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Mines Lighting Regulations.

The particular and early attention of members of the Association of Mining Electrical Engineers is directed to a full consideration of the proposals formulated by the Mines Department as a basis upon which to remodel the regulations relative to mines lighting. A special Committee of the Association was appointed at the General Council meeting last month to take up the question ; all branches were invited to consider the position carefully in detail with a view to furnishing reports for the guidance of the Committee. The full text of the "outline of proposals" issued by the Mines Department was published in this journal last December ; subsequently a short supplementary series of proposals was issued, these are relative to the illuminative values of stone-dusting and are reprinted in full this month (see page 294).

Whatever confliction of ideas there may be in regard to the latitude and nature of statutory limits and restrictions to be observed in mines lighting there will be no two opinions as to the desirability—nay the urgent necessity—of setting the mining industry free to utilise fully, to the ultimate safe extent, all those many remarkable improvements in method and appliance which have so advanced industrial electrical illumination during recent years. Obviously, if there is any sphere of work which above all others demands adequate artificial light as a sine qua non it is in mining. The miners' health and personal safety, his bodily comfort and the easing of hard manual labour ; as well as the quality, quantity, certainty and speed of mineral output: all these factors are greatly dependent upon and inseparable from the mines' lighting equipment.

It is not to be anticipated that there will be any considerable diversity of opinion in regard to the proposals in so far as they are concerned with safety lamps : the suggested figures regarding minimum burning periods and candle powers are conservately modest and well within the reach of modern manufacturers to embody them in lamps easy to carry and convenient to manipulate.

The consideration of means of direct lighting underground other than by portable self-contained hand lamps is, however, beset with controversy. The devising of suitable ways and means for providing what might be termed "bulk" electric lighting at the faces and on the roadways introduces grave problems of risk by open-sparking and electrical faults generally : but, after all, the many lamp terminals, wiring or light cable runs, connectors, etc., introduced with a lighting system are but duplicates of well understood and commonly used appliances ; they are in no sense formidably or fearsomely novel and untried. Provided that certain axioms definitely prescribing compulsory practice in regard to such factors as armouring and earth-shielding, automatic fault protection, and flame-proof fittings are established, there need be no additional or increased risk arising from bulk electric lighting in mines.

It is to be hoped, therefore, that the members of the Association will in approaching this subject apply themselves most closely to arriving at clear and definite figures and details in regard to limitations and designs, rather than be tempted to indulge too freely in the generalities and repititional platitudes which this very interesting theme—so very intimately their own—is likely to engender. There is too another important point to be watched when attempting to formulate fixed rules : the probabilities of near progress should not be overlooked. There is no gainsaying the fact that however good and beneficial for the time being are rules and regulations, they have always some tendency to curb invention and improvement. Even the circumstances and terms of this present outline of proposals can be read as confirming this contention, for who will deny that the changes herein contemplated are long overdue.

As to the probabilities of near progress, most mining electrical engineers, as a result of practice, have developed ideas as to the trend of improvement, and not a few of them have pet notions of great improvements which they hope to try out and develop at the earliest favourable opportunity. Due regard to the natural evolution of better engineering practice should exert a weighty influence in this case, lest enterprise be strangled for want of freedom.

That the near future holds great changes in electrical practice goes without saying. In this matter of the future of mines lighting one immediately recalls the pregnant facts revealed by Prof. W. M. Thornton some seven years ago. Those who care to look up the copies of this journal for February and March, 1924, will read with renewed interest Professor Thornton's opinions on mines lighting. Therein he advanced the suggestion that high frequency a.c. currents are ideal for the purpose. Whereas at 200 volts a direct current of less than half-an-ampere will fire gas, at 200 volts, 150 periods, the minimum of $23\frac{1}{2}$ amperes is necessary, and at 15 volts, 160 periods, a current of not less than 175 amperes is required to flash the most explosive gaseous mixture. This was the promise then held out by Prof. Thornton : "If it is an economic proposition to increase the lighting at the coal face to ten times its present amount, then here is a means of doing it with a factor of safety greater than that of present practice."

We do not know of any attempt having yet been made to introduce the high frequency low-voltage system into practical use. There would appear to be no difficulty whatever in regard to the design and manufacture of the apparatus. Has the proposal been shelved because of the present hide-bound official restrictions ? We mention the matter here for two very important reasons. Firstly, to indicate how necessary it is that, though legal regulations concerning industry to be of any use must be definite and explicit, they can nevertheless be made subject to closely guarded conditions which will permit of freedom for industrial development with the advance of science and discovery. The second reason is that the example quoted is an excellent reminder of the truth that the standards of to-day will be obsolete to-morrow. Both these reasons should be kept well in mind when dealing with the making of new rules for mines lighting.

Self Help in the Coal Industry.

Under this title Mr. R. A. Burrows, Past-President of the Lancashire and Cheshire Coal Research Association, is to present a paper on March 24th at a joint meeting of the Coal Trade Luncheon Club, the Mining Association of Great Britain, the Coal Merchants' Federation, and the Institute of Fuel. As indicated in the advance copy of the paper, the author urges the coal industry itself, and those concerned with it, to undertake the very urgent task of reforming the industry, its products and the methods by which those products are distributed ; he points out that while coal owners have interested themselves in safety and general mining research, they have almost completely neglected to give attention to "commercial research", which factor the author attributes to the unbalanced organisation of the industry.

Even to-day at most collieries the mining or production side of the concern is overwhelmingly in control, and the sale or distribution side is definitely subordinate. The treatment of coal after it has reached the surface, has been carried out by 'rule of thumb' methods, and collieries put on the market grades of coal which might or might not suit their customers, whereas a more detailed investigation of the nature and qualities of the raw material might have led to the production of a better and more saleable article.

The author holds that the section of the colliery organisation dealing with the preparation and treatment of coal can make or mar the whole business, and should be recognised as a separate department with a competent executive officer in control, who should also, of course, work in close co-operation with, and largely to the dictates of the sales department.

It is suggested that collective research associations supported by the co-operation of collieries and merchants, could with advantage to the industry, carry out researches in the commercial utilisation of coal, and that there are several processes which should be watched with keen interest by the coal mining industry, e.g., low temperature carbonisation, pulverised fuel, and the hydrogenation of coal.

The subject of the extraction of oil from coal should be particularly studied, as the solution of this problem on a commercial basis would probably do more than anything else to restore the prosperity of the coal industry.

The industry could do a great deal towards popularising coal by standardising nomenclature and grading sizes more regularly. In the past there has been far too much coal sold under very general trade names, and the great strides made by gas and electricity have in part, at any rate, been due to the dissatisfaction of householders with the classes of coal supplied. The actual distribution of coal from the truck to the householder could be vastly improved, and if the use of coal for domestic purposes is to be maintained, or, as it may be hoped, increased, the cost of distributing it must be cheapened.

The coal industry must not look outside for help, but must take the necessary steps itself to remedy its own defects and overcome its own difficulties. The days of isolated individualism have gone and co-operation between all parties is vitally necessary. Once those concerned in this great basic industry are convinced of this ; once they sit down together with a wholehearted determination to overcome the many difficulties that will present themselves, there is no doubt that a way will be found to extricate the trade from its trouble and restore the prosperity that is so sorely needed.

The Lighting of Mines.
Mines Department Announcement.

In *The Mining Electrical Engineer,* December, 1930, page 207, was reprinted the outline of proposals submitted by H.M. Secretary for Mines to mining associations and other interested parties relative to contemplated changes in the statutory rules governing the lighting of mines. The following Supplementary Proposal was subsequently issued.

Indirect Lighting.

(1) For the purpose of improving the lighting of roadways by means of reflected light, the incombustible dust with which they are treated in pursuance of Part I. of the General Regulations dated 30th July, 1920, shall (except for slight colouration caused by impurities) be *white.*

(2) (a) So far as practicable, the roof and sides of all haulage roads at places where persons are regularly at work shall be kept effectively whitewashed ; and this shall be done in particular at all sidings, landings, passbyes, haulage junctions (offtakes) and the tops and bottoms of all permanent self-acting inclines

(b) All pit bottoms and mid-landings or insets which are in use for the descent and ascent of workmen shall be effectively whitewashed.

(c) The tops and sides of engine rooms, motor rooms and rooms containing transformers or switchgear shall be kept effectively whitewashed.

A.M.E.E. Examinations.

This year the Examinations for the Certificates of the Association of Mining Electrical Engineers will be held on April 25th and May 2nd.

Alternating Currents.

F. MAWSON.

(This is the Twelfth of a series of Articles intended more particularly to help Students and Junior Engineers.)

AN alternating current is a quantity which varies with cyclic regularity, and is alternately positive and negative, each half wave, positive or negative, being exactly similar. The outline of the alternating current or EMF waves met with in practice are usually irregular, for the form of the wave depends on the construction of the alternator and the nature of the load it supplies.

Wave Forms.

The simplest, and at the same time the best wave form, is shewn in Fig. 1; it is known as a Sine Curve. This wave form is closely approached in the case of large alternators designed for electric power transmission. The curve is symmetrical as regards the horizontal line *o a b c* and a vertical line through the highest point of the curve.

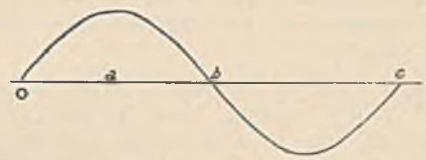

Fig. 1.

To construct a Sine Curve. Draw a horizontal line AC, take any length OA to represent a certain current and assume that this rotates about O. Describe the circle and divide the circumference into twelve equal parts, numbering them 1 to 12. Now let BC represent the time of one revolution to some scale, divide this line into 12 equal parts and draw lines at right angles to BC from each point. As OA begins to rotate it moves through the angle OA1 in the time represented by B1. From point 1 on the circle draw a line parallel to AC to cut the vertical through 1 in F. Repeat the operation for all the points 1 to 12. Join the points F G H etc. thus obtaining one complete wave of the required Sine Curve.

The variation of the current in passing through a complete set of positive and negative values is repeated over and over again during equal intervals of time. When the current has passed through one complete set of values both positive and negative, it is said to have performed One Cycle.

The number of cycles performed in one second is called the Frequency and is denoted by the symbol ~ The standard frequency for power distribution is 50 cycles per second. Frequencies below 35 cannot be used for lighting purposes as at this speed a current produces a flickering of the light wihch is perceptible to the eye. For special purposes frequencies both higher and lower than 50 are used.

The duration of one cycle is called the Period and it is denoted by the letter t

$$\text{period} = \frac{1}{\text{frequency}}$$

$$\text{or } t = \frac{1}{\sim}$$

Two-phase and Three-phase Currents.

In Fig. 2 in order to draw the complete sine curve B F G H C the line O A must be rotated through one complete revolution or through 360 degrees.. It is sometimes convenient to replace the horizontal scale B C by a scale of 360 degrees representing one complete cycle. In comparing different currents of the same frequency, it is customary to denote the relation between them by an angle, equal to the angle between the rotating arms O A which trace out two curves at the same time or equal to the angle between two simple coils which will produce the currents when rotating in a bipolar magnetic field. If two currents each reach their positive maximum values at the same instant they are said to be in synchronism or in phase. If two or more alternators run in parallel on the same load and supply currents which are in phase the alternators are said to be in synchronism. If the zero or maximum values of the current do not occur at the same instant, the currents are said to be out of phase, and the angle denoting the difference of time between them is called the angle of phase difference.

Fig. 3 shews two similar current waves at right angles to each other; that is, with a phase difference of 90 degrees. If these currents are fed into a common circuit the resultant current would be represented by the diagonal O C.

If these two currents are fed into two separate lines a two-phase system is obtained, that is two distinct circuits from one alternator, the currents in the two circuits differing by 90 degrees or one fourth of a period. Very few two-phase systems are in operation the standard a.c. systems being three-phase as shewn in Fig. 4.

Three-Phase Currents.

These are used universally in connection with power transmission systems. These currents have a phase difference of 120 degrees or one third of a cycle. Such an arrangement is shewn diagrammatically in Fig. 4. At any point in the curves if the sum of the currents be taken it will be found to be zero; thus at a, ab + ac — ad = 0.

This property of a balanced three-phase system should be kept in mind as it is taken advantage of in connection with three-phase machines and transmission lines. The resultant sum of the currents in a three-phase

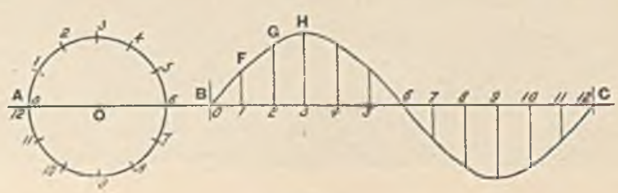

Fig. 2.

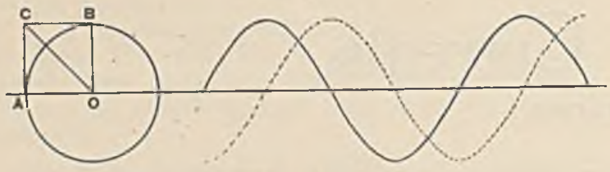

Fig. 3.

unbalanced system is not zero, that is if C_1 C_2 C_3 have not equal maximum values; but where this system is used the currents in the different lines are kept as equal as possible.

During a cycle an alternating current passes through a set of values ranging form its positive maximum value through zero to a maximum negative value and back again to zero. These instantaneous values are used very little in practice. When it is said that so many amperes are flowing in a circuit or that an alternator is supplying a pressure of so many volts, a certain constant average value is implied, which must necessarily be less than the maximum value yet at the same time must produce the same effect as the alternating current or E.M.F. of varying values which it represents.

It has become the universal custom to express alternating currents in terms of the value of a direct current that will produce the same heating effect. For example, when an alternating current is said to be 20 amperes, it means that the alternating current will have the same heating effect as a direct current of 20 amperes. There are therefore in alternating current circuits three values of importance namely the maximum, the mean, and the virtual values.

The maximum value or highest value of the E.M.F. is given by the ordinate 3 H Fig. 1 and hence indicates the maximum stress to which the insulation of the apparatus is subjected. The average value is the length of the mean ordinate of half a cycle, the average value of the whole cycle is necessarily zero. If the maximum value is E then the mean value can be shewn to be $\frac{2E}{\pi}$ or 0.636 E. The average value like the maximum value is of little use in calculations.

The virtual value is equal to that of a direct current which produces the same heating effect as the alternative current. If a direct current I is sent through a wire of resistance R the wire is heated and the power used in watts is W and this value is obtained from the expression $W = I^2R$ watts; but since R may be considered constant, the power used is proportional to the square of the current. If an alternating current is sent through a wire the power expended is proportional to the square of the current at each instant. The mean heating effect will therefore be proportional to the mean of the squares of the different instantaneous values of the current. This is called the Root Mean Square or R.M.S. value. This value is slightly greater than the mean value and can be shewn mathematically to be 0.707 times the maximum value, or 0.707 E.

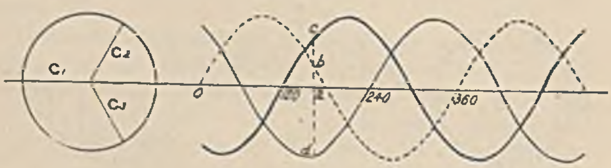

Fig. 4.

Unlike direct current the flow of an alternating current does not depend simply upon the pressure and the resistance, according to **Ohms** law; inductance and electrostatic capacity also effect the alternating current. Electrostatic capacity, simply known as "capacity" is the property possessed by a circuit or body to store up a certain quantity of electricity. An apparatus capable of storing electricity is called a condenser.

When the E.M.F. of a circuit is alternating and possesses capacity it alternately stores and discharges a quantity of electricity, the quantity would remain as a constant charge if the E.M.F. was constant.

Inductance is the property of a current which consists of setting up a magnetic field round the conductors forming the circuit. When the value of the current changes the magnetic field reacts and tends to prevent the change. Most electrical apparatus possess inductance to some extent though in varying decrees. Motors, transformers and even transmission lines shew its presence; overhead lines of considerable length shew capacity, but underground cables possess a considerable amount.

Inductance not only increases the apparent resistance of a circuit, but it makes the current behave as though it possesses inertia, consequently the current does not respond to the changes in the E.M.F. instantaneously but lags behind in time. The maximum and zero values of current are reached later than the corresponding E.M.F. values. The current flowing in an inductive circuit is said to be a lagging current. The effect of capacity is exactly opposite and the current reaches a maximum or zero value earlier than the E.M.F. The current therefore which flows in a circuit having capacity is called a leading current. The amount of lag or lead in a circuit containing capacity or inductance will necessarily depend on the amount of either factor compared with the resistance of the circuit. The lag or lead is measured by the angle which the current lags or leads the E.M.F. The maximum phase difference that can occur is 90 degrees or a quarter of a phase lag or lead. If a circuit contains both these and they are balanced one against the other their separate effects can be neutralised and the current can be made to flow in phase with the E.M.F.

With a given pressure and current in an alternating circuit the power transmitted by the circuit depends upon the phase relation between the current and the E.M.F. When the current and the E.M.F. are in phase then the power in Watts is equal to the product of the E.M.F. in volts and the current in amperes, as in the case of direct currents. If the E.M.F. and the current are out of phase the true power is less than the product of the virtual volts and amps., in which case the product is known as the apparent watts; and the ratio of the true watts to the apparent watts is called the power factor. The power factor bears a definite relation to the phase angle between the E.M.F. and the current and has the same value whether the current lags or leads and is equal to the cosine of the angle,

Let E = Virtual E.M.F. in volts
I = virtual current in amperes
f = power factor
w = true power in watts
$W = f E I$

The practical unit of apparent power is the Kilo-volt-ampere or apparent power $= \frac{E\,I}{1000}$ Kilo volt-amperes.

Proceedings of the Association of Mining Electrical Engineers.

LONDON BRANCH.

Electric Battery Locomotives and Tunnelling.

N. E. BAYLIFF.

(*Continued from page* 278.)

CONSTRUCTIONAL DESIGN.

Weight.

The determination of the weight of a locomotive is dependent upon a number of factors: viz., the pull required to move the train on the level; gradients; acceleration required at starting; the co-efficient of adhesion of the locomotive on the track; and the conditon of the track tself, whetheir dry or wet or sanded. The maximum drawbar pull which a locomotive can exert on the level is limited by the slipping of the wheels, and is reduced when climbing a gradient, as a percentage is required to raise the locomotive itself up the gradient.

Assuming a locomotive weighing 5000 lbs. with steel wheels the maximum drawbar pull on the level will be approximately one-quarter, or say 1200 lbs. on a light track such as is commonly used by public works contractors. Taking an average figure of 30 lbs. per ton of rolling resistance, and a train of 20 tons gross weight, the running drawbar pull on the level is 600 lbs. This allows a further 600 lbs. for starting effort and will give a reasonably rapid acceleration. Considering the same train on a gradient of 1 in 100; the drawbar pull behind the locomotive is reduced to 1150 lbs., the running drawbar pull required to haul 20 tons up the gradient is 1050 lbs., leaving only 100 lbs. for starting. For this duty, the load would have to be reduced or the locomotive weight increased.

The locomotives at present supplied by British manufacturers generally, have a nominal haulage capacity of from 5 to 6 times their own weight when mounted on steel wheels. Weight in the storage battery locomotive is not difficult to obtain, as the weight of the battery itself will approximate one-fifth to one-quarter of the total weight. In some cases, the ratio of battery weight to a total might even be greater. For a given gross weight of locomotive, a lighter battery means more weight of material in the locomotive itself and, if properly designed, a stronger machine. On the other hand a locomotive, on account of a heavy battery, may have a greater gross weight than is required either for mechanical strength or for the tractive effort required. Excess battery weight then means useless dead load which is continually requiring battery energy to haul it around.

Regardless of the weight of the locomotive desired, there are many instances where conditions such as low roof and narrow headings determine the size that can be used. It is not unusual to find that it is impossible to instal one locomotive of the size usually desired, and it has become common practice in such cases to use two smaller locomotives.

Speed.

The speed of the storage battery locomotive is considerably reduced when the battery is discharging at high rates due to the drop in voltage at the battery terminals. The speed at which the locomotive operates is an important consideration. In order to distribute the energy stored in the battery over a shift, or working day, there is but a limited amount of energy available for each cycle. The speed of the locomotive should therefore be just sufficient to cover the required distance in the time allowed with no idle time, thus leaving as much energy as possible for tractive effort.

Battery Capacity.

Where no severe gradients exist, an approximation of the battery required can be estimated from the formula:

Watt hours $=$ 3 $\times$ Total Tractive Effort $\times$ Distance in Miles.

In obtaining the total tractive effort, consideration must be given to gradients and the effort required to move the locomotive itself. The duty should be divided into sections such as:—

(1) Locomotive hauling loaded wagons on the level.
(2) Locomotive hauling loaded wagons up gradient.
(3) Locomotive hauling empty wagons down gradient.
(4) Locomotive hauling empty wagons on the level.
(5) Waiting time.

and the watt hours for each item totalled.

Fig. 7.—Battery Locomotive at work underground in London.

It is usual to allow 20% to 25% extra for shunting or marshalling of wagons and for starting load.

Unless charging plant is already in existence, the number of cells in the battery is not of prime importance to the user. For a given motor, the speed is roughly proportional to the applied voltage. Thus, on a typical locomotive the speed is 3 miles per hour when exerting 400 lbs. drawbar pull, this being the 1 hour rating of the motor for a temperature rise of 60 degs. C., and when fitted with a 40 volt battery.

The same locomotive, if fitted with a 60 volt battery, would have a speed of 5 miles per hour. For reasons of mechanical strength, the insulation of the motor windings is made ample for this extra pressure and, since the drawbar pull is directly proportional to the motor torque, the amperes and heat rating remain about the same. Two points, however, require due consideration : Should the motor become stalled, the resulting current will, of course, be higher for the 60 volt than the 40 volt machine: the voltage should not be increased to a point at which the armature revolutions per minute will reach a dangerous point when the locomotive is travelling light. For any particular drawbar pull, the torque at the motor is dependent upon the wheel diameter and gear ratio, and the torque is proportional to the current.

When the work to be done follows a regular cycle, such as is given above, the root-mean-square value of the various amperes multiplied by time in minutes for each section, with an allowance for waiting time at the end of each trip, will give the continuous rating of the motor or motors required.

Whilst this h.p. rating is of value to the designer, it gives little or no indication of the normal h.p. required by the user for any particular duty. It is now customary to specify the 1 hour motor rating for a temperature rise of 60 degs. C., and to supply motors capable of developing twice the maximum torque required for the heaviest duty on the work under consideration for five to ten minutes. This permits the locomotive to maintain a good speed acceleration on the heaviest grades, and to deal with exceptional overloads for short periods.

Drive.

For locomotives up to one ton weight, chain drives have been used with apparent success. The ease with which chain and sprocket wheels can be replaced when worn, would appear to be an advantage where the maintenance staff is small. In actual fact, however, chain drive locomotives have never been popular, although low in first cost. Double reduction spur gearing, one motor driving both axles, has shewn remarkably good performance, even without the gears being totally enclosed and running in an oil bath, and with the whole of the locomotive weight unsprung. The enclosing of the gears often presents a difficulty on narrow gauges, with resulting rapid wear of the teeth, and loss of efficiency due to increased friction as the bearings wear and the gear centres separate. The use of the worm drive has now become almost standard practice in this country, and for this method, the following advantages are claimed :—

(1) Drive may be totally enclosed in oil bath.
(2) Sprung frame and motor.
(3) Increased ground clearance.

Speed and drawbar pull may be obtained by various gear ratios, using standard worm case, etc., permitting a fair amount of standardisation, and for reasons which may not be so apparent, the worm drive facilitates the design with regard to battery layout and locomotive weight.

Comparing a worm drive with a spur gear drive, after each has had a similar period of use and wear, it is not unlikely that the worm gear drive will be found to be the less worn. Operating experience, however, has not borne out that there is any marked difference between the efficiency of the two drives and, in consequence, the author is not prepared to commit himself on the question of relative efficiencies of the worm and spur gear drives.

The advantages incidental to the using of the worm drive do, however, justify its adoption in most cases, even if the efficiencies are equal.

In the locomotive under consideration one motor drives each axle. The motor windings are specially impregnated to withstand the effects of oil and moisture. The worm case and motor are rigidly coupled : the drive is through totally enclosed worm gears running in a large oil bath : the worm is of hardened steel, and the worm wheel is of phosphor bronze alloy, mounted on steel flanges. Four taper roller bearings of the high angle type support the worm shaft.

The motor cradle is of special interest ; it is supported on four springs, which carry practically the whole weight of the motor, reducing unsprung weight to a minimum, and so arranged that the movement of the locomotive superstructure on the axle springs produces the least possible displacement of the motor. Four springs mounted above the cradle absorb any shock at starting : this arrangement reduces the stresses in the motor coupling to a minimum. For smaller locomotives, only one motor is used, the two worm sets in that case being connected by a hollow cardan shaft with universal flexible discs at both ends.

Frame.

Variation in gauge, limiting height and width, weight and individual service, impose conditions which make a wide difference in details of construction and equipment essential, but the distinctive features of leading British locomotives may be described as follows.

The frame is of steel plate, securely stayed with stout centre plate and longitudinal channel members. The outside frame construction was decided upon as affording the greatest possible reliability and freedom from accidental damage to vital parts on the locomotive. Although this is not necessarily the cheapest form of construction the advantages fully justify the extra cost involved. There is no danger of the workers' clothes being caught by the wheels or axle nuts when operating in narrow tunnels and, at the same time, the mechanism, wheels, brakes, etc., are protected from falling stones, and so on. The massive steel end-plates are extended to within 2 inches of the rails, so that any track obstruction which is small enough to pass below them, cannot damage the driving mechanism. In the event of a derailment these low ends also offer a ready means of lifting the locomotive with pinch bars without having to resort to ramps or special jacks.

It is noteworthy that since the introduction of sprung axle boxes, the majority of locomotives have also been fitted with spring buffers, of which a special and very effective type is shewn in Fig. . The towing link and pin are fitted in the curved steel buffer plates, which is spring loaded whether the locomotive is pushing or pulling. Central buffers have been found to be the most satisfactory type for tracks with small radius curves and are generally accepted as standard equipment.

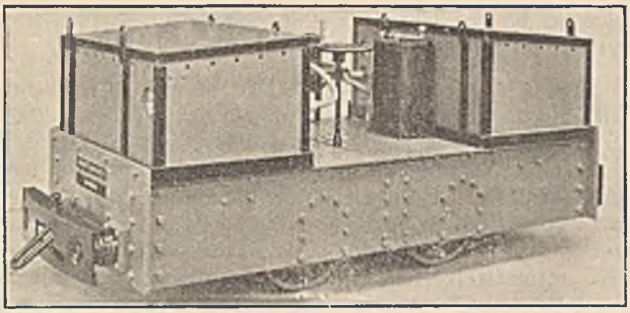

Fig. 8.—Locomotive with Two Motors: Worm Drive to each Axle.

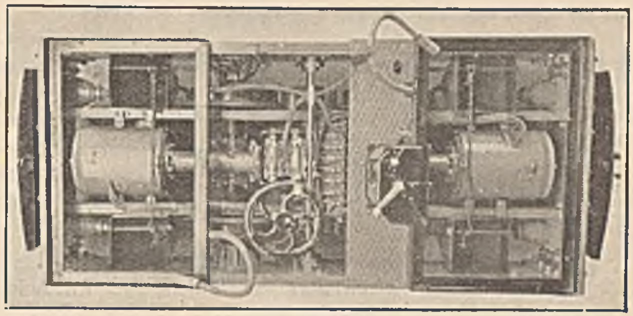

Fig. 9.—Locomotive Chassis: Batteries removed, shewing Double Worm Drive.

Axles.

The axles are of heat treated 3% nickel steel, carried on two taper roller bearings at each end, which take care of the heavy side thrusts due to small radius curves and turnouts. The chassis is supported on rectangular section, dual coil springs, the axle boxes working in machined cast steel horn guides secured to the main frame with fitted bolts.

Wheels.

Toughened cast steel wheels are used, they are keyed on to tapered axles and secured with large nuts, provision being made for easy withdrawal in case of need.

Control.

When the headroom in the tunnel exceeds 5 ft. 6 ins., it is usual to seat the driver on the locomotive deck-plate above the driving mechanism, the driver facing sideways, with the brakewheel, the controller, light switches, and ampere-hour meter, main switches or fuses, if fitted, conveniently placed so that he has full control, and may drive both forward and reverse without moving from his seat. The elevated position allows a clear view of the track in front and over the frame at the back. If headroom is limited, the control position is a small well at the end of the locomotive. Such machines will pass through a 3 ft. 6 ins. high tunnel with the driver seated.

Controller.

Revolving drum type electric controllers have generally been accepted as standard equipment, giving three speeds in each direction, by series parallel control of the fields for single-motor locomotives. Five speeds in each direction are provided on two-motor machines. Full series-parallel control with separate reversing drum mechanically interlocked with main drum is the rule. The main drum is usually made up of cast iron segments secured to an insulated square steel shaft. Finger and drum contacts are of heavy high conductivity hard drawn copper, all readily removable for replacement. Definite notches are provided for each speed. The whole is enclosed in a substantial weatherproof cast iron box fitted with removable inspection cover.

Batteries.

The type of batteries available for use on locomotives are well known to members of the Association, and their respective merits have been fully discussed on previous occasions.

Many devices are available for speeding up the operations of battery changing where the locomotive is required for continuous 24 hours' service. Probably the most widely used is to mount the battery in a steel container with a lift-off lid and a quick release plug and socket on the outside of the box. This container rests in a shallow steel tray and is fitted with lifting straps for removal as described earlier in the paper.

Battery Charging.

Electric power is now generally available at all large undertakings, either generated on the premises, or bought at a fairly low rate per unit from a public supply. Whether the batteries are charged above or below the ground, is a matter governed entirely by local conditions, the staff and space available, and the disposition of other electrical apparatus about the site. To charge a lead battery, the supply should be variable, from 2.3 to 2.7 volts per cell; and, for a nickel iron battery, from 1.4 to 1.85 volts per cell, supplied by a shunt wound generator with shunt field regulation.

For charging a number of batteries in parallel the higher voltage mentioned above is required with variable series resistances for regulating the current to each individual battery. Motor generators and multiple charging panels are available with full or semi-automatic control features for varying the charging current from the starting to the finishing rate, and to shut down the complete equipment when all batteries are charged, and fitted with the usual reverse current cut-in and cut-out switch and no-volt release coils.

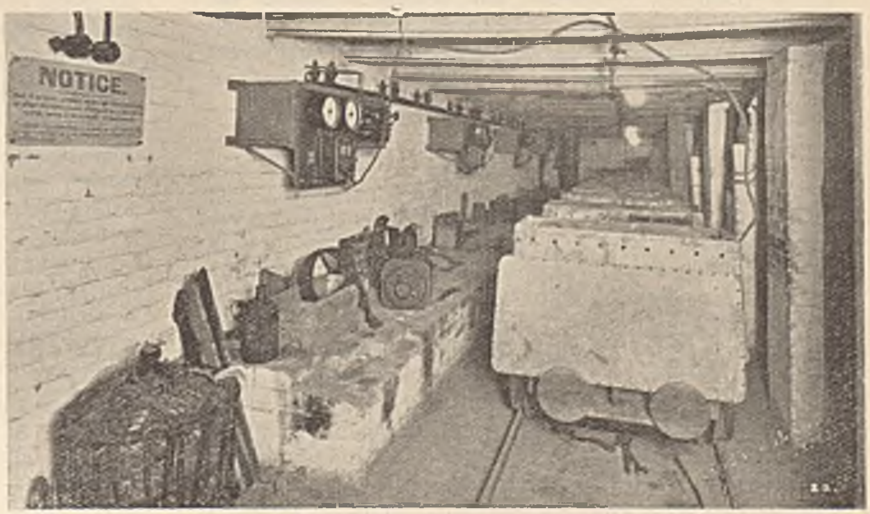

Fig. 10.—Underground Charging Plant at Ebbw Vale.

CONCLUSION

Underground electric traction has been widely used in the mines of the United States of America for many years, a trolley type locomotive being used in a coal mine as early as 1887. More recently the storage battery locomotive has become increasingly popular due, no doubt, to its greater safety as compared with other forms of haulage.

In May, 1928, the United States Bureau of Mines Department issued a circular of which the following extracts may be of interest.

The Bureau of Mines from the first has looked upon the permissible type of storage battery locomotive with favour because of its inherent safety advantages. That its energy is self contained and limited to the immediate zone of the locomotive is a factor of safety of great importance.

A storage battery locomotive does not depend upon a trailing cable, a fact again very much in favour, although trailing cables have been allowed in permissible equipment, they are a constant source of worry and are the weakest link in the Bureau's approval system.

The permissible type storage battery locomotive can operate in any part of a mine with the same factor of safety, and at night or any time when not in operation, it can be brought to a point of absolute safety. In summing up the situation, certain facts can be enumerated.

(1) Early types of storage battery locomotives were crude in design and not too satisfactory in operation. Also, no attempts were made to make them safe.

(2) Such open type equipment is still unsafe for use in gassy mines.

(5) The permissible storage battery locomotive offers a high order of safety and it has certain inherent advantages not common with any other type of equipment.

(6) The Bureau of Mines strongly advocates the use of permissible storage battery locomotives for use in gassy mines.

In this country, lack of capital during recent years has no doubt hindered the development of locomotives for use in coal mines, but it is hoped that with improved conditions now believed to be imminent, we shall see the storage battery locomotive more generally employed.

The battery locomotive has definitely passed the experimental stage as is evidenced by the new and repeat orders placed each year with British manufacturers for industrial purposes and for use in tunnelling and certain mines other than coal mines.

Discussion.

Mr. G. M. HARVEY (Past President of the Association) asked what were the definite advantages in favour of either the lead acid or the alkaline battery, from the points of view of efficiency of working and of the emission of fumes during operation. He asked if the hydrogen emitted by lead acid batteries during working was found to have any injurious effects upon the drivers of battery locomotives in tunnels. Finally, he asked whether any advantages were to be derived by arranging the motor across the frame rather than longitudinally, or *vice versa*; whether the running of the locomotive was affected, or whether the springing could be arranged more conveniently. One of the problems that might have to be considered in this connection was that of gyroscopic action.

Mr. H. M. MORGANS (Past Branch President), referring to a statement that certain battery locomotives were running a distance of 20 miles per charge, said he assumed that the locomotives were hauling full tubs for 10 miles, and empties for 10 miles. With regard to the figures shewing the relative costs of horse, petrol, and battery locomotion for certain work—£657, £442, and £236 respectively—he asked if those figures represented the total annual costs in each case.

Discussing tracks on which the locomotives had to work, doubtless various gauges could be used, but he asked what was the minimum weight of rail that should be used for battery locomotive tracks. In his opinion the tracks used underground in this country would in future have to be heavier and better constructed than those often seen now. It had been the policy to use light tubs in order to ensure that when they ran off the rails the men could rerail them, but he would prefer to use bigger tubs and to have the track constructed so well that tubs did not run off the rails.

Mr. J. W. GIBSON (President of the Association), referring to the costs of battery locomotive transport, said that the figure of 3s. 5d. per shift, representing the proportion of annual charges to be borne by each locomotive was a low one. There was no doubt that quite a large number of small locomotives, of both the petrol and the electric type, were coming into use industrially. He had noticed that the Fife Coal Company were experimenting with the use of electric locomotives underground and he believed they were using the lead acid batteries.

In asking for information concerning the life of batteries, Mr. Gibson said he understood that the nickel iron battery was assumed to have a life of three years, and he imagined that the life of the lead acid battery would be much shorter, judging by the comparative strength of the two types of battery.

Discussing construction and types of electric locomotives, Mr. Gibson recalled that when in America some four years ago he had seen in use underground some electric locomotives having a total height only 2 ft. above high rail level. In another American mine, which was non-gaseous, a trolley wire was used for current supply to locomotives; these locomotives were very much larger than the others to which he had referred.

Finally, he asked if series wound machines were used for electric motors, and whether automatic cut-outs were provided against damage to batteries due to the stalling of a locomotive.

Capt. A. C. SPARKS, Branch President, commenting upon a statement in the paper that on a typical locomotive the speed was 3 miles per hour when exerting 400 lbs. drawbar pull, this being the 1 hour rating of the motor for a temperature rise of 60 degs. C., and when fitted with a 40 volt battery, said that a temperature rise of 60 degs. C., was rather more than one usually worked to. He suggested that unless some special impregnation was used there might be trouble with the windings.

Discussing the emission of inflammable gases from batteries, he asked what steps were taken in America to deal with that matter, because several types were used in that country and the problems to be faced in the mines there were similar to those in this country: if the Americans were satisfied, it seemed that there was not very much reason to be scared as to the possibilities arising from the use of electric battery locomotives in British mines.

He also asked for information as to the comparative tractive efforts of the nickel iron and the lead acid batteries, and the comparative weights of them.

Another matter on which he asked for information was that of the comparative efficiencies of battery locomotive traction and haulage by stationary winding engines and ropes ; it was true that the battery locomotives referred to in the paper were small, but they were fairly heavy, and a certain amount of tractive effort was necessary for moving the locomotives themselves. In this connection he recalled that in one instance within his experience some steam locomotives which had been used on an out-door track had given trouble continually due to wheel slip when the track became wet, and for this reason the locomotives had been scrapped in favour of haulage by stationary engines. The results obtained with the stationary engine haulage were better than with the locomotives. If battery locomotives had been used, the same difficulties would have been experienced as with the steam locomotives, so that apparently battery locomotives could not replace other forms of traction under all circumstances.

Mr. G. M. HARVEY emphasised the advantage of using locomotives in place of rope haulage from the point of view of preventing accidents. All mining engineers, he said, should welcome any system of haulage underground which would enable them to reduce the number of haulage accidents that occurred. Many such accidents are due to the use of the old rope haulage system, where the rope is controlled by an operator situated at a distance from the point at which an accident occurs. When locomotives are used, on the other hand, the operator is on the spot all the time, and can take the necessary action at once in the event of a man being trapped between the tubs.

Col. OZANNE, who in the absence of the author had read the paper at the meeting, replying to the discussion, said it was difficult to answer all the questions which had been put as to the respective merits of lead acid and alkaline batteries, but the alkaline battery undoubtedly had a longer life than the lead acid battery. The alkaline battery was guaranteed for ten years; the lead acid battery was guaranteed for only three years. Probably, however, the lead acid battery had a certain advantage on overloads, in that it would not heat up quite so rapidly as the alkaline battery where steep gradients were encountered.

Dealing with Mr. Harvey's question as to whether it was better to place the motor across the vehicle or with its axis longitudinal, Col. Ozanne said he did not think its positioning made any appreciable difference so far as gyroscopic action was concerned, because the speed of the locomotives was only 5 miles per hour; at any rate, he had had no experience of difficulties in that respect. The positions of the motors had been decided in accordance with the design of the locomotives and the types of drives used. When using a worm drive, as in the later locomotives, very much in the same way as in a motor car, with what might be called a cardan shaft, it was more convenient to place the motor in the locomotive longitudinally rather than crosswise. In the earlier design, however, the motor was placed cross-wise, because, with the spur gear drive, that was the more convenient position.

Replying to Mr. Morgan's question as to whether the locomotive which had run 20 miles per charge had hauled full tubs for 10 miles and empty tubs for 10 miles, he said that in practically all cases in the classes of work for which locomotives were used they were shifting material in one direction only, and the wagons were nearly always returned empty. Sometimes the return journey was difficult and against the gradient and that made a good deal of difference, and sometimes they had to haul return supplies of concrete, iron sections, and so on.

With regard to tracks, naturally the better the rails that were used the better were the results obtained. For constructional work the rails were usually thrown down very hurriedly and probably were mounted on sleepers before-hand and hooked together when on the ground. In a mine one might probably put down that type of track to start with in order to get the locos. started and might possibly improve the track later. His Company had worked down to 18 lbs. rails and that was considered quite a good weight. The gauges used were from 18 ins. to the ordinary standard gauge and locos. could be made to suit any gauge between those limits.

Col. Ozanne agreed that it might be more convenient in some cases to use larger tubs than are used at present, but it seemed to him that in other cases it was quicker to fill a larger number of small tubs ; again, where sharp corners had to be negotiated the use of the small tub was an advantage. As one concerned with the manufacture of battery locomotives, however, he could not say exactly what were the advantages of the small and the large tub respectively, though he did not think there was very much difference ordinarily.

With regard to the figure of 3s. 5d. per shift mentioned by Mr. Gibson, Col. Ozanne pointed out that that represented only the standing charges and did not include the charges for the supply of current, and so on. It was merely the proportion of annual charges to be borne by each locomotive per shift ; other costs such as battery charging, drivers' wages, and so on, would have to be added.

He had not actually seen, but had heard of, those very small locomotives which were known in Canada as "trammers", but he had seen locomotives which would fold up. The driver's seat was at the back and the driver, when seated, could just see over the top of the loco. ; the whole of the back part was folded over the top of the loco. so that it could be placed in a lift. The dimensions of the loco. were very small indeed and, of course, it did not haul very much ; it might haul probably 4 or 5 tons, and he believed some of the very smallest were hauling loads as little as 2 tons.

With regard to the possibility of the motors stalling, he said that in most cases his firm provided a "dead man's handle" so that if an accident occurred or if the wheels became jammed the current was at once switched off. The device was applied either to foot or hand control, or to the seat. The motors were usually series wound.

Col. Ozanne was unable to reply to Capt. Sparks' question concerning temperature rise. The figures in the paper were not worked out by himself personally and he was not prepared to say exactly how they were arrived at. He was also unable to say whether the gases emitted from the lead acid and the alkaline battery were dangerous, or as to whether there was likely to be danger of explosion : he stated that the Sheffield University distinctly required that there should be no gas from the batteries, and presumably they were dubious about it; they seemed to be very shy of many things but he really did not know what their objection was in this case. Col. Ozanne said, however, that his Company had overcome any difficulties that might arise by enclosing the motor and the controller and any other part which might give rise to sparking. The batteries were usually disconnected at a place remote from any source of danger due to gas, so that any sparking which might occur at the time of disconnecting could not be dangerous. The batteries were only disconnected of course at the time of recharging.

Col. Ozanne said he had had no experience of rope haulage, but one obvious advantage of locomotive haulage over rope haulage was its flexibility, because the locomotive could be moved about. He imagined that the extension of a rope haulage system would occupy far more time than the throwing down of a track. Obviously, of course, the efficiency of a locomotive was governed by its weight and by the question of wheel slip. The small locomotives were not very heavy and, naturally, the wheels slipped fairly easily but, generally speaking, he believed the battery locomotive system was cheaper and more flexible than other systems of transport. There was also the advantage that in locomotive transport, of coure, where the man in control of a train was on the spot, he was in a better position to avoid accidents than was a man who was controlling a rope from a distance.

In a further, written, reply to the several queries, Mr. N. E. BAYLIFF says:—

The amount of hydrogen emitted by a lead acid cell when discharging under normal conditions is very small and has no apparent injurious effect upon the driver of the locomotive even when the locomotive is being constantly used in an air lock with the pressure at 18 to 22 lbs. above normal atmospheric pressure. Proof of this is afforded by the fact that British manufacturers have within the past few years supplied more than 400 storage battery locomotives for use underground.

Mr. Gibson was presumably referring to wide gauge locomotives as frequently used in American mines where headroom is restricted. Trolley locomotives have been used for some time in the American mines but they are now in the majority of cases being replaced by storage battery locomotives.

The B.E.S.A. specification for series d.c. traction motors allows a temperature rise of 75 degs. C. for armature and field windings for class A, and 95 degs. C. for class B insulating materials, measured by the thermometer, at the one-hour motor rating. For the continuous rating of a motor these figures are 65 degs. C. and 85 degs. C. respectively.

It is doubtful if the American practice relating to battery locomotives would be accepted in this country. The American locomotive manufacturers do not attempt to make the battery container flame-proof. On a well known American locomotive the battery box consists of steel sides and ends. The bottom is closed by wooden boards only, slotted to provide ventilation. The cover is in two sections, one of wood two inches thick next to the cells, and one of steel sheet overlaying the wood cover, the wood preventing any possibility of short circuiting the battery in case of a heavy fall of roof on to the battery box cover. These wood covers are notched out along the outer ends to provide ventilation openings at the tops. These notches are such that all terminals can be reached with difficulty, if at all through the openings. Locking bars and padlocks are fitted to prevent unaufhorised removal of the covers.

Nickel iron batteries are lighter in weight than lead batteries of the same watt-hour capacity, the difference varying from 15% to 30% according to the type and manufacture. The normal tractive effort of the locomotive is of course the same for either type of battery, the maximum effort available is, however, dependent on the total weight of locomotive and battery.

NORTH WESTERN BRANCH.

The Switchgear Problem and the Colliery Engineer.

Capt. I. MACKINTOSH.

(*Continued from page* 280.)

Direct or Remote Control?

Up to and including circuit breakers of 250,000 k.v.a. rupturing capacity, direct hand operation of the breaker is quite easy so long as currents are not too heavy, say up to 2000 amps. Beyond that limit, electrical operation becomes necessary in order to close the circuit breaker quickly, particularly when synchronising has to be carried out. Even on circuit breakers within the limit of hand operation, it is often necessary to provide what is known as a synchronising position on the handle, making it possible to close the switch to a position from which, when synchronism is obtained, the remaining part of the operation can be quickly completed.

In electrically operated equipments all controls should be brought to a simple control board of the desk or upright type, accommodated preferably in a room apart from the engine room. This arrangement ensures that the operator is away from noise and other distractions which might tend to upset the nerves when they require to be at their best, as when some emergency switching operation has to be carried out quickly and calmly. The upright type of control board is undoubtedly the better, as indicating instruments can more easily be seen at a distance than when they are in a sloping position on a desk panel.

When the installation consists of more than two generators, with a number of feeders and perhaps interconnectors with other plant, it is an advantage to include on the upper portion of the control board a key diagram of the connections of the system, with electro-magnetic indicators or lamps in the run of the diagram to represent oil circuit breakers and isolating devices. Such an arrangement will add appreciably to the cost, as pilot cables must be run between the switchgear and the panel, but the expense is justifiable if the system has any complications, as it gives the operator an immediate indication of the position of the control gear.

Considerable attention should be paid to the layout of control boards, as the concentration of numerous meters, relays, etc., can easily cause the operators endless trouble, particularly during emergency operation. If a large number of such details are used, it is much better to have separate meter and relay panels, so that all the circuit control apparatus is grouped together in a clear and orderly manner.

SELECTION OF SWITCHGEAR.

Having paid some attention to the types of switchgear available, it may be wise to review some of the conditions which in practice may be the deciding factor as to which type will be used.

(a) *Capital Available.*

It often happens that the deciding factor as to the gear ultimately chosen is the cost. From time to time the author has wished to instal a certain type of switchgear which, in his opinion, was the best for the particular conditions, but the clients had insufficient money available for the job. Thus, it was necessary to purchase a cheaper type of switch, and although it was not the most suitable type, it had to be capable of standing up to the conditions under which it had to operate. It is the old story, so often met with in colliery work these days, of having to cut one's coat according to the yardage of cloth. It is often the case that the money available will probably to a large extent govern the type of switchgear which will be installed, and it is a factor over which the engineer usually has little or no control.

The cost of switchgear should, however, always be considered in respect to safety. The switchgear has to control and protect much valuable plant, and should be adequate for the work it has to do. If the installation must be "skimped", it is surely better that it should be skimped in other details, rather than on the switchgear, which has the onerous duty of protecting the whole of the plant.

As an analogy may be taken the case of the battleship, with its valuable machinery and guns, to say nothing of the man-power on board. Unless the armour plating is beyond doubt the very best, it would be madness to take the ship into an engagement. The armour plating is the indispensable protection for the valuable lives and plant on board. The provision of the best switchgear is similarly essential for the good ship colliery plant.

(b) *Space Available.*

It often happens, particularly in the case of substations, that the engineer is given an old building, which he has to convert with the least possible capital outlay into an up-to-date substation. In this case, the deciding factor may be the amount of space taken up by a particular type of switchgear. This question of available accommodation is closely allied with the first factor, as it is obvious that if the money were forthcominig a new building would be erected.

PROTECTIVE GEAR.

So many forms of protective gear are available for different purposes that it is impossible to touch upon them all in a paper of this length. It is therefore proposed to outline briefly only the more usual forms applied to various circuits, and merely to comment on these.

Generator Equipments.

The form of protection applied to generators should be such that unless a fault is so sufficiently prolonged as to endanger the machine, the breaker controlling the faulty feeder should open, and not the generator breaker even though the machine be overloaded. When only one generator is installed it is sometimes thought sufficient to fit overload protection only. This, however, is not very satisfactory and it is better practice to instal a somewhat more discriminating form of protection if only to ensure the safety of the costly generator. Overload protection only is not sufficient for systems with two or more generators running in parallel, as the breaker of the more heavily loaded machine opens first and the overload is then imposed on the remainder whose breakers will probably trip in turn and result in a complete shut down.

For nearly all cases, therefore, some form of circulating current protection is desirable in conjunction with a field suppression device. The usual form is the Merz Price, although there are others such as the McColl self-balance, etc. In addition, it may be necessary to instal reverse power protection, but a difficulty with this is the unreliability of the relay when the voltage falls below 10% of normal : a condition often experienced when a short circuit occurs close to the busbars.

Feeder Equipments.

Overload and leakage protection generally suffice on feeder circuits, care being taken to ensure that on main cables supplying branch feeders discrimination is possible between branch and main breakers. This is a similar problem to that discussed under "generator equipments", and the general solution is the use of inverse time limit relays with definite minimum characteristics, so arranged that the branch breaker opens before the main breaker in the event of a fault on the branch feeder.

Transformer Equipments.

The circulating current system can be profitably employed in this case also, the only difficulty being that of tripping out during switching operations. This can nearly aways be overcome by the insertion of what are termed "kick" fuses connected across the relay coils. This form of protection is always arranged so that on the occurrence of a fault both the H.T. and L.T. breakers are opened, thus entirely disconnecting the thransformer. For many cases overload protection can be applied, reverse relays being fitted on the outgoing side when two or more transformers are in parallel.

Miscellaneous Circuits.

For the protection of such circuits as Shop Feeders, Haulages, Pumps, etc., overload protection should be sufficient, with leakage protection as an added refinement. In certain cases circuits require a low volt trip to be fitted, either for interlocking purposes, or where the attendant is not always present.

INSTRUMENTS.

It is not intended under this heading to discuss types or designs of instruments, but to indicate what should be installed on various circuits, so that correct and full particulars are available.

Generator Circuits.

The usual requirements are :—

Frequency Indicator.
K.W. Meter (Indicating)
Ammeter (Main).
Ammeter (Exciter)
Power Factor Indicator.
Voltmeter.
Integrating Wattmeter.

When there are two or more generators in parallel, it is essential to instal synchronising instruments, comprising a pair of voltmeters (one for the running, and one for the incoming, machine) and a synchroscope. This does away with the necessity of a voltmeter on each generator panel, as an indication of busbar voltage is always available on the synchronising voltmeters.

Feeder and Transformer Circuits.

The only instrument necessary on these circuits is an ammeter, although a watt-hour meter should be installed if it is desired to keep separate costs.

Miscellaneous Circuits.

Here again an ammeter usually suffices, the only addition occurring in the case of synchronous motors when it becomes necessary to add a power factor indicator, excitation ammeter and voltmeter. For isolated equipments it may be an advantage to include a main voltmeter to indicate the supply pressure. On motor circuits, care should be taken to see that ammeters are heavily damped and capable of dealing with the rush of current on starting. As a rule, a scale reading 33⅓% in excess of normal load is satisfactory.

INDIVIDUAL SWITCHGEAR.

Workshops.

The author is firmly convinced that for all colliery workshops the switchgear should be ironclad and totally encolsed. It may be of the air-break type with fuses, and if properly looked after this will give satisfactory service. Fuses, however, are always a potential cause of trouble and an oil-immersed circuit breaker with protective devices overcomes many worries experienced with air-break switches and fuses. This is particularly true in the case of overloads as only a short stoppage need occur before the breaker is reclosed, whereas the time taken to replace blown fuses is considerable, and spares are not always at hand.

Other advantages of the oil circuit breaker are :—

(a) It can be accurately calibrated and has a maximum setting.

(b) It is perfectly safe in action.

(c) It has interlocked blades, ensuring that a fault on one pole makes the whole circuit dead. It is possible with fuses for two phases of a three-phase system to remain alive.

(d) The operating coil does not age like a fuse and can if necessary be immersed in oil.

Screens.

Switchgear situated near screens should be of the totally enclosed ironclad type, and the features embodied in the self isolating type of switch are such that they appear to be eminently suitable for such situations. In and about a screening plant there is usually coal dust in suspension. This is the condition most likely to cause trouble, and it is presumably for this reason that interpretation of Regulation 127.V. is so stringent. Nevertheless, the author has not heard of an explosion of coal dust in a screening plant and sees no reason why flame-proof switchgear should be installed in such situations, though he is convinced that totally enclosed ironclad gear of robust construction should be installed.

Dry Cleaners.

The conditions in a dry cleaning plant are far worse than with screens, as a large amount of coal dust is in suspension in a more or less confined space. In such situations the author would most certainly advocate flame-proof switchgear or, perhaps better still, remote control with the push buttons at the control points of the cleaner, and the contactors operating in a separate room free from dust. This method has been installed in many cases with successful operating results and, although it entails extra wiring, etc., it is an excellent way of getting over the difficulty.

UNDERGROUND SWITCHGEAR.

Before dealing in particular with switchgear for use underground it might be of advantage to give a little attention to flame-proof switchgear in general. The flame-proof switch is a familiar piece of apparatus to members of the Association, and it is not necessary here to enter closely into details. It is suggested that the following features should be embodied in a flame-proof switch :—

(a) Self isolation.

(b) Renewable sparking tips.

(c) Trifurcating boxes. These should be of sufficient size to allow the Erector reasonable facilities for working. Provision should be made for fitting the box in various positions.

(d) Busbar chambers should be suitable for compound filling.

(e) Protection. Facilities should be made for fitting leakage protection, overloads with time lags and a low volt coil.

(f) Combined Board. The switch pillar should be suitable for becoming a unit of a flame-proof board.

(g) Potential transformers. Provision should be made for accommodating potential transformers, which should be adequately protected.

(h) Instruments. Suitable provision should be made for fitting the usual instruments.

(i) Interlocks. The switch should be suitable for incorporating an electrical interlocking device.

(j) General. The switch mechanism should be robust without delicate details. It should be impossible to withdraw or return the switch, with the breaker in the "on" position.

Other features of the switch have so much in common with the metal-clad units described earlier that there is no necessity for repetition.

The author would state that he sees no reason for making a fetish of flame-proof switchgear in every case of installation underground. So far as he can see, based on a fairly long and intimate connection with mining conditions, it is practically impossible to have gas in a substation situated at or near the bottom of a downcast shaft, therefore there is no need to instal flame-proof switchgear in such a position. On the other hand, if a number of flame-proof switches are installed in the pit, it might be worth while paying the extra money for the sake of standardisation. This is a question of economics, and like most colliery problems must be considered on its merits ; but the author would emphasise that flame-proof switchgear is installed in many cases where there is no real need for its use. It is practically impossible to lay down any hard and fast rule.

It is essential to ascertain the conditions regarding the occurrence of inflammable gas before installing any electrical plant underground. Should the engineer have any doubts about the condition he should consult the manager, and obtain his official ruling on the point. If naked lights are used in the pit there is obviously no need for flame-proof apparatus. Taking the other extreme, if $1\frac{1}{4}$% of inflammable gas is normally present in the air no electrical apparatus may be used, as Section 60 of the Coal Mines Act prohibit the use of electricity in such circumstances.

Main Substation.

One of the first and most difficult problems met with is to obtain accurate information as to future developments, or better still, the ultimate development of the underground load, so that the main switchboard may be designed with sufficient reserve capacity. This aspect of the problem should have careful consideration.

Normally, the substation should be near the pit bottom, properly built of brick, with an even floor, and well ventilated and lighted. It should have two doors opening outwards to give more room in the substation.

A telephone should be installed in the main underground substation, for communicating with the surface.

Usually the switchgear will be feeder control switches, although there is a possibility of motor control switches being required as it is sometimes convenient to have the main board in a pump house situated near the pit bottom. When possible, however, the author prefers the main substation to be kept separate, in which case only the electrical staff have right of access.

There is no doubt that the most suitable switchgear for underground use is the unit type, with self isolating features. It is essential that the operating mechanism, etc., should be readily accessible, so that repairs and adjustments may be done quickly. An isolated failure may stop the work in a whole district of a pit, and the time involved in making the repair or adjustment must therefore be carefully considered.

In view of the importance attached to Reg. 131 (g) it would appear to be necessary in designing electrical schemes for collieries to give consideration to the method of discharging, and prevention of recharging, a conductor. This particularly applies to feeder switches.

Armour glands are also of importance since these are depended upon for reliable earthing. This is a convenient stage to mention that unless the manufacturer has exact information as to the type and dimensions of the cable, it will be difficult for him to provide an armour gland to fit the cable accurately.

Another point which has to be considered is the position of trifurcating boxes. Manufacturers provide boxes suitable for most positions, provided they are given the necessary information.

Metering and protective devices have been dealt with in a previous section of this paper.

Haulages.

Normally the switch controlling a haulage should be of the self isolating unit type. If the ammeter is fitted to the switch itself, care should be taken that the switch is in a suitable position for the driver to see the ammeter, as this instrument is his best guide to what is happening to his "journey" or train. The usual protective fittings would be overloads and time lags, and if electrical interlocks are required it will be necessary to fit a low volt coil. Leakage protection may be fitted as an added refinement, although the author does not consider this necessary on a motor control pillar.

Pumps.

The same type of switch might be used for pump motor control, with much the same fittings as for a haulage. In the case of a pump time lags should not be necessary, but a low volt coil is recommended in case the attendant wanders away while the pump is at work. If possible, the switch should be placed in a convenient position for the attendant to see the ammeter when starting up.

General.

In conclusion the author would say that he has paid most attention to power station or main substation switchgear, as he thought this would be of more general interest to the members. He would also indicate that the switchgear criticised has been taken as suitable for a three-phase a.c. supply, earthed neutral, as this is the type most generally in use for colliery work.

Discussion.

Mr. BOLTON SHAW said it was always somewhat difficult to open a discussion on a paper which had only been read to them, and he would be glad if the old practice of having galley proofs in advance could be resorted to. The Committee, he understood, were quite willing that advance copies should be supplied but the difficulty appeared to be that authors often were not able to finish their papers in time for that to be done.

With regard to low voltage releases, in his opinion the proper place for those was at the motor itself. It was not always desirable to have the supply cut off from the feeder when the voltage failed; the motor itself should be switched off so that the supply might be restored without the difficulty and delay which might occur if the motor and the switches were hanging on to the feeder when it was made alive again.

The author appeared to advocate a separate control room with control switchgear not necessarily of the desk type. No doubt that was the counsel of perfection which stations of large size generally adopted, but in the average colliery the question of expense generally prohibited anything of that kind being done. As Capt. Mackintosh had pointed out, it was desirable to have the gear compact and at hand, and usually there was not sufficient room to put down a control board as well as a main switch board.

That led to the subject of the best suitable position of the switchboard. Personally he, Mr. Bolton Shaw, could not agree that switchboards at collieries should be perched on galleries, because if they required to be supervised by an attendant it meant that he had to remain in the gallery and could not carry out any other duties. Even with a colliery plant of a moderate size it was as well that the man in charge of the switchboard should have something else to do than merely sit down most of his time and possibly fall asleep. It was a most uninteresting and heartbreaking sort of job for a man to have.

The position of instruments on the switchboard had been mentioned. Designers had a habit of placing the instruments so as to make a nice pattern on the board. From the operating point of view it was more a disadvantage than otherwise. Something ought to be done to distinguish one instrument from another. For instance if there was a volt meter and an ammeter on the same panel it was an advantage to have them of different sizes or shapes so that the operator could tell at a glance which instrument he was reading. Sometimes meters and indicators were placed in such a position that the dazzle from the lamps illuminating the switchboard made it impossible to read what was on the instruments; in other cases they were placed very high, or so low that one had to get near the floor in order to read the scales.

Capt. MACKINTOSH said he had referred to the use of low voltage trips for certain positions but did not think it necessary to have one for a haulage drive, unless for use with interlocks. When a man is there all the time he ought automatically to bring his operating gear back to the "off" position. It would add an extra to the cost and colliery companies object to paying these extras.

He agreed with Mr. Bolton Shaw that for the smaller colliery power stations it was not necessary to have a control room; but when considering installations like that of the Powell-Duffryn, or such as might be put down in this area should there be a complete merger of Lancashire collieries and which would involve the erection of a fairly big plant, it was the right thing to aim at and it was not a luxury.

With regard to the switchboard he agreed if one man had to act as attendant and engine driver it was very trying to have to run up and down steps.

Mr. A. M. BELL remarked that the author had so thoroughly covered a wide field of switchgear, that there were very little to discuss. He, Mr. Bell, was not in agreement with the use of no-volt coils on feeder switches, because a lowering of the system voltage may cause the feeder switch to come out unnecessarily.

While it was the best practice to provide metering equipment, Mr. Bell had never yet found the sum of the feeder meters equal to the sum of the generator meters; and, on a comparison, the sum of the feeder meters was sometimes greater than the total of the generator meters. When it was realised that on a Grade One instrument an error of $1\frac{1}{2}$% plus or minus was permissible it was quite possible to have a 3% error between the feeder meters and the generator meters, such errors were difficult to allocate sometimes.

Mr. Bell agreed with Mr. Bolton Shaw's remarks with reference to the no-volt coil. Only in one case would he suggest that no-volt coils should be entirely eliminated and that was on what he would call primary auxiliaries, e.g., motors driving condenser pumps, etc., in connection with generating plant. The use of a no-volt coil in motor starter equipments was very desirable.

Mr. Bell had hoped that Capt. Mackintosh would have said something about earthing devices, as they were all interested in this matter, and to comply with the Regulation with some of the switchgear in use was a difficult problem.

Whilst it was not frequently within the province of the average colliery electrician to have the practical handling of very high rupturing capacity switchgear, Mr. Bell said he would be glad if Capt. Mackintosh could give further particulars concerning the same.

Capt. MACKINTOSH agreed with Mr. Bell in that it is unnecessary to have a no-volt coil on a feeder system, and that it is difficult to make up costs if the meters are incorrect, as they generally are. He must say that Mr. Bell appeared to have a remarkably good costing system if he could persuade his collieries to pay for more than was actually generated at the central station. He and Mr. Bell also agreed that there was no need for a no-volt coil on the auxiliaries, because with low voltage there might be a short circuit which would reduce the voltage by 10% and the low voltage coil might operate. On the other hand if interlocks were desired it was necessary to fit no-volt coil.

The maximum rupturing capacity of switchgear was becoming quite a fetish with some people but that was not the manufacturers' fault. Personally, Capt. Mackintosh considered that for the average colliery switch a 25,000 k.v.a. rupturing capacity would meet all requirements, but for very big systems he would suggest the use of reactors.

Mr. CHALMERS said he agreed with Capt. Mackintosh that the ordinary industrial type of switchgear would meet the requirements of a screening plant. They had occasionally had ignitions of "flour" dust but he could not visualise a coal dust explosion on the screening plant, because it was difficult to initiate. It had to be raised in the form of a cloud before it could be ignited and in the pits the real cause of coal dust explosions was the local ignition of firedamp or a blown out shot. In both those instances there was the simultaneous raising of the dust and the creation of the heat necessary to ignite the dust. He could not imagine such a cloud getting within the industrial type of switchgear that might be employed on a screening plant instead of the flame-proof type.

He disagreed with the author when he advocated the use of the industrial type at the bottom of the downcast shaft of pits to which Regulation 132 applied. That was only courting disaster. It was not only from the point of view that pits might be so gassy or so badly ventilated as to permit gas to accumulate at the bottom of the shaft. They all knew that if they gave some people an inch they would take a mile and there were some mining men who, if they saw a sparking inside would say— "There is sparking taking place, we can have a smoke", or some electrical engineer might say— "If the ordinary industrial type of switchgear can be used here I will take my pipe next time".

Capt. MACKINTOSH replied that he adhered to the opinion that at the bottom of the downcast shaft there should not be enough gas to bring the place under Regulation 132. As to Mr. Chalmers' suggestions relative to the taking down of a pipe and matches, and that if a man be given an inch he would take a mile, the discipline in modern mines would not permit of those things being done. Capt. Mackintosh was against providing expensive flame-proof gear when something not so costly would serve. The term "industrial type" was used as meaning the totally enclosed metal clad switch but not necessarily flame-proof.

Mr. S. J. ROSEBLADE remarked that the author had stated it was always advisable to arrange for compound filling. Was this necessary, say, in a flame-proof busbar chamber? This chamber was usually fitted with insulated bushes between the incoming trifurcating box and the chamber and also between the various outgoing circuits and the chamber, thus isolating the chamber from from all outgoing and incoming circuits; no ignition could possibly take place there. Was it therefore necessary to arrange for compound filling in a case like this?

Capt. MACKINTOSH.—The Coal Mines Act says it is not permissible to use compound to ensure a flameproof condition. It is not from that point of view that compound filling is used, but that it will act as an insulator and enables a reduction in the size of the gear. One colliery engineer put the case in this way: he liked the compound filling because if a heavy stone fell on the switchgear it might crack the casing but the compound would still keep everything flame-proof.

Mr. ROSEBLADE referred to cellular switchgear and said that, though he had not come across it himself, he assumed it could not be used underground because it could not be made flame-proof in any shape or form. Was the concrete likely to absorb moisture and how did this type compare in cost with the ordinary dry type or steel cubicle?

Capt. MACKINTOSH said he did not think there had been trouble with moisture in the use of cellular gear: it was obviously a power station type and not suitable for underground work.

Mr. R. F. BULL (Branch President) said he wished the author had given them more information about the earthing of feeders from main switch and distributing boards and to motor main switches. Reference was made in the paper to a switchboard in a power station with a diagram of connections arranged on the top of the board. That was an excellent idea; if there could also be a diagram of connections of the pit feeders distributing boards, motors, etc. it would be a great help to the men in the power station to show what plant was running below ground.

With regard to the use of flame-proof gear in screens it was well-known that coal dust was easily ignited. This could be demonstrated by putting a candle on the flood and pouring a little dust down a tube 6 inches in diameter and 7 or 8 ft. long on to the flame of the candle. Switchgear in screens should certainly be dust tight, and it was not usual to find the industrial type of switchgear and distributing boards to answer this purpose.

Referring to the immersion of potential transformers in the bottom of oil switch tanks he would like to ask the author if this had proved to be satisfactory.

He agreed with previous speakers that no-volt coils should not be put on main feeders or on feeders supplying auxiliary machinery, such as condensing plant motors.

Regarding the use of industrial type switchgear at the pit bottom the same remarks would apply as for screens. One had also to consider that there was the possibility of a reversal of the ventilation and a stoppage of the fan, when gas might be present at the bottom of the downcast shaft. It was a great advantage to have standardised flame-proof switches throughout.

Capt. MACKINTOSH agreed it would be very useful if one could arrange a live diagram of connections for underground operations, but it would mean a very big diagram and one difficult to read. Flame-proof gear on the screens would, of course, serve well but they would be comparatively costly, the industrial type would be cheaper and it was largely a matter of economics. Oil-immersed potential transformers had been working quite satisfactorily for many years.

WEST OF SCOTLAND BRANCH.

(P) Rotary Converters.

ROBERT WILSON.

(*Continued from page* 269.)

INVERTED OPERATION.

As mentioned in the introduction, the rotary converter, besides converting a.c. to d.c., may be used also to convert d.c. to a.c., but unless the machine is designed for inverted operation (as part of its regular duty), the ordinary straight run from a.c. d.c. machine is not at all suitable, unless the full a.c. load required is very small in comparison with the k.w. capacity of the machine itself, for the following reasons:—

(1) The interpole field of the straight run machine has only sufficient turns to compensate for the a.c. and d.c. reactions, and would require correcting.

(2) Some means are required to control the a.c. pressure.

(3) A converter running from the a.c. mains can only have one speed (i.e. synchronous speed).

Running from the d.c. side, the machine compares with the ordinary d.c. motor; thus, by varying the resistance of the shunt field the speed can be increased or decreased accordingly. A lagging load has a direct tendency to de-magnetise the field: a leading load, *vice versa*. Obviously, any change in the power factor would cause a change in speed which directly affects the frequency. Increasing the frequency may increase the lag.

As the a.c. load would be (most likely) a lagging one, such as running a turbine pump, during the week-end, it is the practice to fit all rotaries, intended for dual operation, with a special exciter to control the shunt field, so that any change in speed is directly felt on the exciter. The exciter, normally has a very weak and unsaturated field. The brushes are kept slightly behind the neutral position, and should never be advanced on this machine. Should the rotary speed tend to rise when a lagging load is thrown on it, a small increase in the exciter speed will give a large increase in its voltage; with something like a 10% increase in speed, there would be a 30% rise in the exciter voltage.

With a rotary intended for dual operation, the exciter would be mounted on the bedplate, in line with the rotary, and used to excite the field when running either a.c./d.c. or d.c./a.c. The rotary could be run normally a.c./d.c. self-exciting and the exciter turned on to the field when used d.c./a.c., usually direct connected without any regulator.

Again, the exciter could be a separate equipment, such as a motor generator started up and switched in as and when required.

Never try to run an ordinary straight-run rotary inverted, even although it can be started from the d.c. side. The machine, on dropping even a small load, speeds up, loses its field, and there is a flash-over on the brushes.

With a straight-run rotary having reactance embodied in the transformer windings (say up to 20%), if the machine has to run d.c./a.c. with a lagging load passing through the transformer, the drop in volts will depend on the value of the power factor. The total drop from no load to full load, may be anything up to 20%. Thus a reactance controlled rotary would anly aggravate the case and to compensate for this drop, an induction regulator would probably be found the most suitable.

With rotary equipments installed for dual operation, there would be provided on the a.c. side, instruments a reversing switch for the current coil of the power factor indicator, also (if wattmeters are to read both ways) a reversing switch will be required. On the d.c. panel there should be a reversing switch for the series field, and a central zero ammeter.

SPEED LIMITING DEVICE.

This arrangement, which is connected in series with the hold-on coil attached to the d.c. circuit breaker, is fitted to all rotaries, whether run a.c./d.c. or d.c./a.c. When running inverted, even with a special exciter, if a sudden heavy load were thrown on, a dangerous rise in speed might occur.

Running normally a.c./d.c. with only one machine installed, there would be no means of testing this device. An actual case is as follows: The old steam plant was still standing by and one set was run up to speed and parallelled with the rotary and the load taken over, leaving the rotary running idle but still connected to both the a.c. and the d.c. sides. The high tension a.c. switch was then drawn, leaving the rotary running from off the d.c. busbars. The speed immediately dropped. By adjusting the rotary shunt field regulator by hand and gradually increasing its resistance, the speed at once rose until the device acted, knocking out the d.c. circuit breaker. Normal speed 1000 revs., 6-pole, 50 cycles: device operated at 1130 revs. The device requires to be reset by hand.

DRY OUT A ROTARY CONVERTER.

If the insulation test after installing, connecting up, and getting all ready to run, should be of low value, and moisture is suspected, one method of drying-out that can be resorted to (provided an alternator set can be run for a period for the rotary only) is: (1) Lift the brushes from off the commutator. (2) Close the field switch and short circuit the series winding. (3) Close the switch between the sliprings and the transformer—full volts position. (4) Gradually bring up the line pressure from zero to 10% of full voltage.

Watch the ammeter to see that not more than 50% of full load current is allowed to pass. The armature being stationary, see that there is good spring pressure on the slipring brushes. Observe that the temperature of the armature winding does not exceed 70 deg. centigrade. Even if one did not know the exact phase rotation or direction of rotation of the armature, this method of drying can do no harm.

STARTING THE CONVERTER.

Tap Starting (*Fig.* 3).

A tap start rotary with reactance control forms the least expensive method of converting a.c. to d.c. It also has the advantage of quick starting and self-synchronising. On the other hand, it has the disadvantage that at the moment of starting, the current rush may be anything up to three times the full load current; also, at the starting period, large circulating currents are set up in the armature and these cause severe sparking at the d.c. brushes. This sparking is not looked on as being dangerous with the older shunt machines, but it is not permissible with interpole designs. Devices to raise the brushes from off the commutator, during the starting period, have not proved desirable additions to a converter. The limit of capacity to which this type of starting may be used is about 500 k.w., although a great deal depends on whether one is paying per k.v.a. demand to a Public Supply Company or using one's own power.

As the name suggests, the machine is started by switching the sliprings across reduced voltage tappings on its own transformer and the machine starts in the manner of an ordinary squirrel cage motor. The damping winding that is generally provided in the pole face of all rotaries forms a secondary or squirrell cage winding of the motor: the armature being the primary.

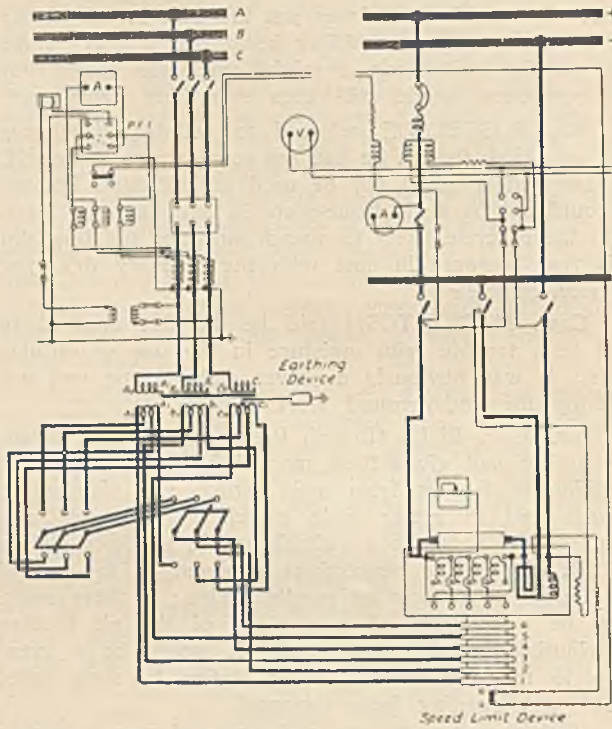

Fig. 3.—*A.C. Tap Starting, Six-phase : D.C. side Compound Wound, Two-wire.*

With a switch provided for changing on to various tappings, the pressure across the sliprings is gradually increased, the machine rapidly runs up to speed and automatically synchronises.

It is good practice to bring out several tappings from the transformer and, by trial, find which one suits best, then using a starting switch with two positions only, namely tappings and full voltage.

STARTING A MACHINE FOR THE FIRST TIME.

The general procedure of starting a rotary converter is as follows: See that all switches are open, including the field splitting switch. If the field switch were left in during starting, the field coils would act as a secondary winding and, since the number of field turns is very much in excess of the number of armature turns, very high voltages may be induced in the fields, and this may break down the insulation to earth.

(1) Close the high pressure switch.

(2) Close the low pressure switch on the first tapping.

The machine should now run up to synchronism. If the direction of rotation is wrong, shut the machine down and reverse two of the high tension phases.

(3) The direction of rotation being correct, close the field splitting switch and note whether the converter has come up with correct or incorrect polarity. If incorrect, turn the reversing field switch on the bottom contacts and watch the voltmeter needle until it has passed over the zero line; then change back the field reversing switch.

(4) The polarity being found correct, change the low pressure switch on to the second tapping; pause a moment and close on to the third or full voltage tapping. The machine is then ready for closing on to the d.c. side.

Precautions.

Should it be necessary to shut the machine down again, do not draw open the high tension switch if the machine has been so far started that it is running on any of the tappings with the field switch closed: by doing so, the converter may build up full voltage with a resulting high voltage on the high pressure side of the transformer.

If the d.c. circuit breaker should trip out when running on load, test the polarity before closing again; it has been known where d.c. panels for rotary sets have been fitted, ordinary moving iron voltmeters, which will give the same directional reading for either polarity. If there is no field splitting switch provided on the starting panel and it is found on starting up that the polarity is incorrect, there is nothing else to do but shut the machine down, wait a few moments and try again.

On six pole, 50 cycle rotaries there is a tendency at the time of starting, if the machine be fitted with interpoles, for the interpoles to behave as main poles and cause the rotary to run up to half speed drawing a heavy lagging current. To prevent this occurrence, there is provided a knife switch to short circuit the interpole winding during starting up. After closing down, see that this switch is closed, ready for the next start.

Induction Motor Starting.
Synchronising on Low Tension Side (Fig. 4).

With this method, the starting current demand is very much lower, amounting to about one-third of the full load value, but it has the disadvantage that the rotary has to be synchronised with the line. A squirrel cage induction motor varying in h.p. from 40 to 100, of the half-hour rating type, having two poles less than the rotary itself, is mounted on the bedplate and supplied with current from the low tension terminals of the transformer as a separate circuit. This arrangement is suitable for all 50 cycle rotaries, running at 1000 revs. or less, and for all 25 cycle rotaries running at 500 revs. or less.

With an eight pole, 50 cycle rotary, speed 750 revs. having a starting motor with two poles less, and the ordinary 2½% slip, the armature would be driven at a speed of some 950 revs., i.e., approximately 33% above the synchronous speed. To bring down this speed, the rotor of the induction motor consists of a cylinder of cast metal, not unlike an ordinary belt pulley, giving a large slip the extent of which will depend on the lead and temperature rise of the rotor. Finally, by adjustment of the rotary field excitation, the speed is brought near enough to enable synchronising.

To Start. Close the high tension switch and then close the starting switch of the induction motor. If the rotation of the armature be incorrect shut the machine down and change over two of the high tension phases.

Start up the machine again and check the polarity. If the polarity be incorrect, do not change any leads. The makers will have marked these for positive and negative, and all that may be wrong is that the residual flux has changed. This often happens if a machine has been dismantled for transport.

To rechange the flux, the most convenient method, if there be other d.c. plant running on the same d.c. busbars, is to lift all the brushes from off the rotary commutator and close the circuit breaker on the d.c. side for a moment. Before opening this circuit breaker again, connect two 250 volt lamps in series across it, or other high resistance to take up the discharge. If no d.c. power be available, accumulators or even primary batteries will suit. See that positive is connected to positive shunt field lead and negative to negative.

If the polarity be correct, adjust the shunt field regulator to give the correct synchronous speed. Connect synchronising lamps across the contacts of each corresponding phase of the low tension switch between the transformer and the sliprings. Remember to have lamps equal to double the voltage. The groups of lamps on each individual phase should now be all bright at one particular instant, then all dark again. There should be no rotation of brightness and darkness of the lamps connected in the various phases. If the lamps do not all become bright together, then all dark at the same time, the machine should be shut down: the phase rotation is incorrect. To correct this change over two of the high tension phases. If the rotation of the armature was wrong, you will have put back the high tension phases where they were originally. Now the starting motor would be in the wrong direction and two of its individual phases must be changed over.

It should be noted that, were the equipment of six phases, it would not be sufficient to change two phases. Four leads would need to be changed so as to reverse the direction of rotation of the starting motor.

To Synchronise.

Watch the lamps becoming bright and dark and at a period when all are dark close the low tension switch. Check the synchroscope and the lamps attached to the instrument. The machine may now be paralleled on the d.c. side. The starting motor can then be switched off.

Induction Motor Starting.
Synchronising on the High Tension Side.

The procedure is practically identical to the previous method excepting that, as the synchronising has to be done on the high tension side, potential transformers are required for the lamps and instruments.

Pony Motor Starting. Self-Synchronising Scheme.

With this arrangement the windings of the starting motor are connected in series with the rotary armature; they are not a separate circuit. The starting motor has the same number of poles as the rotary and has a solid iron rotor. Normally, as a solid iron rotor has a slip of 33%, the machine would never reach the synchronising speed; and, as the starting current would have fallen to a low value, the rotary could not pull itself into synchronism. By altering the impedance of the starting motor windings, the necessary current increase in the slipring circuit of the rotary enables self-synchronism to take place. There are nine leads connected to the pony motor stator.

The starting panel is fitted with

D.C. central zero moving coil voltmeter.
Field reversing switch.
Pony motor and synchronising switch.
Main low tension switch.

To Start.

Close the high tension oil switch. Note the voltages that exist between the terminals on the low tension side of the transformer, to ensure there are no reversed phases. Thus: Delta for 6 phases, 300 v. a.c. to 500 v. d.c., 300 k.w.

A°	A′	B°	B′	C°	C′	410 volts
A°	B°	B°	C°	C°	A°	350 volts
A°	B′	B°	C′	C°	A′	200 volts
A°	C′	B°	A′	C°	B′	200 volts
A′	C′	B′	A′	C′	B′	350 volts

If the voltages are correct, close the field and pony motor switch on the starting side. Should the rotation be incorrect shut the machine down and change over two of the high tension leads at the transformer.

When in the course of connecting up the transformer to the H.T. cable do not seal up the terminal box, especially if the terminal box is bolted on and lies parallel with the tank case, and do not cut the individual cable leads to the exact length, until after the first start; otherwise the leads cannot be transposed, as they are of different lengths, should that be necessary. To reverse either the direction of rotation or the phase rotation from the low tension side requires very careful study and may mean taking down all cable racks to get heavy cables crossed over.

If the rotation is correct the speed of machine will have increased considerably. The d.c. voltmeter needle will have commenced to vibrate and as the speed rises the needle begins to swing well over the scale on either side of the zero line. Now turn the pony motor starting switch over to synchronising and the machine will invariably pull itself into step. The d.c. voltmeter momentarily pauses and then rises straight up to full voltage. If lamps are connected across the contacts of the main low tension switch they will now be seen to glow very faintly or entirely dark.

Close the main low tension switch and turn the pony motor starting switch to the off position. If the polarity be incorrect, turn the field reversing switch down and wait until the voltmeter needle has crossed the zero line, then turn it back again.

If the phase rotation be incorrect, shut the machine down and reverse two of the high tension phases, and also reverse four of the pony motor leads.

Advantages claimed for this Method.

The field switch may be put in at any period; in fact it may be left in and, by leaving in at the last close down, the rotary almost invariably comes up with correct polarity at the next start up.

The polarity can be corrected at any period practically after starting if it has a tendency to come up wrong.

The main low tension switch has not to be closed at any particular instant.

The rotary will pull itself into synchronism with the pony motor stator windings in series and continue to run for 30 minutes without undue heating in the small motor before closing the main switch between the transformer and the sliprings.

Pony Motor Starting Self Synchronising
(Second Method, Fig. 5).

With this method the pony motor has two poles less than the rotary and it is also connected in series with the rotary sliprings. The rotor is of the solid iron type and slips about 33%, depending on the load and temperature rise of the rotor, so the starting motor is designed to bring the maximum speed of the motor when starting cold to slightly above the synchronous speed of the rotary. By careful adjustment of the field excitation the rotary pulls itself into step. This method has the disadvantage that if too much field current is allowed to flow, the rotary will not reach synchronism. Also, the low tension circuit has to be closed at the particular instant the machine passes through synchronism. Then again, if more than two successive starts have to be made (say due to failure of supply), the solid iron rotor becomes so hot that the machine will not synchronise until the motor has cooled down again.

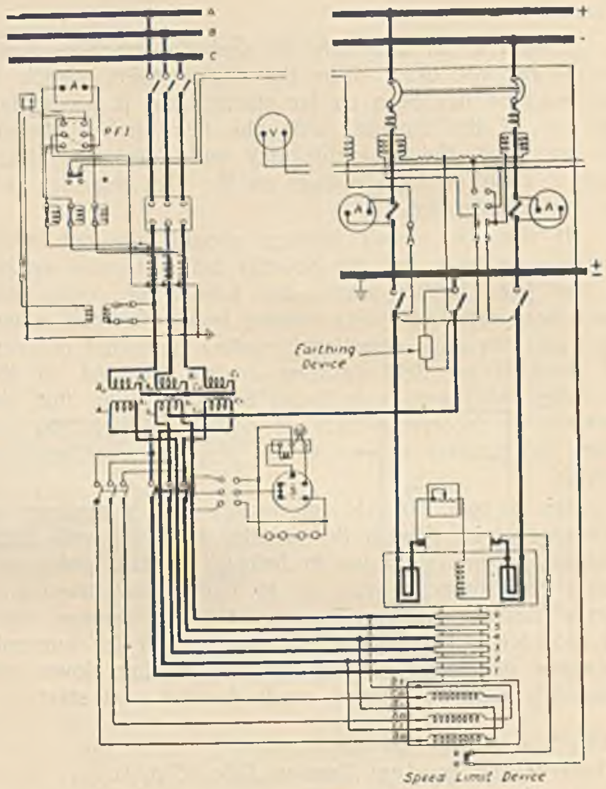

Fig. 4.—Induction Motor Starting, Synchronising on Low Pressure side: D.C. shunt-wound, three-wire.

Pony Motor Starting Self Synchronising
(Third Method).

With this method the pony motor has the same number of poles as the rotary and has a winding on

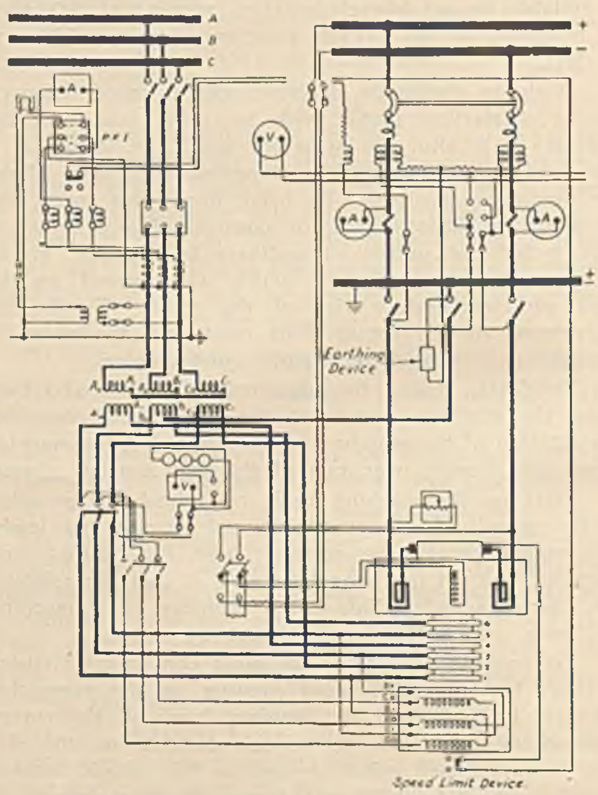

Fig. 5.—Self Synchronising Induction Motor Starting: D.C. shunt-wound, three-wire.

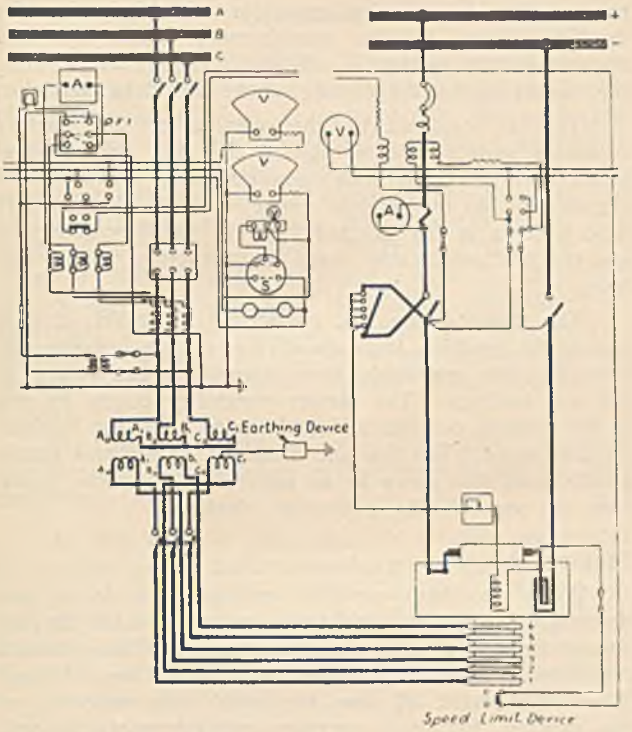

Fig. 6.—D.C. Starting Synchronising on High Pressure side: D.C. shunt-wound, two-wire.

the rotor so designed as to produce a very low slip at normal speed, and thus it always runs the rotary armature up to practically the full synchronous speed. Its maximum speed is therefore constant and uniform under all conditions, and in this respect this method is in marked contrast to the previous method.

The pony motor is not in series with the sliprings. As there is no appreciable heat generated, the motor can be used to drive the equipment indefinitely to turn up the commutator or sliprings and, at the same time, the rotary will remain entirely dead.

The operation of starting is exceedingly simple. A throw-over switch is put in the starting position, this switches on the pony motor. The operator then waits until the set is run up to maximum speed: "He has lamps to tell him but his ear will suffice."

When he is satisfied that the maximum speed is reached, he closes the synchronising switch and the rotary then promptly and invariably synchronises. Finally and at the convenience of the operator, he changes over the throw-over switch, which shorts the synchronising chokers and cuts off the supply to the pony motor.

The two switches are interlocked to ensure correct operation, but it is claimed that were the synchronising switch to be closed when the machines were dead out of phase, no harm would ensue. It could be closed at random and the rotary would pull itself into synchronism.

Starting from the Direct Current Side.
High Tension Synchronising (*Fig.* 6).

This method is sometimes adopted when other machines are running on the d.c. busbars. The machine is started in a manner similar to that of a d.c. motor with a heavy grid starting resistance and takes approximately 10% full load current to start away.

It has a disadvantage in that the machine has to be synchronised; also, on account of the difference which might exist between the a.c. mains pressure and that of the rotary at the moment of closing the switch between them, a surge may happen. The rotary is thus asked to convert a much greater alternating current into direct current, or *vice versa,* than when normally loaded, with the result that the flow of current may be so heavy as to trip the circuit breaker or to set up line surges, unless means are taken to introduce a buffer such as leaving the last step of the starting resistance in circuit.

It is perhaps a better method (than the one just described) to run up the rotary above the synchronous speed by increasing the field regulator resistance momentarily, then to trip the d.c. circuit breaker, watch the rotary speed slowing down until exactly in synchronism, then close the a.c. side and parallel again on the d.c. side.

Starting for the First Time.

Connect synchronising lamps across each set of contacts of the switch between the transformer and rotary sliprings. This will avoid the necessity for putting potential transformers across the high tension side. Close d.c. circuit breakers and the equaliser, if compound. Move starting resistance handle gradually to full on. Close the high tension switch. Adjust the speed by field rheostat to synchronism and note the temporary synchronising lamps. They should all light together and go dark together, as already described.

Check the synchroscope and its lamps. The lamps should be all dark or all bright depending upon the type of synchronising adopted. If the phase rotation be incorrect, shut the machine down and reverse two of the leads on the high tension side of the transformer. If the phase rotation be correct, shut the machine down and take out the temporary synchronising lamps.

The rotary can again be started up, but the high tension switch must not be closed as the machine has to be synchronised on this switch.

When ready to synchronise, make sure that the indicator on the high tension panel is working freely and bring the a.c. voltages equal. If the machine has no booster or induction regulator, the d.c. busbar volts should be raised or lowered, as occasion demands. If the machine has a booster the a.c. volts can be adjusted by regulating the booster field rheostat. It is very essential that the a.c. voltages are equal as well as being in phase.

Synchronise by closing high tension switch. The machine is then ready to take the load and if the set has no booster, increase the converter field. If the set has a booster, increase the booster field and adjust the power factor or converter field.

SYNCHRONISING BRIGHT OR DARK.

The smallest phase difference that can be detected by the dark method is 29 degrees with carbon lamps and 9½ degrees with tungsten lamps, and by the bright method, 28 degrees with carbon and 42 degrees with tungsten lamps. The percentage of normal voltage required to make the filament luminous is 25% carbon and 8% for tungsten. The percentage decrease in voltage to produce distinct dimming is 3% for carbon and 6% for tungsten lamps. Carbon lamps should be used for light synchronising and tungsten lamps for dark synchronising. The most sensitive arrangement of all is the dark method, using tungsten lamps.

AUTOMATIC ROTARY CONVERTERS.

Not so very many years ago, the idea of running electrical machinery in isolated places, without human attendance or staff attendants, was viewed with distrust and uncertainty. At the present time however, the necessary control devices and automatic equipment have reached a high standard of reliability and efficiency and automatic stations are becoming quite common. Automatic rotary sets can be started up and put on load by several different methods, depending on requirements:—

(1) When the load demand reaches a predetermined value.
(2) By a manually operated master switch situated in some distant control room.
(3) By a time switch.
(4) By closing a high tension feeder switch at the power station or some other plant centre.
(5) By a float switch. Hydro-Electric Installations.

When it is found advisable to provide two automatic sets in one station, the first may be started up by any of the above methods while the second is usually brought automatically into service when the load becomes too great for the first set. The control gear can be so arranged that the machines can be changed over and run alternately or for any particular period of time. With a colliery load, it is not absolutely necessary to keep the voltage constant, though it should be kept within reasonable limits of rise and fall. A colliery equipment would most likely be installed for automatic operation and protection under load only.

Rotary Converter Control (Under Load) only.

The equipment for this arrangement of control consists of a compound wound rotary converter with transformer, with high and low tension switchgear.

The high tension switchgear comprises an oil circuit breaker and control transformer for supplying low voltage a.c. to the control circuits.

The sequence of operations is controlled by a motor driven master controller, which replaces the numerous interlocking contacts that would otherwise be required on the contactors.

Sequence of Operation.

As soon as the demand for power reaches a predetermined high value, as indicated by the falling off of the d.c. line voltage, a master starting element closes its contacts and energies a master control contactor through a time relay. This relay prevents a sudden starting up due to momentary fluctuations of line voltage.

The master control contactor is so interlocked that it cannot close unless the motor operated controller is in the "Off" position. The closing of the master control contactor causes the motor operated controller to rotate, thereby closing the H.T. oil circuit breaker.

The main power transformer is now energised and further rotation of the controller closes the starting contactor; at the same time, this connects with an auxiliary field winding on the rotary to an auxiliary generator driven from the rotary shaft.

The starting contactor energises the starting motor, which starts the machine. At this point the controller stops and waits for the machine to synchronise.

As the rotary accelerates, the auxiliary generator builds up its voltage, energising the auxiliary shunt field and this fixes the polarity of the converter.

When the voltage of the generator attains approximately 80% of normal voltage, it closes a synchronising field contactor which adjusts the resistance in the rotary main field to the correct value for synchronising. When the point of synchronism is reached, a synchronous speed indicating relay operates and starts the master controller thus closing the running contactor and connecting the machine direct to the transformer; while the field strength of the rotary is adjusted to the correct value for paralleling by the closing of the full field contactor.

This is followed by the opening of the starting contactor and it will be noticed that the starting contactor does not break with current flowing, it only closes the circuit. As the starting contactor opens, the auxiliary field winding is disconnected from the auxiliary generator and the machine is now ready for connecting to the d.c. bars.

The master controller, continuing its travel, in turn closes the machine high speed d.c. circuit breaker and then the line contactor, thus connecting the rotary to the d.c. busbars. The master controller comes to rest in the running position and so remains, until the machine iis shut down. The machine continues to run and supply power until shut down by an underload or by the operation of one of the protective devices.

Shutting Down.

When the load on the machine falls to a predetermined value an underload relay operates thereby energising a time delay stopping relay. This retarded relay prevents shutting down with fluctuations of load. When the period of time for which this relay is set has expired, the relay operates and interrupts the coil circuit of the master control contactor, causing the latter to open, and this in turn causes immediate disconnection from the d.c. busbars. A normally closed contact on the master control contactor provides a circuit to ensure that the master controller is immediately rotated rotated to the "Off" position. As the controller rotates to the "Off" position, it interrupts the coil contact of the running contactor, thus disconnecting the machine from its power transformer. It also completes the trip coil circuit of the H.T. oil circuit breaker, which opens and disconnects the transformer from the a.c. line. The master controller comes to rest in the "Off" position, ready to restart when required.

Control and Protective Devices.

The equipment is provided with automatic devices for protection as follows :

Against overload and short circuit.
Over-speed.
A.C. under voltage.
Single-phase starting.
Stalling (i.e., failing to parallel on d.c. side).
Overheating of machine.
Failure of d.c. supply for control circuits (i.e. auxiliary generator.)
Earth leakage on the d.c. side.
Wrong polarity.
Hot bearings.
Overheating of the starting motor by too frequent starting.
Reverse power on the d.c. side.
Overload or earth leakage on the a.c. side.

It may be thought that the frequent starting and stopping of a machine, underload demand, would not be economical. It has been found in practice, however, that the ordinary rotary converter can be started up and placed in service with no greater consumption of electrical energy than would be required to run it at no load for two minutes. It is obvious therefore, that if the service conditions demand power for periods of 20 to 30 minutes only each hour, a considerable saving of power is effected.

Discussion.

Mr. A. F. STEVENSON in opening the discussion paid tribute to the author for a very excellent paper. He would like to refer in particular to the paragraph dealing with the mercury rectifiers. Supply authorities have a monoply and can afford to be cautious, indeed super-cautious: but colliery electrical people could not afford to ignore any advance that has been made. The Italian State Railways have standardised mercury rectifiers at 3000 volts and it would appear therefore that any colliery engineer who is thinking of putting in converters ought seriously to consider the mercury rectifier. He should, in fact, base his decision not on fashion but on the results actually being obtained in practice elsewhere.

Mr. Stevenson said he was also rather surprised that there was no reference in the paper to the La Cour converter.

Mr. WILSON, in reply, said, it is quite possible at the present time to build a two-machine converter, namely the La Cour converter, having as high efficiency as that of the rotary converter, by using special windings. It was possible, of course, to use high pressure a.c. on the stator on the a.c. side. He had not dealt with the La Cour converter at all, because the paper was simply concerning the rotary converter.

As to the mercury rectifier, he considered it to be too costly in the first place for colliery people at the present day, and in any event engineers were generally not too well acquainted with this rectifier yet.

Mr. STEVENSON.—It is good enough for railway work.

Mr. WILSON replied that that was so, but as the mercury rectifier could only convert power in one direction (i.e. a.c. to d.c.) it did not suit the intended purpose of the paper. As mentioned at the introduction, having a total d.c. plant, the converter is started up by a 5 h.p. motor from the d.c. side and paralleled with the d.c. supply from the power station, the starting motor then being cut out. The rotary converter is used as a sole source of supply for alternating current: i.e., inverted running, or d.c. to a.c.

Mr. DAVID MARTIN was inclined to agree that the author was rather hard on the mercury rectifier, which was certainly making headway. In his paper Mr. Wilson had said: "The author was informed that the day of the rotary is past." Mr. Martin would be inclined to agree, but for a different reason from that given by the author. Mr. Martin thought that practice in general shewed that the day of rotating machinery, as distinct from static machinery, was gradually ending: substations now were becoming purely static substations. D.C. was gradually being eleminated, and sooner or later there would be nothing but a.c. in public supplies.

Mr. WILSON expressed agreement with Mr. Martin. Even collieries were not introducing any more d.c. plant: but the fact is that since they have already d.c. plant, they had got to use it, practically until such time as the d.c. becomes obsolete in the condition of scrap.

Mr. HOLMES.—In his paper Mr. Wilson had mentioned something about removing a rotary converter from one position into another section altogether, and the result of that change was an extremely low power factor. Surely one of the great advantages of a rotary converter was its flexibility regarding power factor, and in many cases with its use a leading power factor was obtained without difficulty. Perhaps Mr. Wilson would give a little more information on that point.

Mr. Holmes said this subject should not be considered wholly from the public supply point of view. There were still a good many collieries which were essentially d.c. jobs and which run from rotary converters, taking a.c. power in bulk. In the case of many collieries it was far too expensive a job to change-over completely at once, much as they might like to go over to a.c. working.

Mr. WILSON.—In the case referred to by Mr. Holmes, the rotary converter was designed for 3300 volts. It was taken out and shifted to a colliery where the voltage was only 3000 volts. Running at unity power factor at full load in its first position, it fell to about 0.6 P.F. when running in its new position.

Mr. HOLMES.—Was there no possibility of boosting it up?

Mr. WILSON.—Nothing at all could be done with it, for on opening up the transformer and drawing its core, it was found that no tappings had been made on the H.T. side; presumably it was bought during the war when it was difficult to get machines of any kind. Mr. Wilson, continuing, said he had to take 1000 k.w. d.c. underground every day, and it would be appreciated that it was hardly possible at the present time for him to purchase new a.c. plant and throw all that d.c. stuff out. It was quite a big job to take anything up to 2000 amps. at 525 volts down the pit every day

Mr. HOLMES commented that this seemed to be the right time to buy machinery. With regard to the rectifiers Mr. Wilson had mentioned, most of those cases where rotary converters were taking public supply from an a.c. source in bulk were charged on a certain basis for the power. It was possible in those cases to get unity power factor and get the best current. In the case of a mercury rectifier, could Mr. Wilson give them any idea as to what the power factors under those conditions were? Would there be any loss in power factor by using a mercury rectifier?

Mr. WILSON said the rotary converter, a single machine having a single winding on a single rotating armature, still held the field for efficiency. He could not at the moment go into comparative costs per k.w. of the rectifier as compared with that of the rotary.

From graphs of tests on power rectifiers on three-phase work, he could give the following figures:

Load.	*Efficiency.*	*Power Factor.*
¼	92%	0.8
½	93%	0.9
¾	94%	0.95
1	94%	0.96
1¼	94%	0.96
1½	94%	0.96

There had not yet been any considerable experience of large power rectifiers for high pressure at collieries.

THE BRANCH PRESIDENT (Mr. R. Rogerson) in closing the discussion, moved a hearty vote of thanks to Mr. Wilson for his extremely instructive and interesting paper.

In his reply, Mr. Wilson said he desired to thank a number of men who had kindly supplied him with the lantern slides, shewing general views of both manual and automatic rotary converter sets, and also with the graphs and diagrams of connections.

NORTH WESTERN BRANCH.

Electrical Plant Progress.

W. E. MANGNALL.

At a meeting of the North Western Branch held in Atherton last November, Mr. W. E. Magnall delivered a notable lecture in which, based on his own personal engineering experiences, he covered the history of technical progress in electrical practice from the earliest experimental stages. Furthermore, he ventured to step further forward than the modern and entertained his audience with a well-reasoned insight into the potentialities of future electrical engineering methods and problems. His expressed intention was to make his subject interesting to every one of his audience, theoretical, practical and commercial. He set himself a great task and did it well, but it was one of such magnitude that it is only possible to give leading extracts in this report.

Mr. Magnall approached his subject as a practical colliery man; one interested primarily in his own colliery, and who finds his further interest promoted by the Association. The colliery man is seldom in a position to obtain books on current practice and, generally speaknig, the collieries in the district being pretty much all alike, his experience remains local. Mr. Magnall therefore aimed to give the man of that type a few ideas of what was going on outside; although, interpolated the lecturer, the colliery electrician is rapidly being brought forward from his old menial status to one commanding a deserved respect.

Electrical engineering, as applied in practice to-day, has reached a high point in its development. The time has passed when it was necessary to advocate electricity or to convince engineers with regard to the necessity of electrification: particularly is this true with respect to mining, for in no other industrial sphere are the advantages of electricity more fully appreciated than in the colliery world. The case for electricity depends not merely upon energy efficiency but also, and largely, upon its elasticity in practical application and the extreme accuracy with which it can be measured and its causes and effects gauged.

Turning to features of modern development, and considering d.c. machines, the most notable of recent changes is the substitution of built-up rolled steel work for castings: this does away with intricate wooden patterns with their fixed dimensions and costs; the holding of bulky and costly stocks is reduced and output is speeded up. The weakness of this "fabricated" form of machine carcase lies in the risk of improperly welded joints.

Ball and roller bearings are now invariably used, but the housings of these are generally awkwardly inaccessible: they are not readily removable for inspection and cleaning, the end plate of the machine invariably having to be taken off. The cooling of totally enclosed motors is also a vexed question.

Electrical standardisation is very general on medium machines, but for large machines, special compensating windings, tapered air-gaps, and commutating poles have tended to improve commutation. An important feature is the re-introduction of high magnetic saturation points.

The constant current scheme has received much attention. In this the generator produces constant current over a big range of voltage. A large number of motors are connected in series with their fields separately excited, variation of speed and torque being produced by varying the fields. If the load on a motor varies the torque varies, and the adjustment of current and back e.m.f. is accompanied by a compensating change in the generator voltage; therefore, with any given excitation the torque of the motor will remain constant over a wide range of compressed voltage. When load is thrown off, the tendency to racing is counteracted by an automatic reduction of the field.

Wireless has caused a demand for high tensions d.c. machines for energising the plates of transmitting valves, pressures of about 10,000 volts to 15,000 volts are suitable. The design of these machines is still an open question: some advocate two-pole design giving low voltage per bar; other designers advocate multi-pole design in order to avoid difficulties of insulation that occur in the armature end windings, using conductors of smaller section than occur in the two-pole type.

Where there are commutating poles, these are arranged on both sides of the armatures to protect against voltage surges.

There is one point of d.c. machine design which, it appears, is neglected so far as the manufacturers are concerned, and that is the standardisation of brushes. A little has been done towards this but it has not been carried far enough: a notable instance is one in which there are forty different sizes and kinds of brushes for a hundred and thirty motors. Brush holders have been simplified and standardised to a certain degree.

For special purposes the qualities of the series-wound motor have been overlooked: shunt motors are often used when series motors would do the work.

With regard to interpoles, these ensure good commutation and eliminate brush rockers, but few makers seem to have made use of this opportunity to reduce the air gap and thus save field copper and reduce the size of the machine.

High frequency a.c. generators for radio stations are going out and valve generators taking their place, but another field has opened out, i.e. their extended use for H.F. induction furnaces for the production of ozone which is now coming into more general use as an oxidising agent for the re-purification of the atmosphere and for sterilising water.

Synchronous motors shew no distinct changes in design. The auto-synchronous motor is now available. In build, this is similar to the induction motor with a wound rotor, sliprings and external resistance; but it has a d.c. exciter provided in addition. The machine is started as a resistance slipring motor, and after it has gathered speed, a supply of direct current to the rotor brings the motor into synchronism, after which it runs as a synchronous motor.

Preference in induction motors is for the squirrel-cage type on account of its simplicity and low cost. For high torque this type is generally inadequate and its excessive starting current is undesirable; for these reasons the slipring motor is adopted in many cases, though it is rather more complicated and has lower efficiencies and power factors. For mining work simplicity is a first consideration, especially so in order to comply more easily with the C.M.R.A. The aim therefore is to lower its starting current and improve its starting torque. To keep the starting current within reason, and to increase the torque many methods have been brought forward, such as: those involving the rotor; those involving the rotor, to alter the starting characteristic; those involving both; and mechanical methods.

Star-delta coupling of the stator is too well known to need comment, the effect is to reduce both torque and current to one-third normal value; series parallel coupling of each phase of two-phase motors reduces the torque and current to one-fourth; these devices generally reduce the starting current to 1.5 to 2 times the normal. The valve of the starting current may, however, rise above this limit for a short period when passing from the star to delta, due to the fact that according to the value of the resistent torque, the speed reached by the motor when star connected may vary in the same way that the current surge when passing to the delta position may vary.

The field is also shifted 30 deg. resulting in a corresponding surge of magnetising current. In small machines this surge is of small duration 1/30th second, but in large machines these surges are not damped so rapidly and therefore other methods of starting are necessary.

It must be remembered that large machines have a short circuit current up to ten times normal, and so auto-transformer starting is reverted to, this is well known and does not need description.

Another method, rather unusual, but giving better results is to employ an auxiliary winding on the stator. This winding is in series with the stator and it is only used during starting. In this method it is noticeable that no magnetisation current is required as in the auto-transformer, and the auto-transformer is highly saturated on account of the cost.

With an auxiliary winding there are four taps and nine terminals: with an auto-transformer there are three taps and ten terminals.

We may put in an auxiliary step between 2 and 3 and it is possible to arrange the steps in the order: .5 : .6 : .7 : .833 : 1.0. One feature of this method is the poor torque on the first stop and this is not often wanted, especially in mining. This defect may be eliminated by doubling the number of poles during starting, because power is transmitted to the rotor by a field rotating at half normal speed, and it follows that for an equal input the torque during starting is doubled. When the motor runs to speed, the poles are then halved and the motor brought up to full speed in the ordinary way. A two-four-pole combination may be obtained by coupling two coils of each phase in series or parallel, hence the term 'Series Parallel Coupling.'

Two can be split and intermediate stage brought in as before. Ordinarily the steps are:—

1.	Series Coils	Star.
2.	Mixed	Star Delta
3.	Series Coils	Delta.
4.	Parallel	Star.

The rotor method of starting involves the Boucherot double cage motor. An external cage of high resistance and low impedance is coupled with an internal cage of low resistance and high impedance. The external winding is used on starting and the internal winding on running. A single cage of deep conductors is sometimes used. Previous methods of starting may be coupled with this with equal results, and it becomes possible to start up large pumps with, broadly speaking, normal current from the line.

The Boucherot Double Stator Motor consists of two squirrel-cage machines connected either in series or parallel. The rotor bars, common to both, are connected to two copper end rings, and at their centre to a ring of high resistivity. On starting the machine the rotors are placed so that there are poles of opposite sign along any rotor conductor: and, when running, they are placed to give poles of similar sign per rotor conductor. On starting the rotor induced current flows in parallel through the centre ring of high restivity, and on running through both rotors without passing through the centre ring. Motors have been built up to 500 h.p. of this type.

The Richter Motor is more suitable for high voltage and has a larger number of poles (not less than ten). The stator is provided with two windings in series, each with a different number of poles. One winding has poles for normal running: the other has poles for starting which is less than running. Both fields rotate in the same direction. The rotor winding is short circuited and designed to offer low resistance to the normal field and high resistance to the starting field, and so the impedance on starting is higher than the impedance on running.

As the speed of an induction motor increases, the ratio of rotor resistance to rotor reactance increases and is inversely proportional to the slip, so when the Richter motor comes up to speed, the normal number of poles being higher than the starting number, the motor approaches the synchronous speed, corresponding to the number of poles, more rapidly than it does corresponding to the starting number of poles.

When the motor attains normal speed the auxiliary starting field becomes short circuited and the motor runs as an ordinary induction motor. One thing also to be noted is that squirrel-cage motors as compared with slipring motors have the advantage of not being so liable to the objectionable humming noise of the a.c. machinery.

Rotary converters are the most efficient machines for converting a.c. to d.c. in units of as large as 5000 k.w. for voltages up to 600 volts and on load factors down to as low as 30 per cent. machines of 1000 k.w. have been manufactured with an overall efficiency of 95 per cent.: this figure includes transformer and load losses but not the change-over ratio. Rotary converters generating 1500 volts d.c. have been installed, but above 1500 k.w. they are generally two 750 volt machines in series, and a fan is included to produce a blast of air over the commutator. One certain railway has twenty-six of such machines each 2500 k.w.

Motor converter production has increased recently. Previously the speed of motor converters was limited because the current per brush arm was restricted to 1000 amps. and beyond this commutation was difficult; but armature windings have now been developed and without reducing the reliability, have considerably raised this figure. These accordingly have brought the cost and efficiency more to be compared with rotary converters. Motor converters of 3000 k.w., 3000 volts a.c. and 500 volts d.c. have been made. The possibility of converting in the reverse direction is useful in some cases. Transformers are not required and therefore that cost is eliminated: but, strictly speaking, they are generally more expensive than rotary converters for equal outputs, though it is possible with a motor converter to obtain a greater output per square foot of floor-space than with any other converter.

For smaller outputs, motor generators are in greater demand, standard motor windings are available and also high speeds.

There is a new type of converter on the market, but it is so recent that there is no practical record of its use. The stator plays the dual role of the stator of an induction motor and the field system of a d.c. generator: and the rotor serves as the rotor of an induction motor and the armature of a d.c. generator. The a.c. and d.c. windings are separate and there is no fixed relation between the d.c. and a.c. voltages. The d.c. voltage is controlled by a rheostat and the a.c. winding may be designed to suit any pressure without a transformer.

So far as transmission is concerned, copper is still the most widely used conductor but aluminium which costs rather less than twice the amount per unit weight but with a weight one-third that of copper and 60 per cent. of the conductivity would be a serious competitor but for its low tensile strength, and the oxide skin which makes soldering difficult and also introduces high resistance into contact surfaces. A steel core, surrounded by aluminium has removed many difficulties. This makes a conductor which is so much stronger that longer spans are possible with the same height of support. These supports must of necessity be stronger but this is compensated by the fact that not so many are needed. A large proportion of high voltage lines have been constructed with steel reinforced aluminium conductors with spans ranging from 200 to 500 yards.

At lower voltages the same headway has not been made. Another conductor is copper with 2 per cent. cadmium. The tensile strength is increased 80 per cent.; conductivity 80 per cent. that of copper; cost very little more; and on lines of medium section considerable saving is possible due to lessening the number of supports. Porcelain is universally used for overhead line insulation and the suspension type of insulator is taking the place of pin type for voltages as low as 11,000 volts. A greater degree of reliability as well as mechanical strength are still much to be desired. Steel towers are generally fixed and are taking the place of the creosoted built up A poles.

For mining work the practice is to use bitumen or lead-paper cables. Each presents its advantages and disadvantages but in one branch of study has arrived the cable for voltages from 33000 to 132000. Thus in cable making the past few years have introduced new factors that are at present very uncertain.

Progress has been necessary in the design of transformers owing to increased turbo-generator output, increased transmission pressures, larger industrial applications for step-up transformers to give a range of voltage for E.H.T. testing. One of the biggest problems has been the mechanical support of the windings: age-shrinking and temperature expansion have a lot to do with it. The dissipation of heat is also a problem especially "hot-spot" effects and one thing that has been recognised is that it is the internal temperature of the windings that matter and not so much the temperature of the surrounding oil. In large transformers oil circulation and oil cooling by either radiators or circulating water is general practice. Air jets are directed on the radiators where no water is available. In large transformers the circulation is usually automatic on the thermo-syphon principle, although pumps are sometimes used and oil conservators are used to maintain the head.

Sludging of the oil has been closely investigated, suitable oil guarding against air and contact with bare copper has reduced it to a controllable value but it is not entirely eliminated. Mica, porcelain, and asbestos have taken the place of fabrics and paper for insulation but cotton is still used. The deterioration of the cotton at working temperatures is a measure of the useful life of the transformer. Steel with lower magnetic losses is being used but higher efficiency still can be obtained by a closer study and a more accurate estimation of the stray losses associated with transformers.

Solid earthing of the neutral with a minimum of impedance to obtain control is British practice and it is to be noted that the largest transformers are of three-phase type, thus shewing that they are to be preferred to single-phase units. The saving in space and switchgear has perhaps something to do with this. It is practice also to send transformers to site filled with oil, so doing away with long drying out periods

Protection in general demands a greater reliability in operation: the desirability of clearing earth faults at an early stage makes the energy for operating relays very small, only a few volt-amps., and immunity from incorrect operation is as important as is exact automatic operation should a fault occur. The use of biasing transformers can be brought into still greater effect for these conditions to be adhered to.

Switches and circuit breakers have received much attention recently and many new types have been evolved. For air-break circuit breakers as well as those of the oil type for years the laminated contact type has given excellent service; and is still quite in order for circuits carrying comparatively low currents and subject to no heavy overloads. Today, generating capacity has increased and circuit breakers are called upon to carry much larger currents.

Laminated contacts are made from high conductivity spring copper leaves. They are made like a wagon spring with short portions inside. Several of these are bolted together on an insulated bar and each leaf is supported to make a contact of its own: but, unless the leaves are assembled lineable and parallel with the block on which they make contact, it is only at a few points and not on an area that contact is obtained. If thorough contact is not made heat is developed, the laminations lose their flexibility and increasingly more under heavy current fault conditions. This trouble develops by stages, the inner leaves carry most current on account of their shorter length and greatest pressure; by virtue of their position they cannot dissipate the heat owing to the fact that they are sandwiched between the same material at the same temperature. Brass and copper soften at a comparatively low temperature and as mechanical pressure is reduced further heat is generated and deterioration takes place rapidly. However one thing it is most important to guard against is too solid a contact, a springiness to a certain degree ought to be present. The larger the area of a contact, to a certain degree, the larger the cooling and radiating surface. A sphere offers the largest surface area, and hence the ideal contact would seem to be a hemispherical one, fitting in a corresponding cup shaped contact. This, however, is an intricate form for workshop practice and so the next best seems to be a hollow, triangular pyramid contact. This shape provides a large contact area, a hollow cooling space and a wedge-tight fitting. Furthermore, this type could be standardised, say one of one-inch by an eighth cross-section for 50 amps., two for 100 amps., etc. They could be placed in parallel along an arm, they could be used in any position, easily removable and low in cost.

Auxiliary carbon contacts are often placed in circuit breakers and the breaking takes place on the whole area. Could not the same contacts be placed sideways and slide along each other? There would then be less mechanical pressure bearing, no pitting of the whole area and the same electro-magnetic force caused by the current would operate because they would all be on the same or similar arms. The better sliding action would also lessen the mechanical shock which often breaks carbon contacts. The forces and pressures required to close the breaker would not be so large and thus the panel or case need not be quite so strong.

As compared with air-break gear an oil-immersed gear tends to keep the arcing region concentrated at some spot. Stabilising the arc, as it is called, has taken place but it requires further study and application. The method used is to enclose the contacts by a magnetic cylinder having an internal insulated sleeve. This creates a field which assists the arc's tendency in keeping in a straight line. This type of switch flattens the wave form of the arc but does not influence the heat given off. If some method could be evolved which enticed the arc into openings or crevices like a wireless condenser more heat could then be got rid of. There will be further progress made in this direction.

With regard to the fastening of switchgear, when will bolts be placed where they are easily accessible and when will standard heads and nuts be used? The fastening "gadget" is sometimes overdone. A 400 amp. circuit breaker delivered a few days ago had 42 ½ in. studs fastening a door 40 ins. by 18 ins. The "stop" button was 3 ins. diameter and fastened on a baseplate 5 ins. square which was in turn fastened by 6 ½ in. bolts with the nuts outside. The locking in the "on" and "off" positions consisted of a ⅜ in. bolt with a "tommy bar" through the head portion, plainly asking to be turned round!

It is sometimes beneficial in the mining industry not to have the door of a piece of apparatus hinged, because quite frequently there is not sufficient room to allow for the swing of the door.

Room in which to work is important especially in marking off cables. Attempt to get a twin .4 D.W.A. P.I.L.C. cable through a hole 1½ ins. diameter and 3 ins. from the lead make off, into a contact a further 6 ins. away situated at an angle of 70 deg. to the run of the cable without damaging the paper: and listen to the coloured language echoing from a rock roof 4 ft. or 5 ft. high and 18 ins. from the side pack wall!

One does not need to be afraid of putting an extra bit of metal in a sealing gland and since these are still C.I. or brass they should not be planned to follow suit with welded steel cases and be made thinner.

A number of faults of this type may be due to commercial competition and the exigencies of first cost, but such methods do not always pay: electricians are generally consulted and managers welcome their practical working suggestions.

In contactor gear for automatic control the rate of closing can be worked in several ways. The relay method is probably the most common. Each contactor is provided with a relay which causes it to close in sequence with the others when the current has fallen to a certain value. In this method under conditions of overload the current may not at some point fall to the determined value with the result that certain banks of resistance are left in circuit and they eventually burn out. Therefore, a form of control which will proportion the speed of starting to the load is obviously required.

A circuit breaker some time ago was placed in an open circuit position and certainly no contacts were touching but a controller that had flashed over between two contacts on the barrel due to their being insufficient space between to extinguish the arc, was touched and found to be alive. Upon investigation it was found that a circuit was completed from incoming main to the outgoing via contactor coil, economy resistances and the stop button for its operation. Fortunately, having those resistances in circuit damped the voltage and no disastrous results ensued. Had it been more than 500 volts there might have been a tragedy. That experience surely shewed a case involving lack of investigation. It was necessary to find out something that the makers did know existed or their piece of apparatus as designed would not have worked.

Let practical men know the results of theoretical calculation and let the theoretical people bear in mind that observation gives equally as much knowledge as a book on a particular branch of study. There should be no secrecy and all should work together.

Discussion.

Mr. R. F. BULL (Branch President, in the chair) said that the paper was an extremely interesting one. Mr. Mangnall must have gone to a great deal of trouble in bringing together such a mass of information. There was no doubt that he had started at the rock bottom of his subject, as he had begun by quoting from the Book of Genesis.

One very important point had been mentioned with regard to the starting of the squirrel-cage motors. If the high starting current could be reduced by Mr. Mangnall to full load current it would be of very great assistance, provided there was an equivalent torque.

The reference to the contactor gear appeared to be in regard to a switch concerning which the application of the M.D. Circular 23 was very much needed. If it was earthed before work was started there would of course be no danger to the workmen.

Mr. H. E. HEYES referred to shaft cables and wanted to know what kind of a cable Mr. Mangnall would use in the case of a very wet shaft. Would he prefer a paper-insulated, lead-covered, wire-armoured; or an all bitumen-insulated; or rubber insulation with a bitumen worming and sheathing?

Mr. A. A. CARY thanked the author for his interesting paper; he was particularly interested in the remarks on contactor equipment. He stated that he had very little trouble with the types under his supervision which included the type that depended on the current fall for its starting time; and also the type in which the starting time was dependent on an oil dash pot. Of the two types he rather preferred the former. He anticipated very little trouble in the running of present day motors, provided the switch contacts were attended to regularly.

In the matter of shaft cable suspension, he stated that in his opinion, no supporting clamp should be attached to any ironwork connected with the headgear, but arrangements should be made so that the top clamp could be carried from the solid in such a way as to eliminate the possibility of the vibration caused during decking being transmitted to the shaft cables.

Mr. JONES.—With regard to ventilation, it should be remembered that the output of a motor was largely dependent upon the efficient dissipation of the heat, and consequently ventilation played a very important part. The close attention of designers had been focussed on this point recently, and severally improvements made in this respect, other gases, such as hydrogen, having been used as the cooling medium. The Thury system of transmission had been adopted on one or two systems in France but, personally, he was not aware that it had been used in this country. The system had several disadvantages, and consequently was not extensively used.

It was quite correct to assume that the power factor of an autosynchronous motor was higher than that of a squirrel-cage motor, i.e., of the same rating and speed, etc. When considering the spacing of rotor slots attention must be paid to the question of rotor locking. Several methods of starting were used at the present time and in considering the adoption of starting equipment the local factors should be taken into account, such as the load, development of the load, the time required to attain full speed, and any other factors such as "half-speed" operation, etc.

A condenser did not always provide the most satisfactory or economical method of power factor correction, under certain conditions it might be more advisable to use an autosynchronous motor.

With reference to switchgear, mention had been made of the extended use of the magnetic blowout and whilst one must agree that it did in the greater number of cases assist considerably in the arc extinction the fact must not be lost sight of that it might not provide the most efficient method. It was simply a question of the dissipation of the arc energy, and whilst the magnetic blowout might reduce the time taken to interrupt the arc the rate of dissipation might be increased, and therefore the total arc energy be increased. Although the oil filled switch was accepted as the best type in this country at the present time, there had been other developments on the continent, e.g., the steam vapour switch.

Mr. MANGNALL, in replying to the discussion, said that the installation of a shaft cable in a wet shaft would depend upon the nature of the "wet". Some wet shafts were quite good and others were the reverse. He had been confronted with a difficulty in this respect some months previously, and the water had been subjected to several chemical tests. It was found that the water was fit to go into the boilers. A factor like that influenced the design of shaft cables but, generally speaking, in regard to a wet shaft he thought he would still stick to the bitumen cable, although, in his own case, the other side of the shaft was dry and he had put in lead paper. A shaft cable should be securely fastened at the top, but there should also be substantial intermediate supports as well, especially in regard to lead cables.

A fault developed in a 0.3 bitumen cable and a joint box was put in, consisting of a small brass sleeve covering the conductors, without taking into consideration that there were 33% of them corroded away. There was simply a repair of those that were already in, with the result that heating was caused to such an extent that the cable became decentralised. That was one of the disadvantages of bitumen cables under heavy load.

In answer to another question concerning cables Mr. Mangnall replied that the fault occurred at a bend where the cable dipped into a mouthing. It was due to foreign bodies falling down into the pit and probably causing fracture at some time or other. He was unable to determine actually the exact nature of the cause of the trouble, because the cable had been in use for about twenty years. It might have been due to a fault in mechanical construction in the first instance or electrical stresses, or ionisation at that particular point.

Several methods were in vogue for determining the time limits for contactor gear. There was one method, however, of which he had personal knowledge, to which he would like to refer. The rate and sequence of the closing was controlled by a master switch, the moving of which was governed by an eddy current retarder, and which at the same time provided a rate, adjustable by hand for normal starting, and was itself adjustable afterwards in accordance with starting load. This retarder acted at the same time as a brake on the master switch movement. Therefore the retarder only delayed and did not prevent the closing of the several contactors. This method eliminated the use of relays and lock coils and was really free from the flimsy contacts which were so numerous. As a matter of fact, simplification appeared to be emphasised in this particular type.

The use of cast-iron cases probably resolved itself into a question of what might be termed commercialisation, which was a point not applying to the practical man who simply asked for something which would best serve his purpose. Considerations of cost must be left for settlement to the costings department.

There was now considerable ventilation of motors, though some were not ventilated at all. The Thury constant current system had not received much support in England, though it had been in operation for 30 years in France.

He quite agreed with the remarks of Mr. Jones upon the point concerning the power factors of the auto-synchronous motor and the squirrel-cage. With regard to power factor correction and condensers, the remark he had made in summing up the power factor question was to introduce, in the line, leading k.v.a. He did not quote any system as being better than another.

The same consideration applied to remarks upon any damping or flattening of the wave of arcs. He did not maintain that it was the best system by any means; he only mentioned it as a system. There must be many more systems which were not in the forefront of technical notice for the purpose of damping arcs. The subject of arcs could be discussed for many hours.

Mr. MOURNE mentioned that the lecturer had not referred to weights in the suggested list of particulars which manufacturers might be asked to supply. It was advisable to know the weight of a motor before an attempt was made to lift it.

Mr. MANGNALL said that weight was referred to in the design sheet he had produced, though he had not referred to it specifically in his remarks.

Mr. JONES had very great pleasure in proposing that a hearty vote of thanks be accorded to Mr. Mangnall for its highly informative address. One of its outstanding merits was its extremely practical character, and it was to be regretted that the members of the Branch had not had the opportunity of perusing it in print beforehand.

Mr. LOCKHART seconded the vote of thanks. Mr. Mangnall had covered a very wide field and his lecture had been extremely interesting.

KENT SUB-BRANCH.

Circuit Breakers: their Development and Use.

J. R. SMITH.

(*Paper read 6th December,* 1930).

Before the development of circuit breakers, fuses held their own, and whilst it is not intended here to decry the merits of the fuse, it is proposed to shew when the use of fuses would be inadvisable from a safety point of view, and when the use of circuit breakers would prove more efficient.

The old and simple wire fuse which was open to the atmosphere and, to allow reasonable overload protection, was run at a fairly high temperature, deteriorated in course of time, that time period being a function of the load to which the fuse was subject. This deterioration is of course not entirely absent even in present day fuses which come into contact with the air, oil or other arc quencher. The weakening of the wire fuses so caused has always been a source of anxiety to those people whose object was continuous production without interruption, and to whom a "shut-down" meant more or less serious losses.

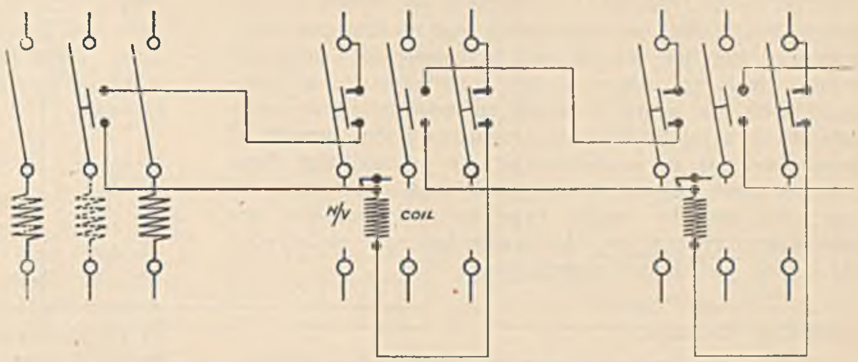

Fig. 1.—Diagram of Sequence Interlocked Circuit Breakers.

No-Volt Coils.

There are also to be considered plants, such as fuel conveyors, and others in the artificial silk industry, which depend for satisfactory operation upon the maintenance of proportional consecutive feeds in manufacturing processes. Such plants demand automatic operation and control quite unobtainable without the use of some form of positive circuit interrupter, the simplest form being cross connection of the no-volt coils. By this means it can be assured that in the event of the failure of any one link in the chain of operations, the feeder unit will cease to operate; the system also can be made to ensure the correct sequence when starting up.

Whilst dealing with the use to which the no-volt releases can be put, it would be as well to bring forward a point which is often raised by the prospective user. Assuming that the circuit breaker is required for a three-phase system, the engineer may consider that, there being three phases, at least two no-voltage releases would be required, considering of course, that if connected on any two separate phase leads, failure of supply on any one phase would operate the no-voltage protection device. This is a fallacy, as will be seen on reference to the diagram of connections, Fig. 1.

Assume a failure on the red phase, current continues to flow in the blue and white phases respectively, and whether the load consists of motors or transformers, transformer action will take place inducing a voltage in the "dead" limb, feeding back along the line and energising the extra no-voltage coil.

In the circumstances, it is as well to fit three overload releases and depend upon the increased current in the two live phases to interrupt the circuit, rather than depend upon the second no-volt release.

Circuit Breakers, Air and Oil.

The first type of interrupter to come into general use was of the air-break style, later aided by a magnetic blowout. It will, perhaps, be as well to consider briefly the theory of this feature, as the magnetic forces exerted in circuit breakers assume an important character later in this paper.

The arc being a most flexible conductor is forced upwards in the magnetic field; this has the effect of stretching it, increasing its resistance and, consequently decreasing the current until a critical arc length is reached, beyond which the available voltage cannot maintain the arc; the critical value being dependent upon the nature of the material of which the arcing contacts are made, the strength of the magnetic blowouts and also, to some extent, the barometric pressure of the atmosphere.

Oil Circuit Breaker.

It was later discovered that by immersing switch contacts in oil, higher currents could be more easily ruptured. This type of interrupter is however, reserved for alternating current, owing to the propensity of d.c. arcs to decompose the oil, throwing down a heavy deposit of carbon upon the insulators, decreasing the di-electric strength of the oil and generally inviting internal flash-over. It is, however, possible in some cases to use oil circuit breakers for direct current, but it is preferable at all times to use a four-pole circuit breaker connecting two poles in series, and remembering meanwhile that the guaranteed rupturing capacity as specified for on alternating currents will be considerably lowered.

Line Contacts.

Everyone is familiar with what is known as the controller type contact, wherein the current is actually carried across a line: but the use of line contacts for oil circuit breakers may not be so familiar. The principle of these is well worth considering and comparing with plain or butt contacts. Consider two plain surfaces coming together as shewn in the sketch, Fig. 2 (A). This type of contact has two disadvantages; the contacts being under oil, there will undoubtedly be a film of oil trapped between the two surfaces; furthermore, if a microscopic examination of the section of the contacts could be taken, it is doubtful whether actual contact could be proved in more than a few points, for it must be remembered that contact surfaces have a commercial finish and even if possessed of a high quality ground surface when new and at the beginning, that would not last long owing to the hammering action of the contacts on "making." It will, therefore, be seen that plane contacts simply consists of a series of points.

The function of a controller type contact is, instead of gambling with points in a plane, to establish a definite series of points and, furthermore, to enforce contact by massive springs either behind or embodied in them. Generally speaking, the springs to be found supporting them are far in excess of those found with any other class, which is really the secret of their success.

There is also another important consideration which is the absence of an oil film between the contacts, which have a wiping action and are therefore possessed of a self-cleaning feature. Experience has shewn that this film can be very detrimental when a circuit breaker is left closed on load for long periods; by long periods is meant anything above three months or so. The film so entrapped, oxidises in time and thus it gives rise to "contact resistance," which is unfortunately cumulative as the hot contacts are liable to get hotter still, owing to the increasing resistance.

Controller type, or line contacts as shewn by the sketch, Fig. 2 (B), are self-cleaning and no film can exist; moreover, the line can be said to consist of a series of points which are under a very high pressure as compared with the points in plane surfaces which are only subject to a relatively low pressure. From results of circuit breakers in commission it can be said that these contacts have proved their worth and have come to stay; this may be judged from the fact that they are coming into general use, the system having been adopted by several switchgear manufacturers.

Rupturing Capacity.

Unlike the manufacturers of electrical machinery, the designers of circuit breakers are without the usual stock of academic formulæ, which will predict the performance of their products within a reasonable percentage of accuracy: the present designs are largely the result of tests and trial and error. The main features controlling the rupturing capacity of an oil circuit breaker are: its ability to dissipate electrical energy in the form of heat; and its power to withstand, without shewing signs of distress, the electro-magnetic forces set up within its structure (Fig. 3).

A disruptive force exists between the stem of each phase, owing to the passage of current. Fortunately, this force may be calculated with some degree of accuracy and the strength of the stems suitably designed. There is also the "kick-off" force exerted upon the "plunger bar." These forces are a maximum when the breaker is closed on a short circuit, more especially if the instantaneous value of the voltage at the instant of closing be zero, (see Fig 5) in which case the short circuit current might quite easily amount to forty times the normal full load capacity of the feeder whether it be a transformer or alternator. This factor is however, governed by the reactance of the circuit as a whole.

Like the proverbial chain, however, the circuit breaker is only as strong as its weakest link, and there are yet other points to consider, viz.:—

1. Tank Strength.
2. Limiting current carrying capacity of the conductors.
3. Speed of separation of the contacts.

Tank Strength.

Opinions differ on tank strength in view of the fact that the pressures to which a tank may be subject are only instantaneous. The elastic steel tank has its followers as also has the rigid tank. The designers of the former believe that it is best to allow the tank to "give" a little under pressure, maintaining that the pressure being static it will drop considerably by the yielding of the tank wall; whilst the supporters of the rigid tanks prefer to confine the pressures within in the belief that the arc will be more difficult to sustain in the new compressed conditions.

However, both of these types of circuit breaker tanks are on the market giving entirely satisfactory service, and perhaps it is worthy of note that the elastic tank type is considered good British practice.

Current Carrying Capacity.

Generally speaking the rupturing capacity of a circuit breaker is reckoned on a one-second basis, since it is limited by the heat dissipating capacity, this period is accepted as one which will cover the total time of the fault. The continuous current capacity rating of copper is generally something under 1000 amps. per sq. inch, and for a one-second rating, 100,000 amps. per sq. inch. There is yet another rating, that being 5 seconds, which is used in the design of circuit breakers for sq. inch.

Contacts.

The current carrying capacity of the preliminary, or, so called, arcing contacts which are called upon to "make" and "break" the circuit, has also to be considered. Perhaps the most important function required of these contacts is the ability to make contact rather than to afford exceptionally good breaking qualities: for, with badly designed contacts, there may be a tendency to "spot" welding at the contact face. Furthermore, these contacts should afford adequate protection to the main contacts, localising the arc to such points as can be most easily renewed, and also to direct the arc and its resultant bubble away from the continuous current carrying parts.

Speed of Separation of Contacts.

The speed of separation of the contacts is another important feature, but a consideration of this will shew that beyond a certain limit the speed may be increased without much increase in efficiency as the arc must be extinguished when the voltage wave is at zero. The time taken to rupture the arc must be long enough to allow the voltage to go through the zero value at least twice, because, should the contacts reach the end of the stroke with the arc still in existence under the influence of a rising voltage, then there can be little hope of extinguishing it.

Multiple Breaks.

In high tension circuit breakers more than one current break is essential in order to utilise the full quantity of oil from a heat dissipation point of view and also to minimise the size of the arc bubble and so utilise the oil to its full capacity. Speaking of multi-breaks, it may be mentioned here that an idea has been developed providing timed serial breaks which is an attempt to ensure that at least one contact opens somewhere near the voltage zero point. In the illustration, Fig. 4, there are shewn four breaks so disposed that each contact separates a fraction of a second after the preceding one. This is of course, based on the principle that if the contacts separate with zero potential no arc will ensue. This method is protected by patent and is in effect the property of the British manufacturers in general who are the supporters of the Research Association.

Switch Oils.

There is probably little to choose from amongst the reputable manufacturers of switch oil when one bears in mind that they are all made from the same base, i.e., crude mineral oil. Switch oils form one of a series of distillates following immediately what is generally known as the "lighter hydro-carbon group." After the distillation, refinement takes place. This refinement is simply a method of removing all oxidisable matter from the distillate: it is affected by agitating the oil with sulphuric acid generally followed by decanting, neutralisation by the addition of an alkali, drying and subsequent filtration.

The derivation of switch oil does not strictly come into the sphere of this paper, but it may be mentioned to shew the difference between what is known as Class

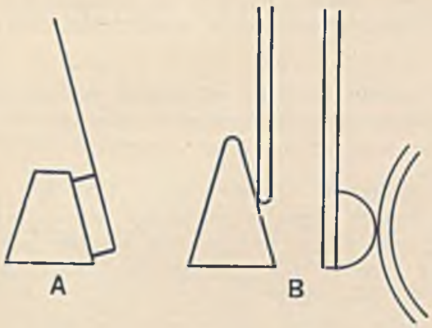

Fig. 2.—A : Butt Contact.
B : Line Contacts.

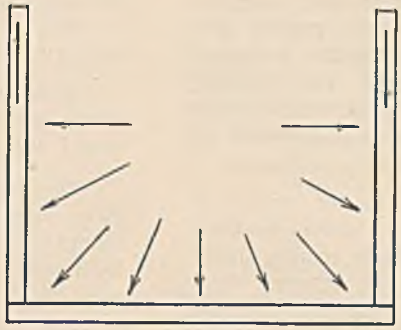

Fig. 3.—Forces exerted in a Circuit Breaker.

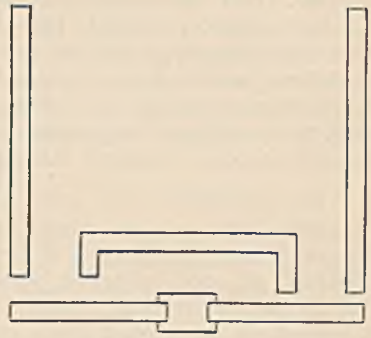

Fig. 4.—Serial Breaks.

"A" and Class "B" oil. These grades differ in their "oxidisable material" content and degree of refinement. It is not to be thought that a Class "B" oil can be transformed into a Class "A" by either filtration or drying as the difference is physical and can only be affected by further refinement.

The question of moisture both in a "free" and "dissolved" form is coming more to the fore with the introduction of the 132 k.v. systems in this country, and it is worthy of consideration.

Oil Tests.

Before oil is used in switchgear on transformers, at least a moisture test should be carried out: the presence of water is generally the cause of failure, but it does not necessarily bring immediate breakdown.

The oil should be sampled in the approved B.S.S. method and when a potential tester is not available a metal rod should be heated to a dull red and plunged into the container. The presence of moisture will be denoted by a crackling sound which will be quite apparent to the normal ear. To those who are hard of hearing, a refinement of this test may be used which necessitates the use of a tube instead of the bar. The effect is to amplify any crackles which take place by a resonance effect. In connection with this test, great care should be taken not to over-heat the test rod or tube, especially in the case of the latter as the oil being a Hydro-carbon will readily vaporise and cause a secondary explosion in the container or tube. This observation is merely made to impress upon the tester the necessity of using the correct heat and not to discourage the use of a very valuable test.

Vaporisation.

The method of manufacture described makes it obvious that the oil will be subject to vaporisation in a similar manner to that of water, although well below boiling point, and an important feature is the amount which will vaporise under normal conditions. Two dangers beset the use of an oil having a high evaporation co-efficient : the first is that a collection of oil vapour in the air cushion and breather invites secondary explosion ; the second is that the loss of oil occasioned by such evaporation results in reduced oil levels, increased maintenance costs and danger of internal breakdown.

Discussion.

Mr. LOWE.—Is there any ultimate carrying capacity for line contacts? It would appear that the use of line contacts necessitates the working of the copper at the point of contact far above its normal carrying capacity.

Assuming the contacts were welded together, which would give a far better conductivity than any which could be created by mechanical pressures such as line contacts are subject to, the rating of the copper at the point of contact would still have to be infinitely high. Is there in practice any means of overcoming this high rating of switch contacts when line contact is adopted? The reason for asking this question is that the speaker knows of a large cement works where the electricity supply is received at 33 k.v. and transformed in one step to 400 volts. As the loading of the works is very high this means that the current loading is also very big, and the makers of the switchgear which was installed to deal with this loading had to put two switches in parallel to deal with it. Given similar conditions, what would Mr. Smith propose if installing switches with line contacts? It would seem that to get similar carrying capacity to two switches in parallel having butt contacts, of which the carrying capacity could be rated much higher than line contacts, it would be necessary to have an infinite length of line contact to deal with a similar load.

With reference to the remarks about magnetic forces on closing switches, which tend to make the two vertical members and the horizontal moving member carrying the moving contacts circular in their form by the magnetic force emanating from a point in the centre of these three members, would it not be beneficial to make the switches having the members approximating to this circular form?

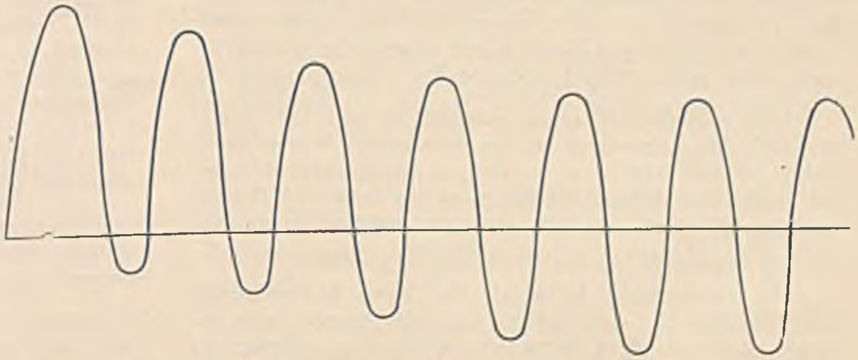

Fig. 5.—Current Surge : Voltage Wave at Zero.

Mr. Lowe also said he would like to take exception to the author's remarks that switchgear makers had not much theoretical data to help them in the design of switchgear as they have in connection with other branches of electrical engineering. If that were so it would appear that the switchgear manufacturers had not advanced so quickly as other electrical manufacturers.

Mr. COOPER said, with regard to the matter of magnetic force set up when closing a circuit breaker, he understood that instead of the contacts coming firmly together at once, vibration was set up between them before the switch finally closed. He believed there was a contact on the market which closed at once.

If the switch depends on a line contact, how could it be so much better than the brush contact, which has perhaps half-a-dozen contacts on each end?

There was a certain amount of danger, when switching in, from gases given off by the arc, had Mr. Smith ever known of a case where ignition of such gases had taken place, say from a switch cubicle, caused by people smoking outside?

At a number of places switches of the brush type, say of 100 amps. capacity, carrying a load of only 40/50 amps., worked for months at a time without giving trouble, then without apparent cause suddenly began to get hot. Did Mr. Smith think this was caused by oil being trapped in the contacts?

Referring to the shape of the edge of line contacts, is this a point or radius? Mr. Cooper said he understood, with regard to the circuit breaker, that all making and breaking was done on the sparking tip. That being so, how came it that in the design of switches the sparking contacts were put very close to the edge of the tank, whereas if they were in the middle of the tank there would be the benefit of a cushion effect from the oil in the tank, etc. Mr. Cooper also asked whether the present tendency is to make switch tanks circular or square with gussets.

Mr. RUSSELL submitted two questions: With regard to the brush type of switchgear is it ideal for the brush to form a fixed contact or a moving contact? At what point does the fixed spring contact touch the wedge?

Mr. J. R. SMITH, in reply to the questions raised by Mr. Lowe, said:

Line contacts like any other type have their limiting current carrying capacity, which is governed by their ability to dissipate heat in order to conform with the B.E.S.A. stipulations that the temperature rise set up under full load conditions shall not exceed 30 deg. C. for gear up to 2000 amperes. With regard to the question as to whether the copper at the point of contact is worked at an abnormal current density, this contact is no different from a butt type contact, wherein only spots make contact and not the whole surface.

Line contacts are rated between 75 and 100 amps. per inch line, according to the pressures. Where very heavy currents are to be carried, a multiplicity of lines are used, would take the form of a number of blades split up at about one-inch intervals making contact on both sides of each "V" of a serrated moving contact.

The circumstance to which Mr. Lowe had referred was probably the case where the total current was in excess of the standard rating of any other manufacturer's products, in which case it would most probably be cheaper to instal two circuit breakers in parallel than to make a special construction which would necessarily be very costly.

Actually there would be little advantage gained by constructing the switch stems in circular fashion as they would still tend to bend at the point illustrated.

Designers of electrical machines know that for a given amount of energy input a reasonable percentage output is expected and unless the finished machine perform within 2 per cent. of the predetermined performance there must be something radically wrong. This is because for a given current and number of turns a definite m.m.f. can be expected and, in turn, a definite flux density with consequent definite working forces. The design of switchgear is without much fundamental data, e.g., one cannot guarantee a definite amount of arc—energy for a given k.v.a. ruptured; all tests made in this connection have shewn great variance. It is obvious that the design of the contacts must control the arc-energy and it is the object of the switchgear manufacturers to determine the best design.

Replying to the several queries raised by Mr. Cooper, the author said:

The special contact referred to is of a "solenoid" design and is constructed to set up forces in counteraction of those within the magnetic loop: it certainly does defeat "chattering" on butt contacts. Chattering, however, is more evident with plain butt contacts than with finger type contacts which are generally considered quite efficient without the introduction of neutralising forces. A brush contact may be called a multi-line contact and if the pressure between the brush and block could be increased approximating that obtained with a line contact it would be ideal. Unfortunately however, the pressure is limited by the mechanical structure and it is insufficient to expel the very fine film of oil which in time oxidises and causes heating. Mr. Smith said he was confident that the trouble experienced by Mr. Cooper was due to oil film. However, it may be mentioned that such trouble can be obviated by operating the switch when the opportunity is afforded and so automatically remove the oxidised film of oil.

Mr. Smith said he was not aware of any case of explosion such as Mr. Cooper had mentioned: the mixture would probably be too weak. There was, however, the possibility of an explosion in a bus-bar chamber should the gases congregate there and that was why modern circuit breakers were vented into the open preferably through an expansion chamber.

The line contacts mentioned consist of a radius making on a flat surface.

To obtain the maximum efficiency from a circuit breaker full use of the oil should be made on account of its cooling properties, and if arcing contacts were situated in the middle of the tank the arc bubbles emanating therefrom would unite and the resultant cooling surface would be less than the total available with six small bubbles. This contention was borne out by the fact that a sphere has a maximum volume for a minimum enclosing surface.

Circular tanks are now being used by at least one manufacturer in one of their lines, it has not, however, become general practice as yet.

Referring to the questions by Mr. Russell the author said that when brush contacts are used they should always constitute the fixed part of the circuit breaker.

A.M.E.E. COUNCIL MEETING.

A meeting of the General Council of the Association of Mining Electrical Engineers was held on Saturday, February 21st last, at Stratford-on-Avon. Amongst those present were :

Mr. J. W. Gibson, President, in the Chair ; Mr. R. Holiday, Past President, Treasurer ; Mr. D. Martin, Past President, Advisory Committee ; Mr. T. Stretton, Past Presdent, Advisory Committee ; Mr. W. T. Anderson, Past President, Certification Committee ; Mr. G. M. Harvey, Past President, Examinations Committee ; Dr. W. M. Thornton, Past President, Examinations Committee; Major E. Ivor David, Vice-President, Examinations Committee ; Mr. F. Beckett, Vice-President, Finance Committee ; Mr. A. W. Williams, Advisory and Publications Committees ; Mr. W. Bolton Shaw, Certification and Papers Committees ; Mr. T. H. Williams, Certification, Examinations, and Prizes Committees ; Mr. S. H. Morris, Papers and Publications Committees ; Mr. J. R. Cowie, Prizes Committee; Mr. J. Dawkins, East Scotland Branch; Mr. D. S. Anderson, Lothians Branch ; Mr. J. Walker, Lothians Branch; Mr. J. Dinnen, West of Scotland Branch; Mr. J. R. Laird, West of Scotland Branch ; Mr. E. E. Shatford, North of England Branch ; Mr. C. C. Higgens, Yorkshire Branch ; Mr. A. V. Heyes, North Western Branch ; Mr. F. H. Williamson, North Western Branch : Mr. E. R. Hudson, Midland Branch ; Mr. C. D. Wilkinson, Midland Branch ; Mr. I. T. Dixon, Warwickshire Branch ; Mr. W. G. Thompson, Warwickshire Branch ; Mr. A. C. MacWhirter, South Wales Branch ; Mr. H. J. Norton, South Wales Branch ; Mr. W. M. Thomas, South Wales Branch ; Mr. C. St. C. Saunders, General Secretary.

Letters of apology for absence were received from Messrs. A. Anderson, Past President ; C. Augustus Carlow, Past President ; A. B. Muirhead, Past President and Advisory Committee ; Capt. S. Walton-Brown, Past President and Certification Committee ; G. Raw, Past President and Certification Committee ; F. Anslow, Past President and Publications Committee ; H. J. Fisher, Certification and Examinations Committees ; T. H. Elliott, Certification Committee ; A. Dixon, Prizes Committee ; R. Ainsworth, Publications Committee ; R. Rogerson, West of Scotland Branch ; W. G. Gibb, West of Scotland Branch ; J. A. Brown, West of Scotland Branch ; S. A. Simon, North of England Branch ; A. R. Hill, Cumberland Sub-Branch ; Sir A. Whitten-Brown, South Wales Branch ; and J. R. Walton, London Branch.

The Minutes of the previous General Council Meeting held on October 18th, 1930, were confirmed. After receiving statements with regard to the number of members as at December 31st, 1930, financial reports were considered. Apparently there were cases where student members who, according to the rules, should have been transferred to the class of Associate Membership, had not availed themselves of this provision. It was decided that should there be any Student Members who declined to accept the necessary transfer, they should be removed from the register.

The President of the Association spoke upon the generally satisfactory position of the Finances of the Association and also with regard to those of the Branches.

Fifeshire Branch.

Mr. Dawkins reported upon the alteration of the constitution of the East of Scotland Branch, and upon the steps which had been taken to form the new Fifeshire Branch ; it was resolved that the title of the former East of Scotland Branch be altered to the Fifeshire Branch. A hearty vote of thanks was passed to Mr. Muirhead and those associated with him for the great interest they had displayed in this matter, and also for the time which they had been good enough to devote in connection therewith.

Examinations.

It was resolved that the Examinations be held this year on April 25th and May 2nd, and it was decided that respective Branches should provisionally arrange for two Local Examiners for the Service and other Examinations, if it should be possible to arrange for Examinations to be held in each District. The Practical Examiner to be a Member of the Association, and the Professional Examiner to be a Professor or Lecturer at a Local College.

The Chief Examiner would supply a List of Questions to the Local Examiners, but further questions might be put to the Candidates as may be considered desirable.

A Member of the Association, Mr. Adam Donaldson having reported that in consequence of shipwreck, he had lost all his possessions, which included the Association's Certificate, asked for a copy to be supplied to him. This was agreed to.

British Engineering Standards Association.

It was reported that Mr. N. M. MacElwee had been appointed the Representative of the Warwickshire and South Staffordshire Branch for the B.E.S.A. Committee in the place of Mr. G. M. Harvey resigned.

British Industries Fair, 1931.

It was resolved that the thanks of the Association be tendered to the Chairman and Advisory Committee for the Electrical Section of the B.I. Fair for the hospitality extended to the Members of the General Council who were present at the luncheon ; and also an expression of the appreciation of the very great value of the Fair to the general engineering community.

Annual Meeting, 1931.

Mr. Norton, Hon. Secretary of the South Wales Branch, reported upon the provisional arrangements made in connection with this year's Annual Convention. It was decided that the dates of the Convention be from June 9th to the 13th inclusive. The Head Quarters of the Convention to be at the Royal Hotel, Cardiff. It was particularly requested that Members who proposed to attend should send in their names so soon as possible, so that requisite arrangements could be made and a well-organised programme provided.

The next General Council Meeting will be held in the forenoon on Friday, June 12th, 1931, at 9-30 a.m., followed by the Annual General Meeting at 2-30 p.m. on the same day.

President, Vice-Presidents, and Treasurer, Session 1931/32.

The following nominations for the principal offices were made :

President : Major E. Ivor David.
Vice-Presidents : Mr. F. Beckett and Mr. R. Ainsworth.
Treasurer : Mr. Roslyn Holiday.

Manufacturers' Specialities.

Electric Annealing of Aluminium.

One of the largest and most important aluminium works in this country is that of the Aluminium Corporation Ltd. at Dolgarrog, Carnarvonshire. In addition to the plant required for the production of aluminium in ingot and bar form, there is an extensive modern rolling mill for the manufacture of every kind of sheet product. The Company is thus enabled to supply the metal to each industry in the form most suitable for the particular purpose to which it is to be applied, and the Dolgarrog Works are perforce maintained at the highest standard of efficiency by the installation of the most modern equipment in every department.

One of the newest items of equipment is a furnace for the precise annealing of aluminium sheets on a large scale. The General Electric Co. Ltd. recently completed the installation of a large single track multi-car type electric annealing furnace which has an effective hearth area 24 ft. long by 7 ft. 5 ins. wide. This furnace has an electric loading of 150 k.w. the heating elements being arranged to ensure phasal balance on a 440 volt, three-phase, 50 cycle supply.

The correct disposition of the heating elements in a furnace of this size is of primary importance. Composed of high grade nickel-chromium alloy, the elements are placed on the side walls and in each section of the car hearth and also suspended from the roof. Those in the car hearth each constitute a self-contained and independent unit or circuit, and an interesting feature of design is the substitution of running contacts for the trailing cables more usually employed. This eliminates the danger and inconvenience which is invariably assoicated with trailing cables in such circumstances. The running contacts are situated below the cars, and are therefore virtually outside the furnace proper and not subjected to the heat of the furnace.

The roof elements are suspended by the patented method of the G.E.C., which ensures long life by relieving them of all strain and stress due to expansion and contraction. The furnace is electrically controlled automatically by gear which works in conjunction with G.E.C. "Witton" contactors. Fitted with this automatic control gear the furnace is operated at a temperature within five degrees of any predetermined setting of the instrument. An electrically driven time switch is capable of bringing the furnace to temperature in time for work to commence on Monday morning, the furnace being closed down for the week-end.

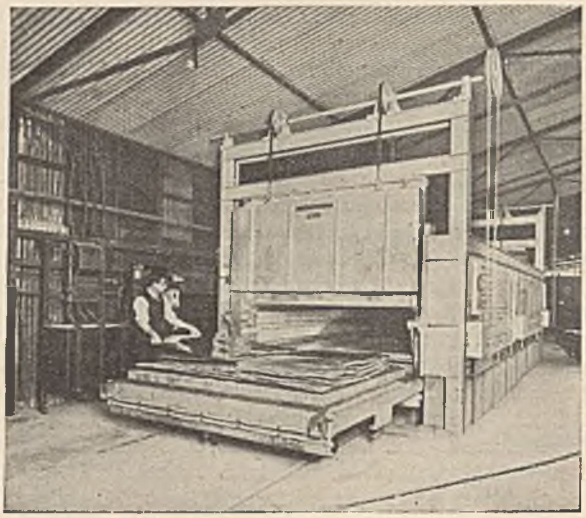

Fig. 2.—View from loading end, door open.

The doors at each end of the furnace are of the suspended counterweight type, well insulated and sand-sealed both at the top and bottom. Special switches are provided which automatically switch off the current from the car hearth when the doors are raised, and similarly switch on when they are closed.

The equipment comprises six cars or trolleys, on which the aluminium sheets are piled. There are four cars in the furnace at one time, and the two others are provided to facilitate cooling, loading and unloading. These cars are effectively sand-sealed along both sides and at the furnace ends and there is also an adequate seal between the ends of the adjoining cars. As each car is unloaded it is returned to the charging end along a rail track running parallel with the furnace.

It is of interest to note that this new "Magnet" furnace occupies the site of an older type of electric furnace which it has superseded, and is turning out a product of exceptional regularity and quality.

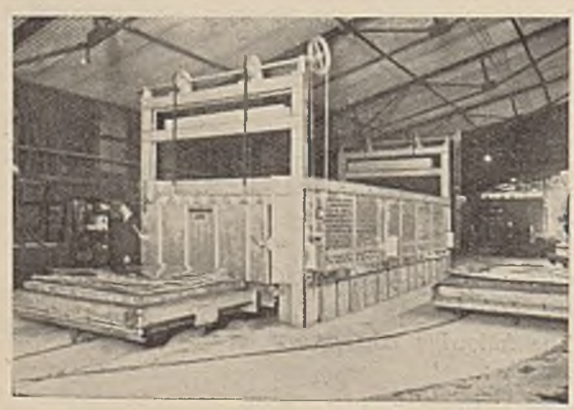

Fig. 1.—View from loading end shewing automatic control gear on left

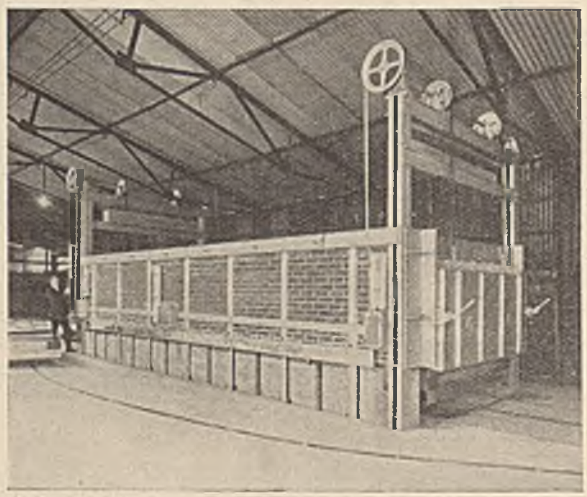

Fig. 3.—View from discharge end.