over the whole length of the conductor joint, tapering down to the core papers over a length of at least 2½ inches either side of this. The core papers should be pencilled to the conductors. The cores may be pinched together with an outer binding of linen tape arranged centrally and wrapped to a thickness of about ¼ in. for the width of the tape only, which will act as a centralising medium for the joint as a whole.

Basting as a final drying measure is advisable for this class of insulation, as it will remove the moisture imparted to the linen tapes during application without fear of introducing a risk of failure through paucity of compound as formerly explained, especially if the process is concluded with cooling compound. In this circumstance basting mitigates a greater evil than that which it introduces.

A semi-plastic resin base filling compound is best for the plumbed lead sleeve which is filled in through the usual triangular cuts at the top of the sleeve which are finally sealed with plumbing metal.

It is now opportune to mention that the regulation that the conductivity of the lead sheath and armour shall be at least 50% of the conductivity of the largest conductor of the cable (*vide* Coal Mines Act, 1911), frequently enforces the provision of a copper strip sheath immediately beneath the lead, the so-called B.O.T. sheath. A similar regulation also applies to H.T. cables for all other purposes. The best method of terminating this sheath at joints is to cut off the strips at a sufficient distance from the cable lead, so that when turned back along the lead they project about ⅛ in. outside the beaten down ends of the lead sleeve, so that they become firmly embedded in metal when the plumbed joints are completed. The diameter and thickness of the joint sleeve being much greater than those of the cable lead, give the sleeve the desired conductivity. It is considered bad practice to lay the copper strips over the joint,

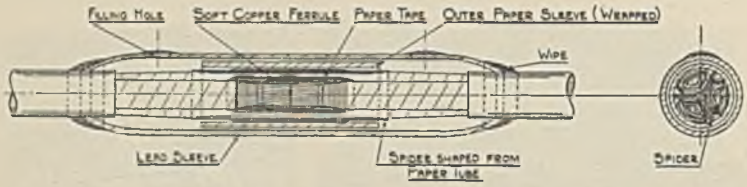


Fig. 7.—Joint on Three-core Cable in Lead Sleeve

uniting them by soldering. A case came to natice recently where this had been done in some 6600 volt joints, the cores having been completely covered with layers of linen tape to form a bedding for the strips which prevented the flow of the filling compound between the cores. The vital insulation of the joints which was impregnated linen tape was thus left surrounded by air, and after being in commission for six years several of these joints were found with the outer layers of the core insulation completely charred. The entrapped air must have been continually in an ionised condition whilst the cable was alive.

Some of the joints had broken down completely which led to the detection of those deteriorated as described.

For 6600 volts and upwards, paper tube insulation is mostly used instead of impregnated or prepared linen tapes. These should either be of an open construction so as to permit the free flow of the filling compound through them, or tightly wrapped as in the case of the Henley or Pirelli joint.

Fig. 7 shows an improved type of paper insulated straight through joint which can be accommodated in a smaller lead sleeve than the loose paper tube type of joint sometimes used. The conductor joint is made with a weak back ferrule (Fig. 5); it is lapped with impregnated "scrim" paper (which is a paper reinforced with cotton threads running longitudinally and transversely through the fabric) which lessens the tendency to breakage during lapping to slightly larger dimensions than the core insulation. A "Y" shaped paper former about 8 ins. long, the limbs of which are made to suit the particular size of cable to which it is to be applied, is inserted between the cores to serve as a separator. As a precautionary measure a layer of tinfoil is embedded at the centre of each limb of the Y to eliminate irregular stresses which might give rise to ionisation of air which might not be entirely excluded from the capilliary spaces formed in the Y when the cores are pressed together.

Impregnated paper of a similar width to the Y spreader length is then wrapped over the cores to a thickness of ⅛ to $\frac{3}{16}$ in. This paper is packed in the form of a roll. By gripping the outside with a sheet of glass paper, and by holding the inner layer with the tip of a knife blade, this wrapping is tightened down by turning it in the direction that it was wrapped, so pinching the cores firmly together and making a very neat and compact joint. One end of the lead sleeve is dressed down to the cable armour diameter before it is slipped on to a cable end, previously to making conductor joints, and the other end is left normal. Both ends are dressed down when the lead sleeve is drawn over the joint Small triangular slits are made at the top of the sleeve, preferably before making the wiped joints, so as to allow vapour to be expelled, through which the filling compound is poured; one acts as a vent to permit the air to be expelled during filling. Compound pouring should be continued after the joint is filled, for several minutes, to ensure exclusion of air bubbles and moisture which appears at the vent hole in the form of froth. It has been found that by so flushing the joint all air is excluded from the paper tubes fitting over the cores, and it is an advantage to arrange the joint slightly out of level, pouring in the compound from the highest side.

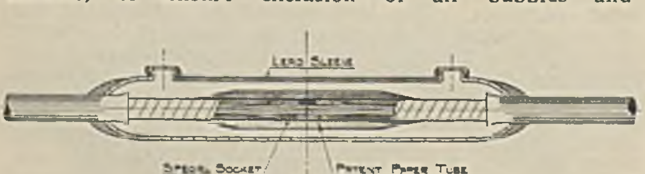


Fig. 8.—Pirelli Joint.

External protection is afforded by a cast iron box filled with hard bitumen compound, bonded at each end by clamps to the cable armour, or by the other means described.

Pirelli Tightened Tube Joints.

This type of joint is shown in Fig. 8 as applied to a single-core joint. Three-core joints are made on preciselv similar lines. The conductor ferrule is a patented feature and is made in four parts, and when assembled on the conductor, it has the same external diameter as the core paper insulation. A cutting tool made to fit the conductor, undercuts the core papers to the same angle as the ends of the conductor fitting, the cylindrical part of which is split and slotted to facilitate the flow of solder. If the conductors are correctly cut so as to butt firmly, the tapered ends of the fitting are forced tightly against the undercut dielectric. The cores are pulled away from the axis of the cables slightly during assembly of the parts of the fitting and when pressed back into their final position the whole is clamped.

A perfectly smooth cylindrical surface is thus obtained to which the cone ended paper tube is applied. This is achieved by slipping a split and hinged tube fitting over the core, upon which the paper is wrapped without handling, the roll being immersed in hot compound whilst so doing. On completion of wrapping this paper on to the tube, this being cut to give the tapered formation shown, the pin of the hinge of the tube is withdrawn and so the tube collapses and is removed. A small projecting tag is provided on the inner turn of the paper tube which is held against the core whilst a tightening process, as previously described, is applied to the paper sleeve. Extreme care is necessary in this operation as there is a tendency for the inner turns to double back during the initial stages which result in folds when the sleeve is fully tightened which form minute air tubes along the surface of the core papers, into which the filling compound does not enter. Breakdowns have been known to occur through this reason. For the higher pressures a vacuum filling process is resorted to, similar to that which will be referred to later. The lead sleeve and outer protection is along the lines of the practice already described.

33,000 *Volt Joints.*

There has perhaps, been a greater diversity of opinion on the construction of joints for this working pressure than those for lower voltages, which is to be expected, as 33,000 volt cables have not been in commercial operation for anything like so long a period. Designs are now converging to a more or less standardised practice as a result of accumulated experience, for given types of cables which are now mostly the H.S.L. type, consisting of three separately lead covered cores laid up in triangular formation and armoured, and the H. type of cable—each core of which is lapped with a perforated metallised paper, the three cores being laid up and then lead covered. The ordinary belted type of cable as standardised for lower voltages is little favoured now, as it has been found to be less mechanically, and therefore electrically, stable. There is, of course, the Pirelli oil-filled hollow conductor cable for which the jointing arrangements are very special, and which cannot be dissociated very well without a dissertation on the cable itself, too large a subject to be satisfactorily treated in a paper of this nature.

(a) *H.S.L. Cable Joints.*

The normal joint in this type of cable is virtually three single-core joints, the general arrangement being shown in Fig. 9, and a single joint is shown in detail in Fig. 10. A point prone to break down is where the lead terminates, to prevent which the core insulation is reinforced with a conical wrapping of impregnated paper or linen tape, which is covered adjacent to the lead of the cable with tinfoil secured by a copper wire binding, making contact with the lead and the spirally wrapped phosphor bronze strip, which is incorporated immediately beneath the lead sheath to preserve the mechanical stability of the cable. A bell-mouthed lead cone is often used in place of the copper wire, the tapered end of which is slotted so that it can be pressed into intimate contact with the reinforcing insulation. A metallised paper covering is sometimes used in the cable instead of the phosphor bronze strip, but it is equally important to ensure that this is in good contact with the metallic cone over the reinforcing insulation.

The conductor joint is made with a "weak back" ferrule which is insulated to a diameter equal to that of the core papers by a tightened impregnated paper tube which is cut to the same width as the distance between the square cut ends of the cable dielectric. The spaces between the ends of the dielectric and ends of the conductor ferrules are built up to the diameter of the latter with shreds of impregnated cotton tapes. The main insulation is an impregnated paper tube which is primarily wrapped to a slightly larger diameter internally than the core papers. It is clipped over one end of the cable before the conductor is jointed or the conical insulation reinforcement applied, the tube being made to a length suitable for this procedure. The tightening operation of both the inner and main paper sleeves is performed in the same manner as described for the joint shown in Figure 7. The protective measures and precautions detailed under the heading of procedure must be seduously observed for satisfactory results. The filling of the lead sleeves can be effected by the simple pouring process described for joints up to 22,000 volts or by a combined vacuum and pressure method.

The three joints are made in a clover leaf formation as shown in the section in Fig. 9 and clamped in hardwood formers split into three pieces and secured together by a copper band.

These formers rest on concrete bridges supporting the joint. At each side of the joints the cable leads are bonded together by a copper strip soldered on, to limit induced voltages and losses in the lead sheaths. The armouring wires are gripped in clamps which are drawn together by three long steel rods which also form the armouring bonds.

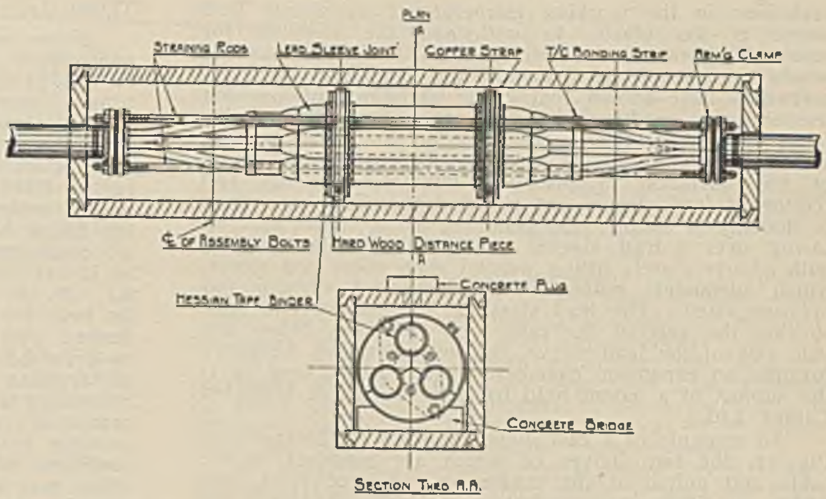


Fig. 9.—Joint on Three-core H.S.L. Cable.

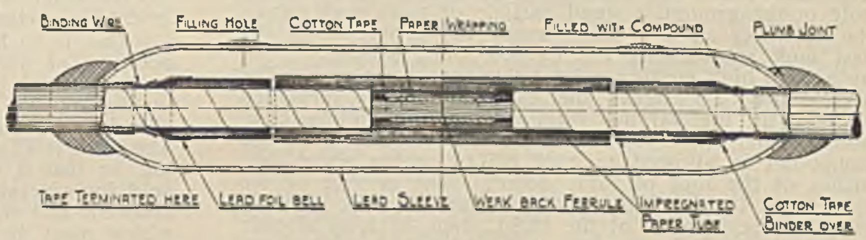


Fig. 10.—Joint on One Core of Three-core H.S.L. Cable.

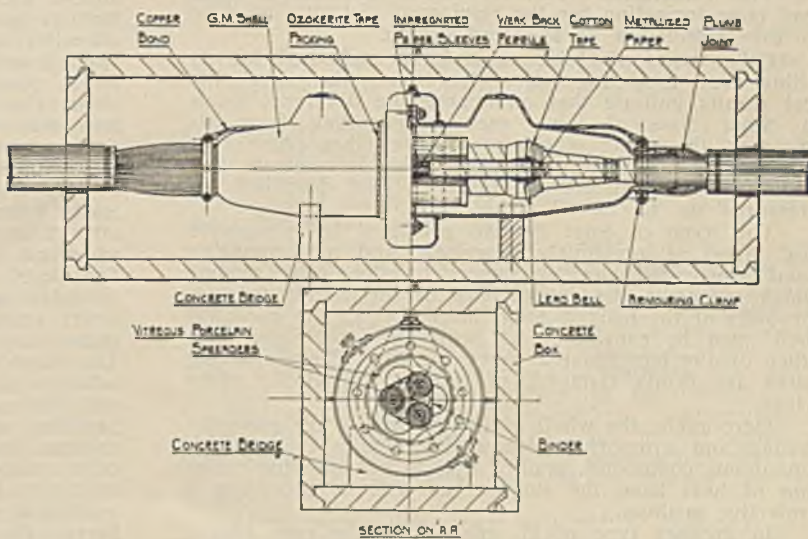


Fig. 11.—Joint on Three-core H. Cable.

The assembled joints are first thickly painted with a hard setting bituminous compound and then housed in a reinforced concrete box which is filled with well-moistened granulated material or such other substance as will promote the dissipation of heat as freely as possible.

Where ground depth does not permit the clover leaf formation of the joints to be used, they may be arranged side by side in a horizontal plane, being each separately supported by bridges, or conversely, where width is a limiting condition, they may be arranged in a vertical plane

(b) *H. Cable Joints.*

With this type of cable the three conductors have to be jointed in a common lead sleeve or box, which is necessarily of much longer diameter than the type of joint just described; which on ordinary cable routes must have sufficient mechanical strength to withstand the hydrostatic pressure created by the expansion produced by variations in the working temperature. A simple lead sleeve is too plastic to withstand the stresses, for repeated alterations of internal and external pressures would soon result in distortion and final bursting. Experiments have shown that cyclic variations of working temperatures produced by the usual fluctuating loads, cause variations of pressure from 40 to 50 lbs. per sq. inch to several inches of vacuum. To combat the effects of this variation in pressure, gunmetal castings and reinforced lead sleeves are resorted to. The latter type of housing is obtained by clamping a sheet iron exterior casing over a lead sleeve and reinforcing the interior with a fairly closely fitting welded seam sheet iron sleeve, which adequately withstands 28 inches of vacuum and pressure cited. The lead sleeve is dressed ex-centrically so that the axis of the cable and joint lies below the true axis of the lead sleeve, the upper part of the latter forming an expansion chamber. This type of housing is the subject of a patent held by Messrs. British Insulated Cables Ltd.

An example of a cast gunmetal shell is illustrated in Fig. 11, the two halves of which are plumbed to the cable and united at the centre by a flanged joint, into which an oiled paper washer is inserted. Although the shells are usually subjected to an air pressure test of 50 lbs. per sq. inch under water to detect leaks, there is a remote possibility that when assembled in a jointing hole in the ground, a small particle of earth may impair the efficiency of the joint, hence the provision of the cast muff surrounding the flanged joint, which is filled by a hard high melting point bituminous compound. The sketch (Fig. 11) shows the expansion domes provided to take up the varying level of the joint filling compound under cyclic temperature variations. Normally the compound is allowed to cool off to within about two inches of the tops of these domes. The interior of the joint calls for but little comment, as it is the embodiment of the features of the H.S.L. type of joint already described, in three cores accommodated in a common housing.

The illustration (Fig. 11) shows the bell-mouthed lead cone formation for the reinforced dielectric adjacent to the termination of the lead sheath.

Other types of H.S.L. cable joints embody a loosely fitting main insulating paper sleeve over the cores; life test results indicate that no appreciable difference exists in either class of joint, each withstanding from six to seven times the working pressure (three-phase) for one hour (See appendix I.) which value is commensurate with that obtaining for the types of joint described for pressures up to 22,000 volts.

This type of joint is also protected by a concrete box, filled as previously described, and an armouring bond is provided which is clamped to either cable armour which augments the conductivity of the circuit through the bolts of the flanged joint, the halves of the gunmetal shell must be considered as being insulated from each other by the impregnated paper washer. The armouring wires are firmly clamped, of course, against the clean wipes.

Here again, the whole of the exterior of the gunmetal casting and armouring clamps are thickly coated with bituminous compound, applied hot, to promote the radiation of heat from the surfaces as well as providing a protective medium.

In another type of H. cable joint the core papers are stepped back one by one over a length of twelve inches or so, down to the conductor at the ferrule joint, and impregnated paper is lapped, so that each layer buts neatly against a cable paper. This in effect is a reconstruction of the cable insulation over the joint. The final diameter of the insulation over the joint is of course, somewhat greater than the normal core diameter. The metallised paper or copper strip, as the case may be, is applied over the joint so that no reinforcement near the ends of the lead is necessary. Although this type of joint gives excellent results, its construction takes much longer than the paper sleeve joints, as the cutting back of the cable papers and applying the new insulation, are tedious processes.

33,000 *Volt Joint Filling Processes and Compounds.*

From what has already been stated it will be appreciated that much more attention must be given to this process than for lower pressures. The methods usually adopted are (a) simple pouring, (b) by the application of the vacuum and pressure. In the case of (a) the whole joint should be heated to 110° C. for 30 minutes or so with blow lamps to expel moisture. A funnel fitted with a flexible metallic tube which reaches to the bottom of the joint shell should be inserted into the filling hole and the compound poured slowly. Thus all compound is introduced at the bottom of the joint as it has been found that this method effectively expels air. As the large volume of compound necessary retains its heat for a considerable period, the joint should be flushed with hot compound as soon as it is filled, so as to drive off moisture, and this operation continued until all frothing ceases. An essential characteristic of the compound used in this process is that its coefficient of expansion—temperature curve—should be as near as possible to a straight line between 0 and 130° C. The coefficient of expansion of some compounds, mostly those which have a well-defined setting point, suddenly increases at this point which causes the formation of cavities; such compounds cannot therefore be satisfactorily used in the simple pouring process.

As regards (b) there are several processes differing in detail, so that examples will be given.

One is to heat up the whole of the joint to a temperature of 100° to 110° C. for 30 minutes or so, to apply as high as possible a vacuum, 28 inches or so, sealing off the joint with a vacuum gauge attached and allowing the vacuum to stand. This is a drying process. The joint is effectively exhausted during the initial pumping, so that if it is free from leaks, this vacuum can be held for several minutes; 5 minutes is the normal period allowed, and should the vacuum fall, a leak is indicated, which must be found and repaired. By means of a suitably designed system of piping and valves, the filling compound is drawn into the joint by the vacuum which almost fills it, the complete filling and flushing until frothing ceases, being carried out as before. Immediately after this, air pressure up to 30 or 40 lbs. per sq. inch are applied and maintained during the cooling period. This forces compound well into all parts of the joint and along the cable for a few inches, and prevents the formation of cavities during cooling. In another process, pressure is applied by a sort of grease gun.

Joint filling compounds contract from 5% to 8% on cooling from the pouring to ground temperatures. At least 12 hours is generally necessary for thorough cooling after filling and shrinkage is made up by pouring in additional compound at a moderate temperature, to the final level.

Ideas as to the best consistency of the compound under working temperatures vary; some prefer a fairly stiff-setting compound, others a semi-liquid compound. The former does not tend to drain away along the cable to any marked degree, but a semi-liquid compound will do so, in spite of the initial forcing process by pressure when filling joints, if applied. If the cable contour involves considerable differences of level, the cable compound, which is always semifluid, will also tend to run to the lower parts, so that as a measure to prevent this and draining of the joints, joints containing barrier diaphragms, are introduced at appropriate points along the route.

Joints of this description, referred to as Barrier Joints, are arranged so that the Cable cores pass through an insulating barrier, dividing the joint into two compartments so that hydrostatic pressures of 50 lbs. can be sustained between them.

In cases where a Barrier Joint lays at the bottom of an appreciable dip in the cable route, so that a considerable head of cable insulating oil may accumulate, both sides may be designed to withstand fairly high hydrostatic pressures, say up to 50 lbs. per sq. in., but generally the joints are designed to withstand high pressures as stated on one side only, such joints being placed at suitable intervals on downward slopes to prevent the accumulation of a head of compound on both sides of the lowest joint.

To cover comprehensively the subject of Barrier Joints, involves more subject matter than can be conveniently included in this paper.

In conclusion, the author would like to state that whilst he has only attempted to outline the principles of modern joint construction, the essential features are the outcome of a great deal of experimental and research work, and it is hoped that the information given will be not only of assistance to those associated with the actual jointing of cables, but also to those whose general interest lies in High Tension Transmission.

APPENDIX I.

The test referred to is in effect a life and breakdown test. A three-phase pressure of three times the working voltage is applied to the test sample and sustained for one hour at the completion of which this pressure is increased without switching off to four times the working voltage and again sustained for an hour, and so on for successive hourly periods, at each the pressure being increased by once the working pressure, until breakdown occurs, the result being expressed in terms of the multiple of the working pressure of the final stage, and the number of minutes elapsing between the commencement of the application of this pressure and breakdown.

KENT SUB-BRANCH.

Notes on Powdered Fuel.

W. EDGER.

(*Paper read 11th January,* 1930.)

Up to some fifteen years or so ago, economy in the use of coal for colliery boiler firing was not given much consideration, as most collieries were then making good profits. At the close of the war, the necessity arose for keeping the cost of coal production as low as possible and, of course, more attention was focussed on the class of fuel going in to the boiler furnaces. This brought about an increased use of the water tube boiler with various types of underfeed mechanical stokers; and eventually a more serious view was taken of the possibilities of using pulverised fuel for boiler firing.

The first pulverised fuel plant, on a large scale, to be applied to steam raising was installed in U.S.A. at the Lakeside Station of the Milwaukee Electric Railway and Light Company during the year 1920.

Although pulverised fuel has been in use for many years for firing the kilns at cement works, for re-heating the ingots at steel works, and at boiler works for the re-heating of boiler plates preparatory to passing them into the shaping presses, it is only within the last four to five years that pulverised fuel fired boiler installations have made much headway in this country.

The attractive features of P. F. firing as claimed by makers can be summarised as: (a) Wide Choice of Grades of Fuel; (b) Flexibility of Operation; (c) Increased Efficiency; (d) Less Labour and Maintenance Costs; for the following reasons:—

(a) *Choice of Fuel.* This advantage is more applicable to power stations and factories situated some considerable distance from collieries where railway transport has to be met.

(b) *Flexibility of Operation.* This means that sudden demands for steam can readily be met and, conversely, light loads can equally well be dealt with while retaining a very high thermal efficiency. Relative to this it might be interesting to mention the author's experience a few years ago while witnessing a week's trial on a powdered fuel installation at a boiler and steam pump maker's works in the North, where a 40,000 lbs. per hour boiler, equipped with a unit type pulveriser of their own manufacture, was regularly shut down during the dinner hour, and started up again by the simple process of running up the pulveriser and blowing the coal into the hot furnace.

(c) *Increased Efficiency* because of: (1) higher temperature of cumbustion; (2) less excess air and therefore a higher CO_2 owing to the air required for combustion being closely intermixed with the particles of burning fuel; and (3) complete combustion, which means practically no loss due to carbon in the ash.

(d) *Less Labour and Maintenance Costs.* This is essentially a claim advanced on the part of the various makers against the heavy bill to be faced by users of the chain grate • class of stoker-fired boilers. In the author's opinion it is a very debatable point whether the heavy charges incurred for grate and arch renewals by users of chain-grate stokers is so very much in excess of the costs incurred in the renewal of pulveriser parts and the large combustion chamber walls.

At most collieries the output includes a certain proportion of low-grade fuel which could be used for P. F. firing, but which cannot be burned efficiently in either ordinary Lancashire or underfeed stoker-fired water tube boilers, and in many cases cannot be burned at all and has to be dumped at, of course, a cost.

Again, collieries with washery plants always have a certain amount of slurry in the settling wells which is a mixture of dirt and fine coal that has passed through the washer in a state of suspension with the drainage water. When this is dried down to 2 per cent. or 3 per cent. of moisture it can be successfully and economically used for P. F. firing.

Better practice still, would be to extract the fines, i.e., all coal from $\frac{1}{8}$ in. to zero by some type of vibratory screen before washing and these fines could, in many cases, be put straight into the pulveriser without drying; a method which would considerably increase the efficiency and lower the operating costs of the washing plant.

There are two systems generally in use in England:

(1) The Central Plant, or Bin and Feeder System.

(2) The Unit, or Direct Fired System.

The Central Plant System.

The central plant system differs from the unit system inasmuch as the coal is stored in pulverised form and to avoid the danger of self-combustion, must necessarily be dried before storage.

The raw coal is fed into either a vertical drier (which derives its heat from the flue gases of the boiler or by a supply of low pressure steam) or into a horizontal rotary type drier which consists, generally, of two concentric cylinders in which the coal travels along the annular space between the two cylinders. Hot gases from a pulverised fuel burner pass through the inner cylinder at an initial temperature of say, 800 deg. F. to 1000 deg. F. and return through the annular space, coming into direct contact with and in the opposite direction to the moving coal. The gase which have air in excess are eventually used in the burners at the boiler.

After leaving the drier the coal is delivered into a bunker and then into the pulverising ball mill from which it is drawn by an exhaust fan through a separator and delivered into a screw conveyor and finally deposited into bunkers where it is ready for injecting into the burners.

The Unit System.

In the unit system the coal is passed in one stage directly from the raw coal bunker through the pulveriser, which is of the beater or impact type, with its combined exhauster fan and delivered directly to the burners.

The pulveriser is virtually a self-contained prime mover in the system and upon it devolves the entire responsibility for the firing of the boiler inasmuch as it is a dryer (where it draws pre-heated air), crusher, pulveriser, separator and fuel transporter, dealing with the raw coal under varying conditions of moisture, hardness and size.

Coal with a moisture content of 12 per cent. can be successfully pulverised by these units without previous drying. Some makers claim to be able to deal with coal having an even higher moisture content.

The above is merely a general outline of the two most common systems. It is to be understood that in the actual plant there is much more elaboration such as cyclones, screw transporters, feeders, etc. This applies more especially to the central system. Further details of the unit system are given at a later stage of the paper.

Choice of System.

When it becomes necessary to make a decision as to which of the two systems to instal, there is no definite demarcation between them.

It is now generally agreed that for large sized plants and for boiler units above 50,000 lbs. per hour capacity the central system should be adopted, which, although heavier in first cost, eliminates the necessity for a multiplicity of pulverisers, and which has the advantage of always having a reserve of powdered fuel in hand to carry on with in the event of a temporary breakdown to any part of the system.

The primary features which commend the adoption of the unit system of firing are its low initial cost, simplicity and economy in space which, in certain circumstances, may prove a deciding factor, especially in the case of contemplated conversion of existing boiler plants where floor space may be limited.

Except in the case of small boiler units it is always advisable to have two or more pulveriser units per boiler so that should a breakdown or stoppage occur, (and there are several ways in which this may happen, such as a motor breakdown, choking of the coal feed hopper through moist coal or foreign matter, stoppage of the feeder wheel, etc.) the boiler can always be kept on part load until either the breakdown is repaired or another boiler is got on to the range.

POWDERED FUEL PLANT AT TILMANSTONE COLLIERY.

Apart from four B. and W. water tube boilers there are two Stirling boilers at this colliery which were purchased second-hand and which had originally been made for chain-grate stokers. Each of these boilers has five drums, a heating surface of 6116 sq. ft., and was fitted with a superheater of 633 sq. ft. heating surface. This last was increased at a later date to 1030 sq. ft. Economisers are installed, one for each boiler and thermostats operating electric horns and with visual indicators for high and low water alarms. The working pressure is 200 lbs. per sq. in. with 190 deg. F. of superheat.

The boilers are worked on natural draught produced by a steel stack 150 ft. high by 7 ft. 9 ins. inside diameter. A contract was made to put in four unit type pulverisers, two per boiler, each capable of handling 3000 lbs. of coal per hour and also incorporating water cooled walls with the boiler furnaces.

The pulverisers, in accordance with general practice, were placed in the stoke hold directly under the raw coal feed hopper and in front of the boilers. They are of the horizontal beater type, each is direct driven through a flexible coupling by a 45 h.p. motor, running at 1450 r.p.m. on the 440 volt, three-phase, 50 cycle supply.

The operation of the system is as follows:

Coal is fed into the pulveriser from the raw coal hopper on to a revolving table which is driven at a constant speed of 10 r.p.m. by the main shaft through a belt driven counter-shaft and worm gearing. This table provides a ready means of controlling the rate of coal feed by an adjustable trunk over the centre of the table giving a coarse regulation, and a finer regulation is obtained by a scraper which can be moved towards or away from the table centre.

Before reaching the barrel of the pulveriser the coal is made to pass over (similar to water over a weir) a magnetic separator, energised with 200 volts, direct current, from a small motor generator; the magnet attracts any tramp iron or other magnetic foreign matter in the coal.

The coal now reaches the barrel of the pulveriser which consists of a cast iron cylinder lined with manganese steel. Rotating in this cylinder at a constant speed of 1450 r.p.m. is a steel shaft mounted on roller bearings with four hubs keyed to it, each hub carries six beater arms also made of manganese steel. These arms are loosely pivoted to the hubs by nickel-steel pins and are free to swing. It should be noted that the coal is broken up and pulverised by impact alternatively between the beater arms and the steel lining of the cylinder and not by being crushed between metal and metal.

A fan is keyed to the shaft at the opposite end of the pulveriser to that at which the coal enters and serves the dual purpose of supplying the primary as well as the secondary air. The primary air is the air required to transport or carry the pulverised coal and is admitted through an adjustable door at the feed end of the pulveriser. The secondary air is the necessary extra air required to obtain complete combustion, i.e., a high CO_2 in the flue gas and is admitted through adjustable sliding doors at the fan end of the pulveriser.

Although there is no specific rule for the correct proportion of primary and secondary air, there is one definite limitation as regards the velocity of the dust cloud and that is, that the velocity must not be less than 30 to 35 ft. per second in order to prevent risk of a flash back in the feed pipe. The quoted figure depends, of course, upon the nature of the coal, its ash and moisture content, volatiles, density of the mixture, etc. This is equivalent to saying that the velocity of coal and air must be greater that the flame propagation. Roughly, the proportion is that the primary air is some 30 per cent. of the total air.

Other things being equal, the fineness of pulverisation is regulated by means of the primary air. The more primary air admitted the greater the velocity of air and coal through the cylinder, and therefore the coal has less time under the hammering action of the beaters.

It will be seen from the foregoing, that within limits the fineness of pulverisation is a factor of the load. With a complete set of new beaters in the pulveriser the degree of fineness is such that 95 per cent. will pass through a 100-mesh sieve and 80 per cent. through a 200-mesh sieve.

The pulverised coal is blown through mild steel tubes to two burners in the top of the combustion chamber. In its travel the mixture of coal and air passes through a mixer box situated on the outside of the burner. This box abruptly changes the direction of the flow and ensures the fuel entering the combustion chamber in a turbulent stream.

The two burners are inclined to one another in such a manner that the two flames impinge one against the other at a point about three-quarters of the depth of the combustion chamber. This arrangement causes the two jets of flames to lose their downward velocity and break up into a fan or ball, and pass through the boiler tubes.

As already stated, the combustion chamber has walls cooled by means of water tubes, built in behind a protective thickness of fire brick. These tubes add a further 1000 sq. ft. of beating surface, and although only a small section of them, near the top of the furnace, is bare they add greatly to the thermal head and increase the rate of circulation which must prolong the life of the boiler tubes, in fact it has now been established that tube failures are less with a water cooled furnace than with a refractory furnace. This is due to the cooler furnace and the spreading of the various stresses over a larger surface.

Another important advantage of water cooled walls is the lessening of erosion of the brickwork caused by the slagging action of the ash, which was such a source of trouble in the early stages of refractory furnaces.

The ash pit of the combustion chamber has a water cooled hearth constructed of square cast iron pipes through which water continuously flows from a header pipe . This is entirely separate from the boiler circulation and the water after passing through the hearth runs to waste . The object of fitting the water cooled hearth is to convert the molten slag into a nodular form which can then easily be raked out into skips and dumped.

It may be of interest to give here the analysis of the coal as used on the P. F. plant and the results of an official test.

Analysis of Coal.

Grade:	1 in. Slack
Moisture:	2.2%
Ash:	24.6%
Vol. Matter:	22.3%
Fixed Carbon	50.9%
	100.0%

Gross Calorific Value: 11,685 B.T.U.'s per lb.

Results of Test.

Duration 3hrs. 35 mins.	
Total water evaporated in lbs.	168,500
Evaporation per hour in lbs.	47,067
Evaporation per hr. in lbs. per sq. ft heating surface	6.54
Total coal used in lbs.	22,400
Coal used per hour in lbs.	6,275
Coal used per hour in lbs. per machine	3,128
Evaporation, lbs. of water per lb. of coal	7.52
Average gauge pressure in lbs. per sq. in.	191
Average steam temperature in °F.	551
Average feed temperature Economiser inlet in °F.	111.3
Average feed temperature boiler inlet in °F	158.8
Total Heat added per lb. steam in B.T.U's.	1,242
Moisture content of coal per cent.	2.1
Ash content of coal per cent.	24.1
Gross calorific value of coal B.T.U's./lb.	11,780
Efficiency	79.2 per cent.

Better efficiencies could undoubtedly be obtained by using a higher feed water temperature, but owing to difficulties with the draught a certain portion of the flue gas was by-passed around the economiser. Again, by pre-heating the air supplied to the pulveriser a higher furnace temperature would be obtained with, of course, an improvement in efficiency.

The plant is now in continuous operation and is working satisfactorily, but this has only been attained after a considerable expenditure of money and the overcoming of numerous difficulties.

Two of the first troubles encountered were excessive water level fluctuations and priming. The former was attributed to the new conditions set up by the water cooling tubes in the furnace which, as previously stated, increased the thermal head and apparently upset the boiler designer's original arrangement of circulation. This was cured by putting in additional circulating tubes between the water drums and the fourth row of boiler tubes.

The priming trouble was very acute and not so readily overcome. This trouble was due to three main causes: (1) Small steam storage, which is not a novelty with some W.T. boilers; (2) sudden and frequent maximum demands caused by three steam winders coming on together on the top of a constant generating station load; and (3) the quality of the feed water used at the time, this was untreated pit water.

The results of priming were choked superheater tubes, filling up of the turbine rotor blades, and sticking of the turbine control valves.

A steam receiver was fitted above and connected to the back drum of each boiler and had water baffles with pipework to drain accumulated water to the back rows of boiler tubes. Also scum trays and a scum valve were added to the centre steam drum.

To overcome the difficulty of sudden demands extra superheater tubes were put in and the outlet steam pipe increased from 7 in. to 9 in. dia. In this way the steam passage was increasd and the steam velocity decreased.

The feed water filter which is of the quartz pressure type was re-conditioned and again put into commission.

After putting the steam side of the boilers into order, attention was called to the difficulties arising out of the burning of the fuel.

These were slagging, sometimes named bird-nesting of the front row of generating tubes and the accumulation of dust and grit in the main flue.

The serious nature of the former can be gauged by the fact that the draught spaces between the front tubes and the tubes themselves became almost completely sealed over, which was equivalent to blanketing-off the fire. At the suggestion of the makers, soot blowers were fitted and these eliminated this trouble.

The flue dust nuisance although not so rapid in its effect was, nevertheless, a serious handicap to the output of the boilers on account of the gradual blocking of the main flue with the consequent loss of draught. A scraper conveyor with an air seal driven through gearing by an electric motor overcame this trouble.

In conclusion the author would express, as his opinion, that where the major portion of the steam generated on any plant is obtained from pulverised fuel-fired boilers, also assuming there is no outside source of electric power available, there should be some auxiliary electric generating plant provided as an alternative supply for use in case of a power station shut down.

This could either take the form of a small house service set or even a quick-starting Diesel set, which could be switched on to the pulveriser motor circuits.

The position regarding pulverised fuel and mechanical stokers continues to be debatable.

The rapid strides made by makers of pulverised fuel plant in regard to efficiencies and lower first cost have had a very stimulating effect upon their rivals. This advance by the P. F. people has been countered by improvements in stoker design on the part of the makers of this class of firing, who have increased the rate of combustion of square foot of grate surface and remodelled their furnace lay-out.

Discussion.

Mr. BARNEY said that he thought all would agree that it was a very interesting Paper, and Mr. Edger had obviously taken a great deal of trouble over it. He thought there was no question that pulverised fuel in one form or another had come to stay, and probably the various systems now in use would be gradually brought into line, and things become more standardised. He would like to ask Mr. Edger whether, after his experience, he considered a pulverised fuel system for medium-sized boilers had any outstanding advantages over the more well-tried chain grate stoker type, say for boilers of 25,000 lbs. to 50,000 lbs

When considering the advantages or otherwise it became necessary to compare:—

(a) The relative first cost of the two systems.
(b) The floor space occupied by both systems.
(c) Efficiency of both systems.
(d) Flexibility of pulverised fuel firing compared with stoker firing.
(e) The nuisance to the surrounding neighbourhood from pulverised fuel system compared to stoker firing.
(f) The possibility of using low-grade fuel. (In this connection, what would Mr. Edger call a low-grade fuel ?)

Mr. Barney said that there were two general systems in use, the central and the unit, and perhaps Mr. Edger would give his views on the relative merits of these. It would appear that generally speaking the central system was the thing for really large plants, and the unit system more for smaller plants, although there appeared to be exceptions to this in some of the modern plants.

He would like to ask Mr. Edger if he considered that the operation of a pulverised fuel plant gave more trouble than the stoker system? Did he find the maintenance cost higher than for stoker firing? Were the defects, when they did occur, more serious?

It would be of interest to members to hear that a large plant in the U.S.A. (namely Deepwater) had recently been started up in which there is no dividing wal! between the boilers and the turbine room; so in that plant they must be pretty certain that the usual dust associated with pulverised fuel would be at a minimum.

Mr. Edger had mentioned the conversion of existing stoker plants to pulverised fuel, and Mr. Barney asked him if he really considered that worth while in view of the fact that most modern pulverised fuel boilers appeared to be specially designed.

With regard to the possibility of using slurry in pulverised fuel plants, that chiefly applies to collieries. The slurry would no doubt take a lot of drying, and taking into consideration the amount of energy and heat required to do that, would the cost of this be counterbalanced by the saving in using this low-grade fuel?

Mr. DAWSON said Mr. Edger's paper had been particularly interesting to him as within the last two months, on behalf of his company, he had been looking into the question of pulverised fuel plants and chain-grate stoker-fired boilers. It was rather significant that boiler makers in this country were not unanimous in recommending pulverised fuel plants for relatively small capacities. It would also appear from data which had been put before him that, apart from higher capital cost, the operating costs of pulverised fuel-fired boilers were considerably higher than with chain-grate stoker-fired boilers. Furthermore, from the standpoint of reliability the lengthy experience gained in the design of chain-grate stokers as against the limited experience of pulverised fuel plant was a factor that could not altogether be ignored.

Mr. NASMYTH said that he had listened with great interest to Mr. Edger's paper. He thought the case for pulverised fuel now appeared to be quite bright, and at least 50 per cent. of the collieries in Kent would be using pulverised fuel plants. The members would probably know that a pulverised fuel plant was now being installed at Betteshanger Colliery. He would like to ask Mr. Edger how the life of the front row of tubes in pulverised fuel boilers compared with the life of similar tubes in a chain-grate boiler. Also, what was the life of the fire-brick lining in the combustion chamber?

He considered they had done very well in burning coal with 24 per cent. ash, and did not think they could do this with a chain-grate stoker. The feed water temperature appeared to be very low for that type of boiler, and he considered that the use of untreated pit water as a feed water was not a very safe procedure. The point recommending an auxiliary supply was very important.

Mr. COOPER said that as a pulverised fuel plant depended very critically on its auxiliaries he would ask Mr. Edger whether he considered that those auxiliaries should be motor driven, steam turbine driven, or a mixture of both, and which would be the more reliable? With regard to 25 per cent. of ash, was this inherent, or might it consist of free particles of shale; and with regard to this shale, would it not be more economical to give the fuel a rough cleaning before pulverising?

Mr. Cooper also asked Mr. Edger if he would explain the method of lighting a pulverised fuel boiler.

Referring to the water-cooled ash pit, as the water was only raised 5 degs. why should it make such a difference to the slag; was there a large amount of cooling water or did the slag require very little cooling?

Mr. FORD asked Mr. Edger, with regard to the motors which drove the plant, whether there was any difficulty owing to overloading, and did the wear of the blades cause out-of-balance.

Mr. GREGORY asked whether, considering the wear on the beaters, there was any wear in the steel lining of the pulverisers.

Mr. EDGER.—In reply to Mr. Barney: drying does not mean using any special plant; the coal is merely dried naturally during handling and only small quantities of slurry were added to the ordinary coal. He did not think it would be possible to burn all slurry, as the plant would not deal with the amount of moisture.

As to his opinion on the relative choice of pulverised fuel or chain-grate for a boiler of 25,000 lbs., he had had experience of both types, and would say from observations that pulverised fuel's greatest score was in regard to flexibility; it was the only plant which could efficiently meet the rapid demand for steam.

With regard to efficiency, they could read tests and papers from different makers and find they all claimed to have a big efficiency; for a chain-grate stoker well over 85 per cent. on contract. It seemed to him that pulverised fuel could score on efficiency, but whether it could beat a chain-grate stoker on test with a good class coal was doubtful, although it was better on low-grade fuel.

Mr. Barney asked what would be considered a low-grade fuel. Mr. Edger replied that he was not referring to this analytically, but more with regard to its suitability for boiler firing. Small coal which contains a large percentage of ash was very difficult to burn with a chain-grate stoker and it was not possible to get the air properly mixed as with a pulverised fuel plant.

As to the question which would be the cheaper of the two plants given the same output, he could not answer this as he had no definite figures, but thought one of the biggest items was that more brickwork was required for a pulverised fuel plant, and there was also the heavy cost for the renewal of the walls. On one set of boilers the wall was renewed after about six months' continuous service.

With regard to the dust nuisance, the largest percentage was extracted by the dust extractor, and a comparison between the two plants seemed to be in favour of the chain-grate stoker.

As to the question whether there was more trouble with the pulverised fuel plants, speaking of his own experience with chain-grate stokers, his opinion would go against the latter. With chain-grate stokers there were various troubles such as breakage of links, breakage of bars, and links burning out very quickly, also the trouble with arches. Another trouble he found was that owing to the coal used containing a large percentage of fines it was found that the forced draught fans blowing air under the chain-grates used to burn hollows through the coal, and caused a bunsen burner effect which was detrimental to the arches. The trouble with pulverised fuel, from what he had experienced at Tilmanstone, seemed to be mostly renewal of beaters and other points now overcome, which were merely a matter of simple mechanical maintenance.

As to whether it would be a commercial proposition to change over from chain-grate to pulverised fuel, this would require very careful consideration, and if backed up by experience such as at Tilmanstone, he did not think it would be. In fact, he did not think it would be a commercial proposition to change over unless some firm would be prepared to give a definite guarantee in regard to total costs and efficiency.

In reply to Mr. Nasmyth, he had not found any serious effect on the tubes and had since got over the slagging trouble. They were now using filtered water, and this water was particularly suitable for boilers. The fact remained that at present no renewals of the front tubes of the boilers had been found necessary. They had had stoppages in the superheater tubes, and this trouble was mostly caused by the scum blowing through with the steam.

Mr. Nasmyth was surprised at the satisfactory result obtained with 24 per cent. of ash, but that was nothing remarkable compared with the claims of the makers, as much as 60 per cent. to 65 per cent. being mentioned, 24 per cent. was not a very low figure.

The energy for pulverising the coal worked out at 17 units per ton, but if one had to work out the figures for a central plant system they would not get such a low figure with all the auxiliaries to be considered, and in any case would not get down to such a low figure as with the unit type of plant.

Mr. Cooper asked whether the auxiliaries should be electrically or steam driven. It seemed to Mr. Edger right to employ electric motors for pulverised fuel plants, and in support of this had all the claims of the motor makers for reliability and constant speed; electric motors were also independent of the steam pressure. He had not heard of any plants using steam turbine driven auxiliaries, but thought that if they had as an alternative steam turbine driven auxiliaries it would put them on a safer footing.

As to the cost of separating the shale, he could not supply any definite figures, but did not think it would pay to put up a washing plant. The only thing done at Tilmanstone was crushing and screening, and by that means getting the largest quantity of shale out of the coal by taking advantage of the difference in hardness between coal and shale.

In answer to Mr. Gregory, he said they did get wear on both linings and beaters, and were now faced with the necessity of having to renew one of the liners.

In reply to Mr. Ford, when the beaters wear down the load goes off owing to the smaller surface of impact on the coal. At Tilmanstone it was the rule to shut down one of the pulverisers periodically for half an hour for examination. They were always in a position to have equal balance, as when they took out a worn beater and replaced it with a new one, they always also put in a new beater on the diametrically opposite side, and thus retained the balance.

Regarding Mr. Cooper's other questions, the low figure was due to the quantity of water used and the large area of the floor. To light the boiler when quite cold, the usual procedure was to put in tarred boards until the brickwork was warmed up, and then the boiler was started, lit by lighted tow on a pole.

MIDLAND BRANCH.

Improved Coal Face Lighting.

W. ZWANZIG.

(*Paper read 12th December, 1929.*)

It has come to be generally accepted that adequate lighting is indispensable for successful industrial operation. Various tests in a wide variety of occupations have proved that men work more rapidly and more accurately when they are supplied with good light, than is possible under harsh and inadequate lighting conditions. The figures given in Table I are illustrative as indicating how improved lighting has brought about increased output in certain classes of work. This Table shews an average increase of 297% lighting intensity and an average increase of production of 12.5%. The additional cost of this lighting averaged 2% of the payroll for the period considered.

Not only have the costs of production been decreased by the installation of better lighting, but the number of accidents has also been reduced. This increased safety factor is one of the most important results of good lighting. How bad lighting can affect the number of accidents is shewn in the statistics of an Insurance Company, indicating that 15% of the industrial accidents are attributable to poor lighting. During one year 300,000 accidents were chargeable to this cause; 4000 being fatal. The workers compensation paid for these accidents was £18,000,000. It was, furthermore, found that the majority of accidents occur in the winter months and that the accident rate by night on account of defective light is much greater than by day. Although there may be other causes to account for the greater frequency of accidents during winter, it appears certain that the shorter duration of daylight necessitating longer periods of work under the poor artificial lighting conditions represents a major cause of the higher accident rate. This is due to the difficulty of seeing the danger in the darkness and, on the other hand, due to the fatigue on account of faulty vision which involves a strain upon muscles and the nervous system.

On account of these facts it would appear obvious that collieries of all places should have good lighting systems, but the fact is that miners, who have to work under the most difficult conditions of a perpetual night, are provided with least efficient artificial illumination. Instead of giving miners more and better light they are now worse than in the old days when open torches, etc., were in (dangerous) vogue. This is clearly shewn by the comparisons in Table II.

TABLE I.

Kind of Work.	Intensity. Lux. Old.	New.	Increase in %	Increase in production in per cent. Total.	Per 1% of increase of lighting.
Soft metal bearings ...	55.2	152.4	175	15.0	0.085
Heavy Steel machining...	36.0	137.0	280	10.0	0.035
Carburettor Assembling.	25.2	157.6	525	12.0	0.022
Semi-automatic buffing Brass shell sockets ...	45.6	163.6	260	8.3	0.031
Letter separating ...	43.2	96.0	122	4.4	0.036
Inspecting of roller bearings ...	60.0	240.0	300	12.5	0.041
Spinning (Textile Mill) ...	22.8	117.6	415	25.0	0.006

TABLE II.

Source of Light.	*Foot Candles.*		
Open Fire ...	300	Old	BELOW GROUND
Torch Light ...	15	Old	BELOW GROUND
Alkali Hand Lamp ...	.5	New	BELOW GROUND
Acid Hand Lamp ...	.4	New	BELOW GROUND
Flame Safety Lamp ...	.2	New	BELOW GROUND
Electric light in factories.	10—20		ABOVE GROUND
Sunlight in Jan.—Dec. ...	4500		ABOVE GROUND
Sunlight in May—June ...	9000		ABOVE GROUND

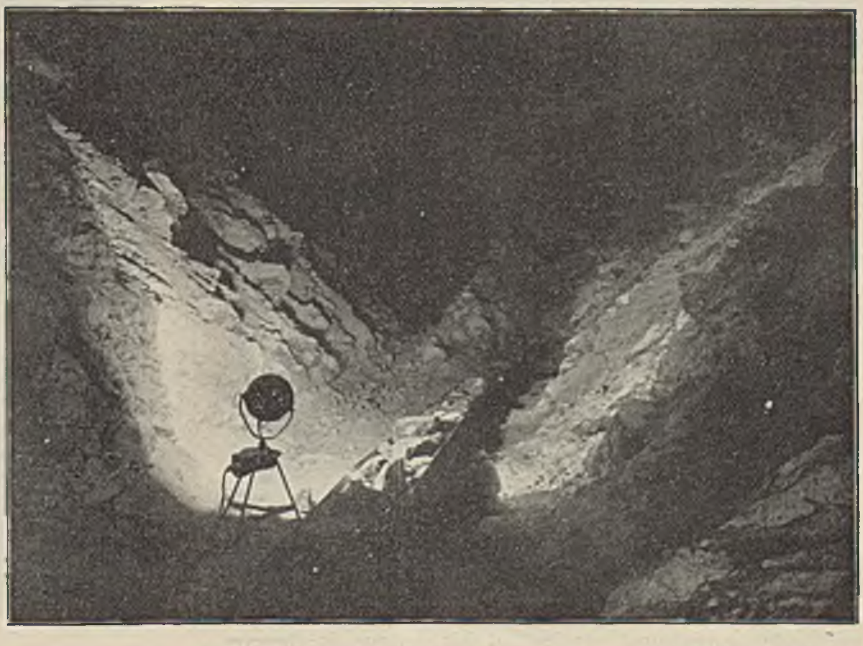


Fig 1.

Fig. 2.

The open fire of the old miners gave about 300 foot candles, a torch light gave an illumination of 12 to 18 foot candles, while a flame safety lamp gives less than half a foot candle.

It is, of course, not possible in the deep and gassy mines to use open fires or torch lights as the old miners did at the outcrop of the coal seams. Every possible effort, however, should be made to keep the luminous intensity at least on the same level as it was before; but even that would only mean a standstill while life requires progress and therefore increase of the luminous intensity. The inefficiency of the present lighting system at the coal face is clearly shown by the fact that the average luminous intensity of safety lamps at the coal face can be compared with the luminous intensity of moonlight in a forest.

Man is a daylight animal and the more an interior can be made to resemble the natural daylight conditions, the more satisfied and contented he will be. On the other hand the darker a room the more lethargic the man will be. But it seems to be expected that the miner should be able to live and work most of his time down in the pit without sunshine and with a light that is worse than moonlight. The constant darkness which surrounds the miner must have a considerable effect on his mentality; it is obvious that by giving him a good light at the coal face he certainly would take more interest in life generally, be happier and more energetic as a worker.

The modern safety lamp does not give sufficient light so that the light can remain in one place during the whole shift, but the light is so bad that the miner has to spend his time at intervals in finding the best new position for the lamp. Then again he wants something which he cannot see on account of the bad illumination. He takes his lamp and looks round until he has found, after a long time, what he wanted. All these operations are a waste of time. It is not true that he rests during that time but on the contrary his nerves and eyes are under exceptional strain and his fatigue is thereby increased. Moreover, after he has found the best position for the lamp, the light is absolutely inadequate. It is considered that at least 10 foot candles of illumination should be employed for shops engaged on rough and medium work, while the flame safety lamp gives only 0.2 and the electric safety lamp about 0.4 to 0.5 foot candles.

The electric safety lamp is undoubtedly an improvement compared with the flame safety lamp but it has the great disadvantage that the illumination goes down considerably during the shift. The reason for this is that the voltage of the battery drops and therefore the lighting intensity decreases. Nobody would dream of attempting to work with such a light at a machine-tool above ground. In the collieries it is common usage to do so, notwithstanding that the conditions are much worse than anywhere else; not only is the space for working very limited, and there is always the risk of a falling roof, but the whole machinery is much more dangerous as compared with machines above ground. A coalcutter, for instance, is not only a powerful machine with a motor up to 40 h.p., but dangerous on account of its fast moving picks, and especially so because the machine is not stationary but travels along while cutting. A man would never be expected to work with a machine like the coalcutter above ground under such lighting conditions.

It seems remarkable that a really great effort has not been made in coal mines to improve the general lighting conditions. This, however, has been held up on account of the difficulties of designing a suitable lamp, especially for safety lamp pits, which would meet all the requirements for efficiency and safety. It was realised very soon, that a good light could only be obtained by using electricity. Early attempts, therefore, were made in this country to instal a cable along the coal face with permanently fixed lamps. These attempts came more or less to a standstill probably on account of the Coal Mines Act which does not allow an installation of such a lamp

Fig. 3.

Fig. 4.

nearer than 300 yards from the face in safety lamp pits. But it is just in safety lamp mines where the miners have to suffer most under bad lighting conditions. The lamp manufacturers, therefore, increased the capacity of the flame safety lamp, as well as of the electric safety lamp; especially the electric safety lamp which gained a better light by using 4 volt accumulators. That was undoubtedly a great step forward. Other trials to secure better lighting introduced the use of more or less stationary accumulators at the gate end as well as at the coal face; but that method has not found very much favour on account of the high weight of the lamp and also because of the high costs.

The following requirements have been laid down for a good coal face lighting system which shall be economical and safe.

Sufficient Light.

Adequate illumination must be provided, i.e., at least 10 foot candles of illumination.

Freedom from Harsh Shadows.

No matter how high the intensity of illumination, harsh and dense shadows prevent accurate visibility and constitute a frequent cause of accidents. Shadows can be avoided by using correctly designed lamp fittings and installing them at right distances.

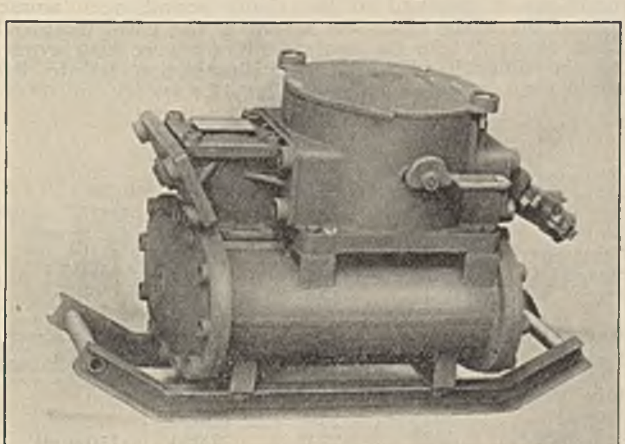


Fig. 5.

Fig. 6.

Freedom from Glare.

Glare is generally associated with a bright light source within the field of vision, which produces discomfort, interferes with vision, and is a direct cause of eye fatigue. It has no productive value and actually wastes energy, since it has been shown that visibility may be reduced by 50% when glare is present.

Fig. 7.

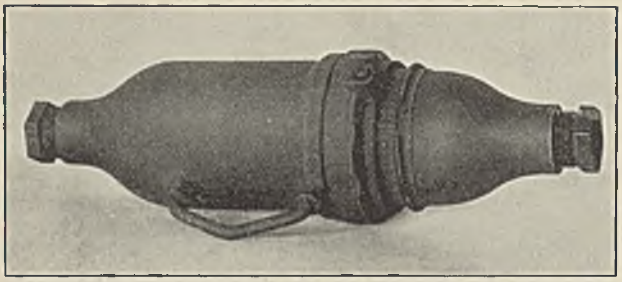


Fig. 8.

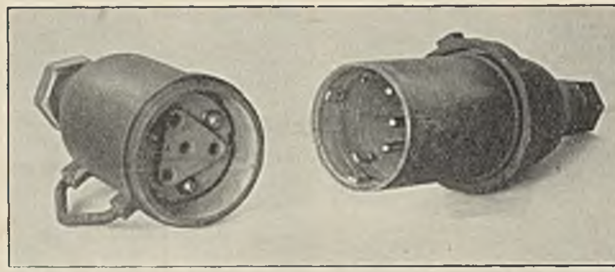


Fig. 9.

Easy Handling.

The apparatus for the coal face lighting system has to be so designed that it is possible even for not specially trained men to instal the lighting fittings in accordance with the advance of the coal face.

Suitability for Rough Usage and Safety.

Lamp fittings, plug socket connections, etc., have to be strong enough to withstand the rough usage at the coal face. The miner is only used to handling heavy material and very often especially in low seams it is not possible to pay much attention to the handling of the lamps. Furthermore it has to be considered that a roof fall may bury the system wholly or in part. A great factor is also the safety against fire-damp explosions in safety lamp pits. This, however, has to be specially dealt with.

Economical Cost.

The whole equipment must be economical, i.e., the profit must be higher than the costs.

TYPICAL SYSTEMS.

The following lighting systems have been in use with greater or less success:

Searchlights have been found most effective in very wide rooms, as for instance in potash mines. The rooms in these mines are very often about 100 yards long, 12 yards high, and 30 yards wide. The shaker conveyor is pushed into the potash or the scraper conveyor is pulled along the face. Even the calcium-carbide lamp was not sufficient for this kind of work and a number of accidents happened. The searchlights which project the light along the shaker conveyor right on to the potash, have made the loading far safer and more efficient (Figs. 1, 2, and 3).

In smaller rooms, as for instance, in coal mines in Upper Silesia or for loading prints, a flood-light is preferable on account of the illumination characteristic of this light (Fig. 4). In ordinary coal seams from two to eight feet thickness, however, neither searchlights nor flood lights can be used. Only comparatively small lamps, which can be installed along the coal face, are suitable.

For mines in which only compressed air is available a small lamp with a combined compressed air motor and electric generator may be used. Though it is made in this country, it is used nearly exclusively and to a large extent in the highly gassy mines in the Ruhr district. The lamps are installed at the coal face about 5 to 10 yards apart and are connected to the compressed air pipes which feed also the pneumatic picks.

Another method is the installation of a small compressed air turbine coupled with a generator of about 1000 watt output. The generator feeds the lamps which are connected to a C.T.S. cable.

Both methods, however, are not very economical on account of the inefficiency of the compressed air. They are only used in case there is no electricity available.

The bast method is undoubtedly the installation of lamps connected direct to the mains. It is, of course, not advisable to use the same voltage as for coal cutters and conveyors, but would hardly be any advantage against conveyors, but would hardly be any objection against 125 volts and this voltage allows of connecting the lamps to a comparatively small and very flexible cable. The voltage of the electric machinery at the coal face is usually higher than 125 volts and, therefore, a small transformer is employed for transforming the voltage.

The whole lighting system, including the transformer is protected against short circuits and overload by a circuit breaker on the high tension side of the transformer (Fig. 5). The C.T.S. cable is installed along the face and in order to simplify the wiring of the system in the workings, this cable is subdivided into lengths of 15 to 20 yards (Figs. 6 and 7). Plugs and plug sockets (Figs. 8 and 9) are connected to the free ends of the subdivided main supply cable, by means of which a simple and rapid connection can be obtained.

Three-way "T" junction boxes are located about 5 to 10 yards apart at each length, by which the lamps are connected to the main supply cable by a C.T.S. cable about 2 to 5 yards long (Fig. 10).

It has been shewn that the better lighting in factories has many advantages. It, furthermore, has been shewn that it is possible now to instal a good lighting system near the coal face. Practical tests have been carried out in a number of mines which have clearly shewn the advantages obtained by good lighting systems.

The efficiency of the better light at the coal face has been tested at the Wenceslaus pit in Lower Silesia. The thickness of the seam is 5-6 ft. including a few dirt bands, the length of the coal face is 130 yards and the incline 20 degs. The results shewn in Table III., and in Figs. 11 and 12, were obtained from May to December, 1927, and with 150 watt lamps installed about 5 yards apart. The seam contains CH_4 and CO and therefore is highly dangerous. Generally speaking, the conditions at the end of the above period were worse than at the beginning. The length of the gates increased about 66 yards and the roof conditions were also worse. On the other hand, the better illumination led to the employment of more miners (Fig. 11).

TABLE III.

1927. *Month.*	*No. of Tubs.*	*No. of Shift.*	*Tubs/Shift.*	
January	3480	1420	2.450	With safety lamps.
February	3370	1424	2.366	
March	3810	1560	2.442	
April	3242	1297	2.499	
May	3825	1378	2.775	About 70 watt lamps.
June	3345	1186	2.820	
July	5810	2030	2.862	150 watt lamps.
August	6445	2200	2.929	
September	6485	2216	2.926	
October	7050	2375	2.968	
November	7095	2280	3.111	
December	7125	2264	3.147	

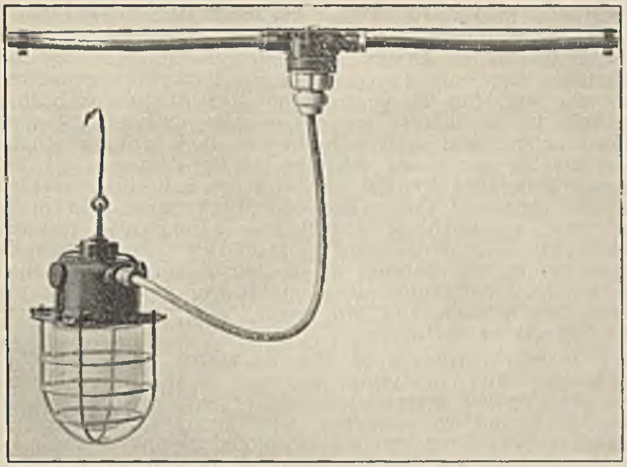


Fig. 10.

The increase in production on account of coal face lighting from May to November is shewn in Fig. 12.

That the lighting system was very economical may be seen from the following figures:—

	£	s.	d.
Initial costs	250	0	0
Operating costs per annum—			
Depreciation	50	0	0
Interest	15	0	0
New Lamps (350 bulbs)	70	0	0
Electric current 45,000 k.w. hours...	100	0	0
Wages, 3 shifts per week	50	0	0
Total...	£285	0	0

for 7500 working hours, or 10d. per hour.

The costs per lumen, therefore, are as follows:

	per hour. cost.	*lumen.*	*per* 125,000 *lumen hours. cost in shillings.*
With 150 watt lamps ...	10d.	100,000	... 1s.
Alkali lamps ...	1s. 8d.	6.3	... 200s.
Acid Lamps ...	1s. 8d.	4.8	... 260s.
Flame safety lamps ...	1s. 8d.	2.5	... 500s.

In accordance with the above figures the output per man and shift was:—

At face with safety lamps in April ...	1831 Kg.
At the same face in Dec. with 150 watt lamps	2457 Kg.
Increase...	626 Kg.

In 2264 shifts during Dec.—output with light	5565 tons
Probable output without light ...	4145 tons
Increase by means of light...	1420 tons

For getting of 1420 tons of coal, 775 shifts are required, instead of which a sum of £24 has been paid, or about 4d. per ton.

Similar tests have been carried out at Zeche Minister Stein in the Ruhr district and have shown an increase of production of 10% on account of better light. The examples quoted here are, of course, not the only installations; in all there are about 200 coal faces which have been equipped with this Siemens-Schuckert system and not including the floodlight and searchlight equipments.

Whether the safety of a better light will decrease the number of accidents can only be found out after a few more years, but the author may mention that he was told by three miners at the Graefin Johanna

Fig. 11.

Schachtanlage in Upper Silesia that they were saved by the electric light. When the roof came down their hand lamps were blown out and they only could escape because the fixed electric light showed them the way. Shortly after they had left the place, the whole roof came down.

A very important factor for the installation of better light is the necessity of reducing the number of cases of nystagmus. It is still very problematic as to the cause of nystagmus, but it is almost certain that if bad light is not a cause, it aggravates the disease on account of the strain on the nervous system. Considering that during the year 1927 there were 1733 new cases of nystagmus and 7632 cases continued from the previous, it would, if only for this reason, be worth while to instal better light at the coal face.

Summing up, the reasons why it is essential to improve the lighting intensity at the coal face are as follows :—

(1) Higher output.
(2) Cleaner coal.
(3) Greater safety.
(4) No nystagmas.

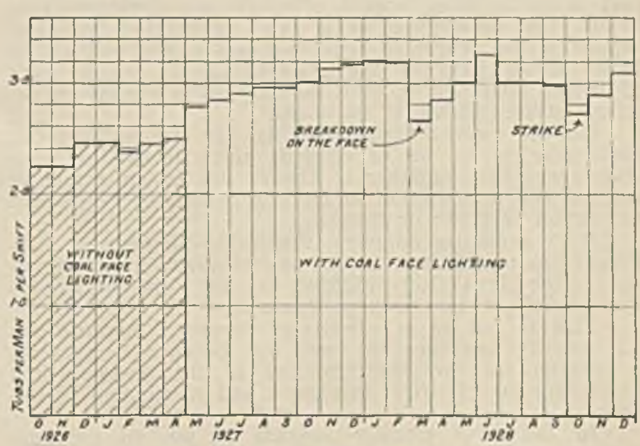


Fig. 12.

NORTH OF ENGLAND BRANCH.

Air *versus* Oil Immersed Switchgear for Underground Service.

Discussion.

(*Meeting held 7th December*, 1929.)

Mr. W. A. A. BURGESS.—There appears to be no room for doubt that the first essential in the design of switchgear for use underground is adequate strength of enclosure. Some divergence of opinion exists as to whether the standard hydraulic test for such enclosures should be 75 lbs. per sq. inch or higher, British practice being of this order, but certain Continental practice being somewhat higher.

The need for withstanding internal explosion also appears to point to the entire elimination of cast iron and similar brittle metal even though of sufficient thickness to withstand the selected test pressure.

Tests made by Professor Thornton, and also at the School of Mines in Sheffield, have demonstrated that such an enclosure need not be gas-tight, and that vents of a flame proof construction may be used with safety and are, in fact, desirable to dissipate the compressed gases and to prevent the more violent explosion likely to result from pre-compression by an initial explosion.

Many types of vents have been adopted by various manufacturers, but the simplest and most efficient appears to consist merely of rough machined flanges in direct contact, having a width of about one inch. These appear to be the essential requisites of design for safe switchgear for use underground whether of air or oil break.

Turning now to the problem of air-break or oil-break, one has first to consider the limitations of the former which is generally agreed by the most competant authorities to be about 2000 k.v.a., although claims have been made that it is as high as 5000 k.v.a. Whichever figure be taken, it is not high enough to meet any but the furthest inbye uses in those cases, where, as in present day practice, there is frequently a considerable power behind the main supply.

Most cases appear to call for a rupturing capacity of at least 15,000 k.v.a. to provide a margin of safety to meet all likely contingencies.

Oil-immersed switchgear of this rating is not only available, but has been developed to a high standard of efficiency, and has been available for a considerable number of years at a reasonable cost.

With air-break switchgear, even where clearances are apparently liberal, there is a great tendency to ionisation of the air by metallic vapour, and not only by vapour released by the arc but by accumulation of vapour from imperfect contact under heavy duty. A case where this occurred on a large transformer due to the terminal stud not making proper contact with the screw thread of its nuts recently caused small localised heat spots to form, which, although not distinguishable before the occurrence of a fault, generated sufficient vapour in the course of time to cause a 6000 volt arc to jump across between the main terminals which were 10 inches apart; it is easy to visualise a similar occurrence inside air-break switches.

On the score of inflammability, the use of air-break switchgear is to be deprecated, since in a fire-damp atmosphere the container is always full of an explosive mixture and is subjected to igniting conditions every time the circuit is made or broken.

It is generally admitted that oil-break gear is electrically more efficient given an adequate head of oil above the break, in addition to the first principles enumerated in the opening remarks.

This is not as is sometimes supposed, because the oil actually quenches the arc, but because it presents a medium for the rapid cooling of the gases, whilst preserving the electrical insulation and eliminating ionisation.

In this it is actually assisted by one of the constituent gases of the arc bubble, viz., Hydrogen, which has been proved to have a much greater cooling effect than the oil itself.

Sufficient is known by reputable designers of oil switches not only to cool quickly the gases generated by the arc, but to control the size of the ascending bubble by a suitable air space ratio and an adequate head of oil, and it is safe to say that ignition of the gas in the air space whether of fire-damp or of the gases generated by the arc, can be entirely prevented if the rating of the switch is not exceeded. In proof of this, a switch of 15,000 k.v.a. rating was recently subjected to a short-circuit of 60,000 k.v.a. with no more emission of gas through its machined flange joints than is obtained by exploding a mixture of nine or ten per cent. of methane and air inside, and without damage to contacts or enclosure.

Some experiments by Mr. Rainsford, and others, in collecting and analysing the arc gases in oil-break switches, when acetylene to the extent of between 10 per cent. and 25 per cent. was found to be present, have recently been extensively quoted against the use of oil-break switches, but the above mentioned short- circuit tests prove that whilst acetylene in the correct proportion to oxygen can give rise to explosions causing pressure rises of as much as twice those with methane, yet the long experience of the makers of this switchgear has resulted in a design in which the gas generation has been so limited and controlled as to render it entirely safe for underground service with a substantial margin in hand above its rated capacity.

On the grounds of the short circuit test mentioned above, and of the experience of at least twenty years, it is claimed that oil-immersed switchgear is superior in all respects to air-break gear for use underground, and is essential in all cases where the short circuit values exceed 2000 k.v.a.

Correct installation and proper maintenance are essential to any kind of switchgear, particularly for use below ground, and an air-break switch improperly connected and fastened is quite as dangerous as an oil-break switch under similar conditions or without any oil.

Oil-break switches should have their tanks secured by studs and nuts of ample size and strength, which should be sufficiently numerous to prevent the tank being readily removed by unauthorised persons, and there should be no drain-cock or similar means of withdrawing the oil. The head of oil should be sufficient to allow for the tilting of the switch by at least 15 degrees without materially reducing the effective immersion of the contacts, and some means (not a sight glass) should be fitted by which the authorised official may check the oil level. The gear should always be levelled up before being put into service.

Where coalcutters etc. are used with trailing cables and plugs, an interlock should always be provided to prevent the circuit being made or broken by the plug.

These are simple precautions, and should be insisted upon to ensure the safety of the men engaged in the mine.

Mr. R. W. MANN.—In getting together certain notes on the subject, it has been assumed that discussion will centre on the application of inbye and subsidiary switch and control gear rather than main feeder sub-station switchgear, as it is undoubtedly where apparatus is subject to removals at long or short periods that the advantages of air-break switchgear are most appreciated.

Whilst being a very definite advocate of air-break switch and control gear, it is essential that to make it clear that the speaker has only automatic gear in mind; fuse gear of any description whatever being totally unsuitable for mining applications where motors have wide variations of starting currents and running currents, and have to be suitably protected; to say nothing of the danger of fuses being so unsuitably wired that the motors are allowed to continue to run on two phases after the blowing of one fuse on peak load, with the consequent burn out of the motor. In this connection, the speaker had had brought to his notice nineteen cases of burnt-out motors, of several manufactures, during the present year.

Briefly, the main advantages of air-break gear may be enumerated as follows:—

Firstly, the fundamental difference between air and oil break gear is that voltage clearances in air-break gear are sufficient with air as the insulating medium, whilst oil-immersed gear has reduced clearances which depend upon the oil as the insulating medium, and therefore, where the oil level is not maintained, or is lost through spillage, short circuits are often found to result.

The question of the supply of the necessary oil, maintenance and examination cannot well be estimated at less than 35s. per annum per switch; which, capitalised at a nominal figure of 5 per cent. is equivalent to invested capital of £35. That is to say, for a given duty it would be possible to pay £35 more for an air-break switch and be no worse off, apart from the fact that air-break apparatus is rarely dearer than an equivalent oil-immersed article.

For fundamental reasons the oil container must be at the base of the apparatus, and this imposes limitations upon design, inasmuch as more headroom is required for clear withdrawal of the tank, added to which the exposure of oily services to coal dust and dirt does not add to the desirability of oil-immersed gear below ground.

The question of adequate flameproofness of either type does not arise, the possibility of internal pressures, displacing the oil from its container does suggest dangers of the subsequent operation of the gear, unless the displacement is observed and remedied.

With regard to the maintenance of oil-immersed contacts as compared with air-break contacts, the speaker hopes this question will be settled on the results of practical experience, which members may be prepared to give. The speaker's experience on severe service application, backed up by very many various applications shews that the air-break contactor unquestionably stands up best to the work.

Mr. Mann then said he had been asked to take the opportunity of shewing on the screen a typical layout of a modern mechanised face, which he proposed to use in conjunction with a description of the apparatus used. Fig. No. 1 shews the arrangement of longwall face, it being noted that no-volt coils are excluded from the feeder switches, which incidentally are of the oil-immersed type, whilst direct acting leakage is provided on both the high tension and the low tension sides.

The transformer has the minimum capacity for the load to be carried, being designed with small reactance for volt-drop reasons, with the neutral point brought out to earthing terminals, and a tapping provided between phase and neutral at 110 volts for "flat" lighting, brought out to a small flame-proof switch and fuse. No line tappings are provided.

A switch on the high tension side is omitted on the score of economy.

The inbye feeder is broken by a three-way Ellison joint box to supply a face haulage, controlled by an air-break combined type switch controller.

At the loading station the inbye feeder is again broken by an air-break switch with no-volt and overload protection, and isolator to feed the mothergate conveyor, with a maximum distance of advance of 100 yards.

The face equipment is then connected by 100 yards of pliable armoured cable coiled in the form of a fiugre 8, a lap being taken off each night as the face advances to the maximum distance, after which the loading station itself is advanced.

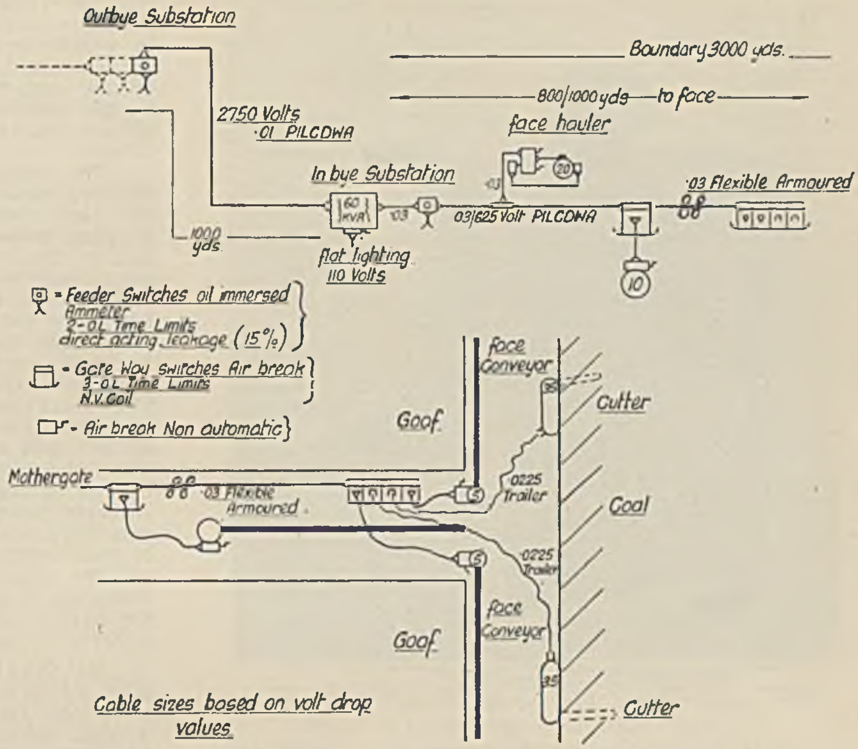


Fig. 1.—*Longwall Advancing: Typical Layout.*

With the self-sealing boxes used on the gear it will be seen that no joints are made below ground, extender lengths being added with each 100 yards advance.

The face machinery is controlled by a four-panel air-break board with no-volt and overload protection and isolators, the conveyor being stopped and started by the air-break switches on the conveyors themselves and interconnected by short lengths of 0.03 flexible armoured cable.

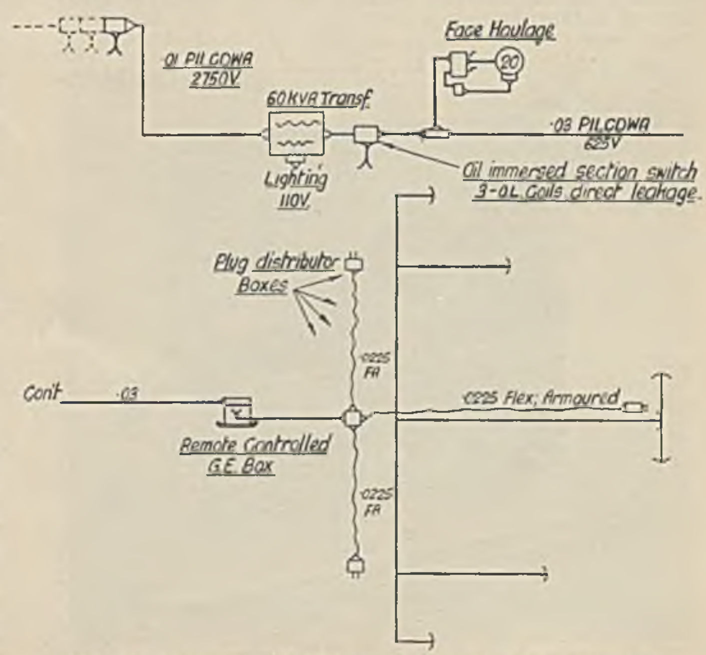


Fig. 2.—*Arcwall Working: Schematic Arrangement.*

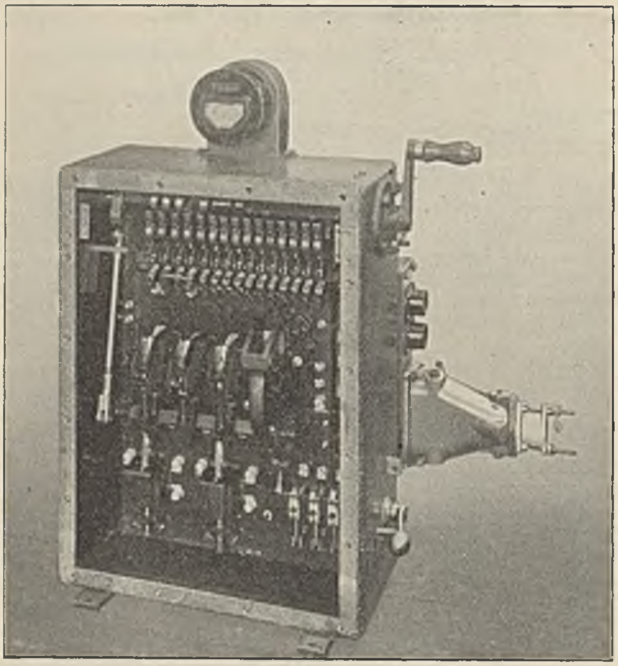


Fig. 3.—Combined Flame-proof Switch Controller.

The gate-end boxes for the cutters are provided with earth continuity and leakage protection and remote control operated. The sizes of cable and switchgear are fixed as a minimum based on the loads and volt-drop, it being noted that the transformer sub-station has to be moved up within the 1000 yard advance.

The illustration Fig. 2 shews a typical arrangement of an arcwall advancing face, forming pillars. A similar general arrangement is followed, the gate-end box being of the remote control type working in conjunction with sub-distribution boxes connected together with pliable armoured cable, each having the necessary trifurcating boxes and trailing cable socket, so arranged that the trailer plug can only be inserted into one sub-distribution box at a time.

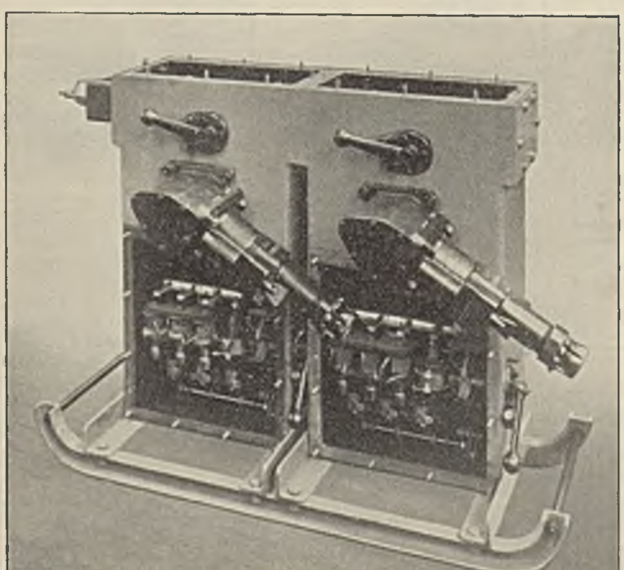


Fig. 4.—Air-break Gate-end Switches.

Fig. 3 illustrates a combined switch controller of the flame-proof type, for the control of small haulages, in which the necessary no-volt and overload protection are contained in the same case as the controller, the making and breaking of the first contactor being done on the contactor. A separately enclosed isolating switch is provided to enable maintenance to be carried out safely.

The range of air-break conveyor and gate-end switches used in the layout is shewn in Fig. 4. These may be arranged in any number of units, without isolating switches or ammeter, fitted in the separate busbar chamber. No-volt protection is provided as required and overload protection by thermal overload with short circuit trips designed to open instantaneously on ten times the full load current. One or two busbar trifurcating boxes can be fitted while outgoing a trifurcating box or plug and socket of the Besa or non-Besa type which can be fitted at will in two positions. The plugs are interlocked with the switch handle as standard, and earth continuity or remote control can be arranged for as required.

To complete the range a further switch is made with isolator, a single or three-phase transformer up to three kilowatts with high tension and low tension fuses and outgoing trifurcating box all self-contained for drilling or face lighting.

The diagram Fig. 5 is a trip curve for the thermal overloads being used, which is a natural line following the heating of the motor and therefore provides both theoretical and practically correct overload protection.

Mr. BAKER said his remarks were from a user's point of view and he assumed that the term "switchgear" on this occasion referred to control gear, that is, gear subject to frequent operation. Points in design had been previously discussed by others more intimately associated with that phase of the apparatus than he was.

Air-break gear for use underground has many appealing features to the colliery electrician and great adoption of welded steel cases has enhanced these considerably. What is needed is a robust housing which will not give way under the most arduous conditions, even to being blown up. Conditions at the coal face are anything but ideal and the handling of apparatus in transit is not always an easy matter; but even where conditions are good, one invariably finds that the switch has been dropped from a tram, or whatever the mode of conveyance may be, and any protruding cast irons, lugs, porcelain insulators, contact pins, which are usually to be found about oil-break gear, are broken off: for, as a rule, only the oil tank is of welded steel construction. Air-break gear can be housed in a construction of a more even and simpler design and fairly free from lugs and projections liable to fracture. As for weight, there will be very little to choose between the two types.

Mr. Baker said his own practice with gate-end gear was to fix the switch on wheels—not new wheels but wheels whose useful life on the haulage road was ended—since in most cases they were not required to move frequently. One feature of this mounting was that in wet districts the plug and socket were clear of water and its accompanying mud. As they only used one panel this worked quite well and he did not see any drawback by extending to two or three, that being merely a matter of extending the tram.

Mr. Baker then turned to the consideration of the accessibility of the two types and said that was where air-break gear has a big pull. The layout of the interior of an air-break switch of modern design lends itself readily to free inspection of the whole apparatus and in most cases the parts are "get-at-able" and can be quite easily repaired or replaced when necessary. Some designs have introduced a sliding door which ought to be an ideal for the colliery man for he dislikes a row of stud bolts to unscrew, and, if these happen to be of a useful size, they are usually put to another use by someone who may be short in another department. Whilst on the question of bolts and nuts he would stray from the point a little to ask manufacturers why they sometimes fitted, say half-inch studs with a 7/16 inch head. Whilst colliery men are very adaptable beings, it was very trying to them to have to deal with nuts of that kind—conditions are arduous enough without expecting the man to be equipped with spanners of all types in grades of one-sixteenths.

As to the accessibility of the oil-switch—first the tank has to be removed: how many of those present had struggled with the studs on the back flange of the tank? Moreover, exposure of the oil to pit conditions does not improve it. Lowering of tanks is not a one-man job, unless attention to oil level is not considered. When the interior of the switch is reached one finds the parts crowded together and not handy to get at by any means.

For auxiliary haulages, Mr. Baker had found air-break controllers do very well indeed and here again accessibility and ease of maintenance stood out prominently. A point he had noticed which has considerable bearing on the life of controller contacts is the leverage embodied in the operating wheel or lever. Personally, he found that either the wheel or short crank handle gives best results. A handle too long whilst easy for operation does not always allow the proper action of the contacts and causes consequent burning. This applies to both oil and air break.

One objection which he had against oil-break controllers, which occurs where external terminal boxes are not fitted, is the decomposition of the insulation of the cables, unless elaborate means of stripping and replacing the insulation with empire cloth or impregnated cotton sleeving are resorted to. Some types with hinged lid, carrying all the contacts and mechanism are fitted with laminated brush contacts to connect with the terminal chamber, these give trouble and are not a success. A few days previously he had examined a 25 h.p. air-break equipment which had been in use for about 12 months; one contact had been replaced in that period. It was a pleasure to look upon such a clean, healthy piece of apparatus. He could say too, that the resistance frame was a further pleasure, that also being air cooled in a flame-proof tank: a type of design which though it may take up more space and cost a trifle more, pays for the extra cost a thousand times over.

Oil level with its consequent dangers is a source of worry to the conscientious electrician and quite rightly so, for it is a dangerous state of affairs calling for strict maintenance. Carbonisation of oil when arcing occurs, and extra cost for oil replacements, all come against the use of this class of gear. One has only to refer to H.M. Electrical Inspector of Mines Report for 1928, pages 20-22 for evidence of the dangerous situations which arise due to wrong oil level and carbonisation.

For voltages above medium pressure, Mr. Baker preferred oil-immersed gear and these usually were of big sizes situated near to the shaft bottom and therefore maintenance could be more easily carried out. But even with this class he could recall a rather bad breakdown. In a stator reversing switch, 2000 volts, 400 h.p. the oil level was allowed to become low and arcing occurred at a contact only partly under oil—the oil became badly carbonised—an explosive mixture formed in the other parts of the switch hood and finally the cast iron housing was wrecked, fortunately without any serious consequences. There is now on the market a combined haulage air-break equipment embodying the isolating switch, main switch, overload trips, and controller in one welded steel housing. That ought to offer advantages and a saving in many ways

In Mr. Baker's case they had adopted air-break coal cutting equipment and have in use four remote control equipments; these have done splendidly, having been in use for over two years, and they had yet to replace a contact either in the coalcutter or the contactor itself, and together with time saved by the machineman, the extra protection afforded, these have amply repaid for the extra first cost. They also have the ordinary types of gate-end circuit breakers in use; these are all fitted with electrical earth circuit interlocks and they, too, have given every satisfaction. For feeder switchgear oil-break gear is used and those extend to the inbye substation.

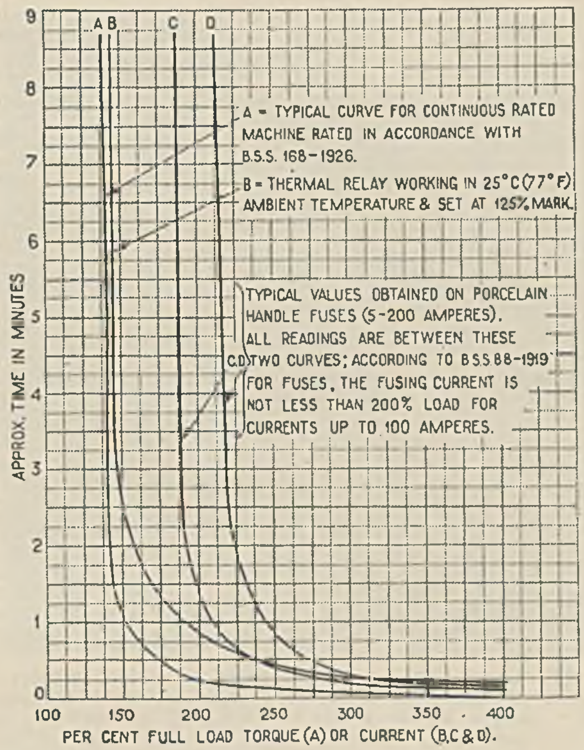


Fig. 5.

Mr. Baker did not consider fuses any protection at all for three-phase power work. They were the cause of most burn-outs and very dangerous when only one fuse of three operates. One has only to probe into the reports of H.M. Electrical Inspector for evidence on that point. Circuit breakers should be compulsory for underground use. Fuses are not a protection, they are a menace to safety.

Mr. MILBURN said he was very much interested in the descriptions of oil-break and air-break switchgear, as given by Mr. Burgess and Mr. Mann, respectively. It was rather unfortunate that they had viewed the subjects from two different points, but it seemed that they both agreed upon the face that oil-break gear should be used for main feeder work.

The question of safety enters largely into the choice of gear and Mr. Milburn was of the opinion that a greater degree of safety was obtained by the use of flame-proof gear immersed in oil, from the fact that should a securing bolt or stud be omitted from the tank, the contacts were still covered by the oil, whereas with air-break gear, the omission of a bolt or stud might render the gear non-flame-proof. There was also the question of maintenance entering into the choice, and from his experience he thought the maintenance cost of oil-break gear was greater than the cost in the case of air-break gear, providing that in the latter case the contacts were correctly adjusted. No doubt, most of the members present had had experience of starters on coalcutters; those have had air-break starting switches fitted for years, and it was surprising how little trouble they gave when the contacts were correctly adjusted. Another point in favour of air-break gear is that it is more easily handled underground.

Reference had already been made to the probable trouble due to an oil switch being rendered non-oil-immersed, due to a switch being out of plumb, but to his mind that was almost an impossibility as he could hardly conceive a switch being erected in this condition.

To conclude: although in Mr. Milburn's case both oil and air-break gear were used and maintained in sound condition, he still considered that where safety was the deciding factor, oil-break gear should be used.

Mr. JOHN GIBBINS.—Referring to a statement by Mr. Mann that for any form of leakage protection one really requires 5 per cent. sensitivity, Mr. Gibbins said he thought that was rather too sensitive because it was likely to trip more often than was necessary. He would like to know what is the British Engineering standard for the accuracy of these instruments.

As to breaking capacity, Mr. Gibbins noted that two or three speakers had said that there was very little air-break gear which had more than two to five thousand k.v.a. rupturing capacity. The gear with which he was familiar had a rupturing capacity of approximately 10,000-11,000 k.v.a. at 440 volts assuming a symmetrical short-circuit; two to five thousand k.v.a. was rather a small figure for pit work.

Mr. HEPBURN—The supporters of air-break switchgear can safely say that, so far as coal mining is concerned, it was the first type to be in general use both above and below ground. During the past 15 years at least, oil-break switchgear has been preferred almost universally for new installations, and in many instances has replaced the former type. It is only fair to say that of recent years the design of air-break switchgear has been improved to such an extent that responsible engineers have thought fit to revert to its use, chiefly in connection with portable underground machinery where relatively small amounts of electrical energy are controlled. In this direction quite satisfactory results have been obtained which tend to shew that there are applications in mines for each type of switchgear under review.

There are dangers to be guarded against whatever type of switchgear is in service. Mention has been made of the danger involved due to tilting of oil switches in service, but surely there are only isolated cases of this nature. Proper maintenance is essential with either type of gear, and may it not be due to the employment of what is known as the half-inch type of electrician that such failures are unwittingly produced. Mr. Hepburn said he was firmly of the opinion that all colliery electricians should have a preliminary mechanical training, but their electrical training should not be subordinated thereto, and in all cases only those who, by virtue of their training, were competent to properly maintain electrical equipment, should be permitted to undertake or attempt to supervise any electrical work. He agreed that present day competition demanded rigid economy and may call for dual duties to be undertaken by certain persons, but could see no objection to this procedure provided the person in question was in possession of the necessary qualifications for each of the duties involved.

Mr. Burgess had spoken of ionisation in the case of air-break switchgear, and this sometimes occurred with oil-break gear. Mr. Hepburn quoted a case of this kind which recently came to his notice.

Oil switches have proved so reliable in service that he was of the opinion that on this account they do not at all times receive the attention due to them. Strength of enclosure is of vital importance with either type of gear. Cast iron and very thin steel plate oil tanks and enclosures ought to be avoided as far as possible. The stresses induced by the opening of a switch on short circuit are on occasion sufficient to produce rupture of the switch casing and this fact should not be overlooked by those in authority at collieries.

A switch may operate quite satisfactorily under normal working conditions, but may be a source of danger if called upon to clear a short circuit even if the maintenance has been the best possible. There appears to be greater intensity of burning of the contacts when under oil than obtains with the air-break type, but this may well be more apparent than real.

The Westinghouse Company of America were responsible for the development of an air-break switch of unusual design, the "Deion" circuit breaker, which is said to deionise the arc resulting at break. The arc is driven at a speed of 2400 miles an hour over a circular metallic path until it dies of exhaustion. The invention appeared to be distinctly novel and if the claims made for it were supported by its practical application, it might be possible to dispense entirely with fuses, even in the case of domestic lighting, in the near future.

Mr. S. A. SIMON.—A point which perhaps might be a little more stressed is that both the leader and and seconder of the discussion have approached the subject from entirely different and comparatively restricted points of view. Mr. Burgess considered circuit breakers only and Mr. Mann confined his remarks to intensive face working. Between these extremes there is a wide range of important applications involving numerous types of switchgear where the particular merits claimed for their respective types by the leader and seconder are not so self-evident and the pros. and cons. for the air or oil immersed switchgear are fairly evenly balanced.

As an example, switchgear for haulage motors may be cited. The control involves frequent manipulation, with production of arcs but not necessarily the rupturing of large amounts of power, so that the high rupturing capacity produced by quenching the arc under a head of oil, is not a decisive advantage. On the other hand, air-break controllers can be more simply designed and more easily inspected and maintained, while avoiding the dangers incidental to the presence of oil in quantities.

Incidentally it has not been postulated, that the switchgear under discussion should be suitable for places where C.M.A. Regulation 132 applies, although probably both speakers had that in mind. In this connection Mr. Milburn argued that with flame-proof oil-immersed switchgear double protection is secured, the oil immersion itself in a properly designed apparatus preventing open sparking and rendering the apparatus flame-proof apart from any special mechanical features; the flame-proof joints and casing providing a second line of protection which need only come into action in emergency. Certain people even go a step further than this and affirm that with oil-immersed motor switchgear, the addition of flame-proof casings and joints is unnecessary and a needless expense, and they support the argument by saying that as the Regulation (132 v.) imposes the obligation to cut off the pressure whenever there is any indication of fire-damp, the risk of the switch acting and failing just at the moment when fire-damp appears, but before it is noticed, is so remote as to be practically non-existent. The Regulation (132 i) prescribes that in the normal working of all apparatus there shall be *no* risk of open sparking.

Mr. Burgess mentioned ionisation in regard to a transformer but Mr. Simon said he failed to understand how this affected the question of air or oil immersion—ionisation might occur in the air space above the oil of an oil-immersed switch.

Mr. W. A. A. BURGESS in reply said he would like to correct the impression that he intended his remarks on oil-immersed gear to apply only to switchgear controlling main circuits. He certainly emphasised points which are more easily recognised under such conditions, but intended it to be understood that he strongly advocated oil-immersed equipment right up to the coal face.

The necessity for strength in enclosure had been considered by all speakers for both types of gear, and entirely agreed that cast iron should find no place in the enclosure proper, and was to be deprecated elsewhere. He, personally would prefer a fabricated contruction throughout, although cast steel top plates have proved ample in service for a number of years. The elimination of breakable projections was a point which needed to be brought to light by the users and which would no doubt be given more attention in future, although it did not directly affect the question of oil versus air.

Mr. Mann had shewn illustrations of air-break gate-end switches and other speakers had referred to this design and commented adversely upon oil-immersed designs. While certain designs of oil-immersed gate-end switches were undoubtedly open to criticism, there were also designs available which embodied all the requirements of strength of enclosure, adequate clearances and sufficient head of oil in a thoroughly flame-proof form with core balance and earth pilot protection.

Figs. 6 and 7 are illustrations of such a design which has many years of experience behind it. It can be had in the form of single (Fig. 6) or mothergate units, and is particularly adapted for heavy duty under coal mining conditions. It embodies a form of combined cable dividing box and connecting plug which can also be had as a detachable joint box (Fig. 7), and which Mr. Burgess would venture to suggest, is more robust and more workmanlike than the design Mr. Mann had referred to.

With regard to controllers for haulages, etc. Mr. Burgess maintained that properly and amply designed oil-immersed controllers were superior to air-break designs. Carbonisation may be and is eliminated by incorporating a snap movement, contacts are of ample bulk and the contacts are so arranged that what little sludge forms, deposits in the bottom of the tank. Ionisation of air spaces is inevitable in course of heavy duty, and if the duty is heavy enough, flashover can and does occur. With properly designed oil-break gear, ionisation is impossible, and flashover in the air space above the oil never occurs because the oil reaches, as it should do, to the metal bosses in which the insulators are fixed.

For mining duty, Mr. Burgess had found the flat type of controller best for head room reasons, and a hinged top carrying all contacts and working parts is an added advantage for the same reasons. A simple earth pilot interlock can quite easily be incorporated to ensure that the circuit is dead from the master or gate-end switch before the lid is raised.

For coalcutter work, he was aware that it was common practice to embody the switch in the coalcutter body with the motors, and the disadvantages of this had led to the development of the contactor gate-end switch. This is by no means a cheap piece of apparatus and is consequently in comparatively small demand. Were the demand greater, oil-immersed remotely operated gate-end switches would undoubtedly be available at a competitive price. He considered however, that an equally serviceable and cheaper method was to detach the coalcutter controller from the coalcutter and to use instead a manually operated oil-immersed gate-end switch on skids or wheels, which could be linked to the cutter and hauled along with it, and from which the connections could be taken to the cutter by means of a short flexible cable through the standard mining plug and socket. The same arrangement may also be applied to conveyors and other forms of portable apparatus.

Mr. Burgess quite agreed that fuses should have no place underground. The "Deion" circuit breaker which had been mentioned is still in an experimental form and is much too bulky for mining and industrial use; it has its prototype in the "Grant" oil-immersed circuit breaker however, which, while likewise still in the experimental form, shews great promise, but would appear to be more suitable for heavier duty.

Mr. Mann's figures for oil and maintenance are on the high side and, furthermore, they presuppose no maintenance charge on air-break equipment which, to say the least, is an unsafe assumption.

Mr. H. J. FISHER.—Mr. Burgess spoke about adequate strength of enclosure, from the point of view of switches withstanding large internal pressures. This of course is essential, but great care should also be taken that adequate strength is provided to resist rough usage and falls of stone. Some of the small oil switches that are made to-day are not fit to go into a mine, being made of very thin cast iron, they soon get broken up, and may become a source of danger.

Mr. Fisher said he was also pleased to note that Mr. Burgess advocated heavier contacts and sparking tips. The practice of many manufacturers is to skimp matters in regard to this question. For many years past he had insisted that all oil switches having laminated main contacts should be fitted with "Lambton" sparking contacts which were of special though simple design, and functioned better than most other forms.

Mr. Mann had shewn some very interesting slides illustrating the adaptability of the Metrovick gate-end panels, one good feature being that the cases were of fabricated steel construction and should stand up well against rough usage of falls.

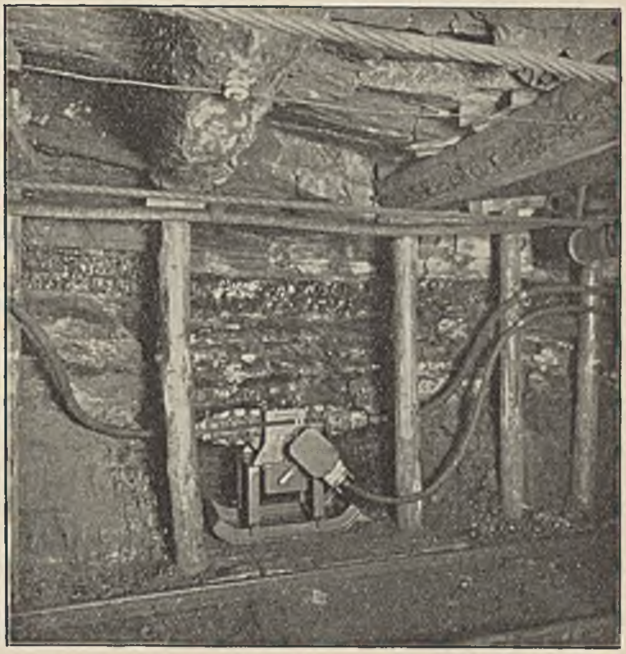


Fig. 6.—A portable Gate-end Switch fitted with detachable dividing boxes.

Mr. Fisher avowed himself an advocate for the use of air-break switches fitted, of course, with automatic features. He had no use for fuses for power circuits. Perhaps the most important feature in those panels was the provision for protection against sustained overload.

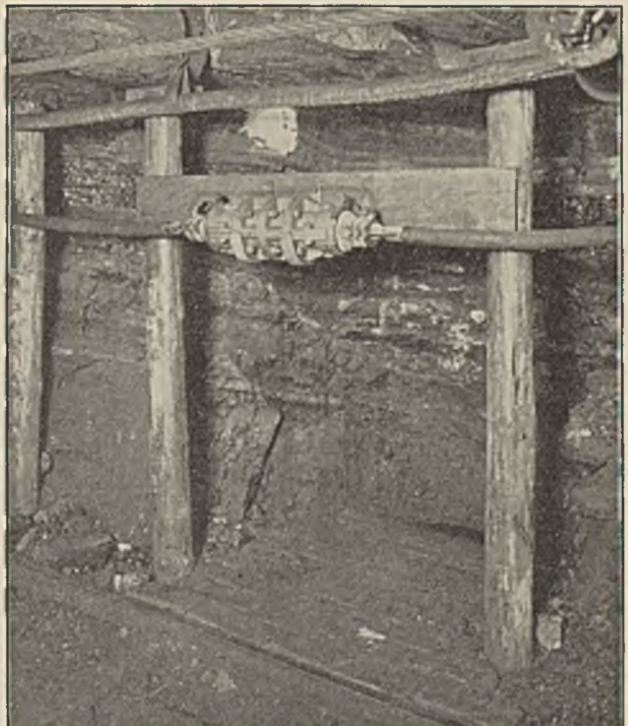


Fig. 7.—Cable Joint made by utilising detachable dividing boxes.

It was quite common to have conveyor motors absolutely roasted out, simply by overload. Many speakers had pointed out that air-break switches and controllers require less maintenance than oil-break and with which he thoroughly agreed.

WARWICKSHIRE & SOUTH STAFFS. BRANCH.

Air-Break Control Gear for Mining Service.

H. T. BALDWIN, B.Eng.

(*Paper read 24th October*, 1929.)

The object of introducing these remarks to the meeting is to consider in the first place the relative merits of oil-immersed and air-break switch gear for use at the coal face; secondly, to describe roughly the layout of air-break switchgear, coalcutters, and conveyors in the pit; and, thirdly, to give a brief description of the internal mechanism of a type of air-break switch. Owing to the conditions existing in the mining industry today the question of installing in the pit coalcutters, conveyors and loaders with their attendant switch gear is becoming more and more important, and collieries are doing their utmost to instal the most up-to-date gear and so avoid the troubles experienced by those who were first in the field.

In February, 1929, Prof. Statham of the Sheffield University Mining Department, read a paper before the Institute of Mining Engineers, in which he stressed the the point that oil immersion alone is not sufficient precaution against ignition of fire-damp. Ignitions of fire-damp due to loss of head of oil over the contacts, or exposure of contacts by tilting of the casing, shew that confidence in such gear has been misplaced.

It therefore became necessary to enclose the oil-immersed circuit breaker in a flame-proof case, and when designing this case, it must be borne in mind that fire-damp ignition is not the only risk to be contended with. Recent researches shew that one of the chief effects of the arc-energy liberated by the separation of current carrying contacts is the production of gases from the oil which consist largely of hydrogen and acetylene. Both these gases are more explosive in character than is fire-damp, and if the head of oil above the contacts is insufficient, ignition of this highly explosive mixture will occur.

It seems therefore, that the balance of advantage is in favour of air-break gear. Both oil-immersed and air-break gear must be in a flame-proof enclosure. The oil-immersed gear to be absolutely safe must be housed in a much more robust case than the air-break gear. We have then two switches very similar in general design with the added complication of oil in one of them.

As regards the ability of contacts breaking in air to withstand the rough use which they are subjected to in the pit, sufficient data is now available of tests made actually under working conditions at the coal face which proves that air-break gear gives every satisfaction in use. Switches normaly designed to work with magnetic blow-outs have been deliberately put in commission without this protection and have been at work for over twelve months, controlling conveyors, loaders and coalcutters without any attention beyond occasional cleaning of contacts.

There is another point to be considered when reviewing the question of coal face switchgear. Some manufacturers, by working in closer co-operation with mining electrical engineers are producing switchgear which more closely coincides with that ideal gear which can be adapted to suit the varying conditions to be met with in the pits, and these manufacturers seem to be concentrating their attention on air-break gear. Big strides have been made by designers in producing air-break switch units which can be easily assembled by the colliery electrical engineer into switch boards for controlling any number of machines in the most efficient manner. Spare parts have been standardised and simple means provided for rapidly interchanging units or parts of units. By the use of interchangeable plugs and sockets a simple method of extending cables is provided and valuable time saved. It seems therefore that in order to ensure obtaining the most up-to-date system of control for coalface machines, colliery companies must standardise on air-break gear.

As a typical example of machine mining where unit control is used, there is the case where the coalface runs parallel to the main haulage road, and supply gates and loader gates are at right angles to the main road. The length of face between supply gates may be, say, 170 yards, with a loader gate in the middle position. Coal is carried in each direction to the loader by means of conveyors, the loader being situated in the loader gate. In this example the number of machines to be controlled is as follows:

2 Coalcutters	35 h.p. each.
2 Conveyors	15 h.p. each.
1 Loader	7½ h.p.

The motors used are squirrel cage machines and started direct on to line, necessitating the following switches:—

Ripping Lip	1 coalcutter switch.
	1 main switch.
	1 three-unit board.
Supply Gates	1 coalcutter switch.

The switches controlling the coalcutters and the main switch in this case are provided with core balance, earth leakage protection, and all switches are provided with earth circuit continuity protection. The arrangement consists of a number of separate switch units, built up into welded boiler plate boxes, which may be attached together by means of a plug and socket connection.

Feeding such a switchboard is a semi-permanent type of plug which fits into a socket in the side of the box: this plug is provided with a flange and is secured by means of four bolts. The plug is provided with a sleeve to ensure that its flame-proof joint is not broken until the contacts are separated, according to the B.E.S.A specification.

One circuit from this plug goes to the switch contacts, and then to the outgoing plug mounted on a right angle adaptor underneath the box, and the other circuit is carried straight through to another semi-permanent plug base at the other side of the box. If the box is being used as a single unit this second semi-permanent plug base is fitted with a cap.

When it is desired to add another unit, the cap is removed and the second unit is plugged direct to the first unit, and the through busbar feature is carried right through this second unit to another capped semi-permanent plug base, the outgoing plug being fitted underneath this second unit as in the case of the first. Thus it is possible to add standard units as required.

When moving the switchboard up, the feeding semi-permanent plug is withdrawn, the switchboard moved up without cables, and an extra length of cable, with a semi-permanent plug at one end and socket at the other, is inserted, and the original semi-permanent plug becomes part of a joint box.

The switch mechanism itself is of the simple drum type controller pattern, which has proved itself in the past in such arduous duty as tramway controllers, etc. The operating handle is situated on the door of the box and operates through links. The first movement of the handle causes a no-volt coil to become energised, provided the earth circuit is complete, and on further movement the main switch contacts are closed, and are maintained closed by means of a catch and roller. In the event of failure of voltage, or breakage of the earth circuit through the cables, the switch trips mechanically. Overloads are provided with variable time lags, which are placed at the front of the box and are readily adjustable. The arrangement gives free handle features

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and the switch cannot be closed unless the supply is established, the earth circuit complete, and the door closed. The door is provided with mechanical interlock, so that the door cannot be removed with the switch in the "on" position. The handle is withdrawn with the door and an electrical door interlock is also provided.

The remote control gear is similar in general outline to the hand-operated gear, and the units are interchangeable with the hand operated units, so that a bank of switches can be arranged consisting of one or more hand-operated units, and one or more remote controlled units. Central control for the hand-operated gear is thus provided, whilst the remote control units are operated from a distance, giving a very flexible system.

The internal mechanism of these remote controlled units consists of a three-pole contactor of a special type, in that it is provided with a closing coil which is cut out of circuit when the switch is closed. This closing coil is very liberally rated and will pull in the contactors under any circumstances of voltage drop likely to be encountered in any part of the pit, and it plays no part in retaining the contactors in the closed position, being cut out of circuit immediately. The switch is maintained in the closed position by means of a mechanical catch and roller gear which is itself retained by the no-volt coil.

The overload protection provided in all three phases is similar to that fitted to the hand-operated gear, in that it trips the switch mechanically. In the event of failure of supply the switch is tripped by the no-volt mechanism, and if the earth circuit is incomplete the pull-in coil cannot be energised. This method of operation ensures that it is impossible to operate the switch from the push button unless the circuits are complete.

The operating push button is fitted into a flame-proof case with suitably shrouded press knobs. To start the machine the knob is pulled upwards and, when released, it returns to its neutral position. To stop the machine the knob is pressed downwards. This arrangement ensures that the switch will be tripped in the event of anything fouling the push buttons.

The automatic switch units can be provided with a hand-operated emergency switch, or banks of gear can be controlled by means of one master hand-operated unit as part of each bank. Both the hand-operated and automatic gear can be easily arranged for sequence switching, to ensure that the loader motor is started before the switches controlling the two conveyors can be operated. Inversely, if the loader motor is stopped, the two conveyor switches will automatically trip.

In the case of direct current systems the double pole switches and starters are built up into one unit and are operated by one handle. The first movement of this handle closes the double pole switch and further movement operates the three or four starter contacts. In the event of the switch being tripped through overload or failure of voltage the starter contacts fly back into the "off" position, and the mechanism gives free handle features. The mechanism is so arranged that if the plug is withdrawn either from the machine or from the switch, the switch will trip.

The boxes are of welded boiler plate construction of ample proportions to withstand any rise of pressure which may occur. The flanges are suitably grooved for the relief of such pressure and they have proved very efficient. The maximum pressure registered when the switches were undergoing tests of their flame-proof properties was 45 lbs., which compares very favourably with other methods of venting, the pressure in some cases being as high as 100 lbs.

The bolts securing the lids are all welded into the flange, and the nuts are shrouded, necessitating the use of a special spanner to remove them. The mechanism is readily accessible, and can be withdrawn completely from the box by removing four retaining nuts which secure the boiler plate base on which the mechanism is mounted.

The method of earth circuit protection is worthy of particular attention, depending for its operation upon the variation of impedance of a coil in series with a no-volt relay. The no-volt coil is placed in series with the primary winding of a small transformer which is supplied at the normal voltage of the system. The secondary winding of this transformer is shorted through the pilot and earth core or ferflex of the cable. So long as this secondary winding is shorted the impedance of the primary winding is low and sufficient current is allowed to flow through the no-volt coil to operate the mechanism. Immediately the secondary circuit is opened, through failure of the earth circuit, the impedance of the primary goes up and will not allow sufficient current to flow through the no-volt coil to operate the mechanism. Hence the main switch trips immediately. One advantage of this method lies in the fact that the induced open circuit voltage in the secondary winding can be kept much lower than in other systems, where the no-volt coil is in series with the secondary of the transformer.

WEST OF SCOTLAND BRANCH.

Annual General Meeting.

The Annual General Meeting of the Branch was held in Glasgow on Wednesday, 16th April, 1930 last, when Mr. G. N. Holmes, Branch President, presided over a good attendance. After the minutes of the last Annual General Meeting had been read and approved, two applications for membership were unanimously passed.

The Secretary submitted his report for Session 1929-30, from which it was learned that the membership during the year had been increased by eight, and that the active interest and enthusiasm of members had been well maintained.

There was also placed before the Meeting a certified copy of the accounts for the Session just finished, which showed a surplus on the year's working. The accounts and Balance Sheet were considered highly satisfactory, and were unanimously adopted.

Mr. Holmes invited Mr. Rogerson, the newly elected President, to take over the Chairman's duties. Mr. Rogerson in a few words thanked the members for the honour they had conferred on him and hoped that with their assistance the affairs of the Branch would be carried on as satisfactorily as before.

Other Office Bearers for the Session 1930-31 were elected as follows:

Vice Presidents: Messrs. A. Dixon and A. F. Stevenson.
Hon. Auditor: Mr. James Laird.
Treasurer and Hon. Secretary: Mr. W. G. Gibb.
Hon. Asst. Treasurer: Mr. John A. Brown.
Members of Council: Messrs. D. Baird, R. Russell, W. McCallum, P. Burt, D. C. Gemmell, J. Comrie, James Howat, G. Boyes, H. Smith, Ivan C. Rushton, James Dinnen, and Stewart Chambers.

The Chairman and Secretary of the Ayrshire Sub-Branch were co-opted members of the Branch Council.

Strict business having been attended to, the members assembled for tea, followed by an excellent musical programme submitted by the following members:

Messrs. Mailer and Robertson (Songs); Mr. James R. Laird (Recitations); Mr. C. E. Hart, (Piano Selections) and Mr. A. Dixon (accompanist.

The company also joined in community singing, and altogether the Meeting was voted one of the most successful yet held.

NEW ADDRESS.

The Birmingham Office of the Metropolitan-Vickers Electrical Co., Ltd., has been transferred to Wellington House, 39 Bennetts Hill, Birmingham. Telephone Nos. Central 2801 and 2802; Telegraphic Address, "Multiphase, Birmingham." This removal has been made to afford greater space in which to handle the rapid growth of the Company's business in the Midland Area.

Obituary: Mr. J. B. Thomson.

With the recent death of Mr. J. B. Thomson, of St. Helens, Hamilton, the West of Scotland Branch of the Association of Mining Electrical Engineers lost one of its earliest Branch Presidents. Mr. Thomson was, until the time of his death, General Manager for John Watson Ltd., Coalmasters; he died in a Glasgow nursing home on the 7th instant.

A Film Demonstration of E.H.T. Switchgear.

A joint exhibition of films demonstrating modern oil-circuit breaker practice was presented recently in London by Reyrolle & Co., Ltd., and British Brown-Boveri Ltd. It was very clearly impressed on the audience that though these two firms had combined for that occasion and purpose, there was no other combine to be discovered. The reason behind the joint display was that both companies had developed their practice in this class of apparatus on the same main basic principles—they both favour the open-type arc with the multi-break for high power and high voltage gear—though the constructional details of their respective manufactured plants differ materially.

The Reyrolle film demonstrated the manufacture, testing, and installation of switchgear of the metal-clad type which has been designed as a practical application of the results of research which have combined to produce a robust gear reliable under all operating conditions and proved by many years of practical experience. Typical examples of such designs are being installed for the 66 k.v. and 132 k.v. systems now being erected in parts of this country.

The first part of the film illustrated the detail manufacture and testing of medium-voltage and high-voltage modern switchgear with examples of typical multi-break switchgear in actual use. A part of the film shewed the manufacturing section of Reyrolle's works at Hebburn. Among the examples of finished gear illustrated were: three-phase 110,000 volt switchgear, comprising 3 single-phase 600 amp. units operated through a common shaft from one solenoid mounted on the end tank, as supplied to the Shawinigan Engineering Co., Canada; a three-phase 135,000 volt circuit breaker of similar construction, but with operating solenoid mounted on a separate pedestal, as supplied to the Hydro Electric Commission of Ontario; a series of internal and external views of 132,000 volt circuit breakers, notable features being the six breaks per phase and the hexagonal disposition of the contacts to obtain the best use of the oil in the tank; examples of modern outdoor e.h.t. substations, as the three-phase, 66,000 volt, 600 amp. circuit breakers with air-break isolators incorporated, installed in the North East Coast area.

The final section of the film shewed views of the high power testing laboratory recently installed at Hebburn. It is intended, by means of this plant, to carry out further research work at considerably greater powers than have hitherto been available in this country, and thus prove the practical application to high-power switchgear of the data obtained by the Electrical Research Association. Included in this part of the film was an oscillograph record shewing one phase of a three-phase short circuit on this plant: the initial peak current was 70,000 amperes which corresponds to a 1,500,000 k.v.a. short circuit at 17,100 volts.

The Brown-Boveri film dealt entirely with research work. The whole process of rupturing heavy currents under oil was admirably depicted. The fundamental phenomena that entered into the process of rupturing such currents were clearly portrayed and confirmed by slow motion pictures of the actual rupturing in a specially constructed circuit breaker with heavy glass sides illuminated by flood lights of 200,000 c.p. The development of the arc and the gas bubble during the rupturing process was clearly seen. In the first tests 10,000 k.v.a. at 8,000 volts was broken by means of a single pair of contacts. The gases produced formed an opaque ball which increased rapidly while the oil above the contacts was thrown against the cover of the switch in the form of a piston. For heavier loads the character of the breaking process was essentially the same, but accentuated. This was demonstrated by the next test, in which 24,000 k.v.a. at 8,000 volts was ruptured. This capacity was in excess of the rated rupturing capacity of the breaker. The oil reached the cover quickly and expelled all the air. From this moment the static pressure increased rapidly and quickly caused the glass walls to give way.

Tests were shewn on a breaker fitted with an explosion chamber, 10,000 k.v.a. at 8,000 volts being interrupted. The explosion chamber was provided with lateral circulating ports. It was seen that carbonised coal escaped through these ports before the moving contact had left the explosion chamber. The film shewed that the oil piston only forms at the moment when the gases begin to escape through the lower opening in the chamber. The same capacity was also broken with the explosion chamber provided with circulation holes at the top. The formation of the oil piston was clearly observed, and the shock to which the breaker was subjected caused an oil leak. In the next test multiple break contacts were used, and it was noticeable how the duration of the arc and the work done by the switch were diminished. This test shewed 10,000 k.v.a. at 8,000 volts being ruptured by three pairs of contacts in line. This part of the film seemed clearly to demonstrate the advantages of the multi-break principle.

The next portion of the film gave a representation of the magnetic field produced by the arrangement of the contacts in an oil-circuit breaker when closed on a short circuit. The effect is that powerful repulsion between the contacts occurs, and, in consequence, they tend to open again under such conditions. Due to the unevenness of the surface of the contacts, it is found that, if closely examined, they only touch on a small portion of their surface. Consequently, the magnetic lines follow the current and are loop shaped; therefore repulsive forces are created between the contacts. These forces are sufficient to separate the contacts, especially when closing breakers on short circuit currents exceeding 10,000 amps. The arcs thus formed damage the contacts, and often cause them to weld together. A slow motion picture with the glass walled breaker shewed the effect of the repulsion of solid contacts under oil. The repulsive forces were so considerable that the circuit was broken twice in succession, and part of the copper of which the contacts were made melted and was dispersed into the oil. The contacts finally welded together. It was further demonstrated that repulsion and welding can happen also with the plug type of contact, and, on the other hand, that contact repulsion can be prevented by the use of solenoid contacts wound in the same sense, and, therefore, attracting one another. A normal oil-circuit breaker was equipped with three different types of contact and each in turn closed on a short circuit current of from 30,000 to 50,000 amps. One pole was equipped with brush contacts and ordinary arcing contacts; another with plug contacts; and the third with solenoid contacts. In the case of both the brush contacts and the plug contacts a considerable amount of oil and gas was ejected from the tank, and could be clearly seen in the film. The cover of the switch was not quite closed in order to prevent an explosion due to static pressure. When the solenoid contacts were closed the only visible indication that a heavy current had passed was the violent movement of the cables to the switch. On opening up the switch the condition of the three pairs of contacts was seen. It was noticed that the brush and plug contacts had been considerably damaged and burnt away, while the solenoid contacts were absolutely undamaged.