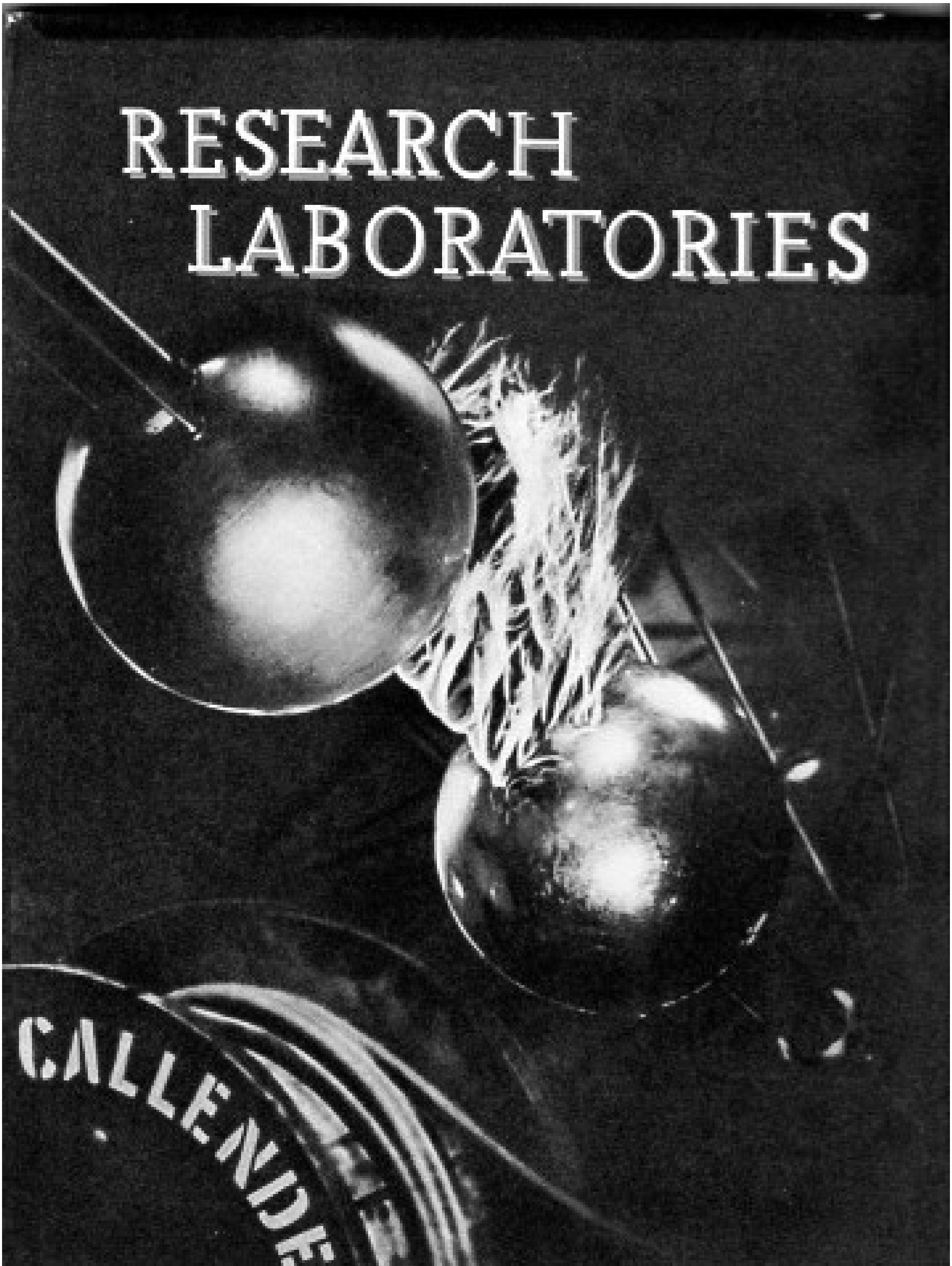
RESEARCH LABORATORIES



The cover shows a flashover at 1,400,000 v. peak voltage between the 1,000 mm. spheres. For this purpose, the two high voltage transformers are placed in cascade connection. The equipment can maintain a continuous supply of 1,000 kVA. at this voltage, or 2,000 kVA. on a two hour overload. The large kVA. capacity of the equipment is made necessary by the large capacitance currents required for the high voltage testing of cables. It also enables the effect of very high powered high voltage arcs to be studied.

RESEARCH LABORATORIES

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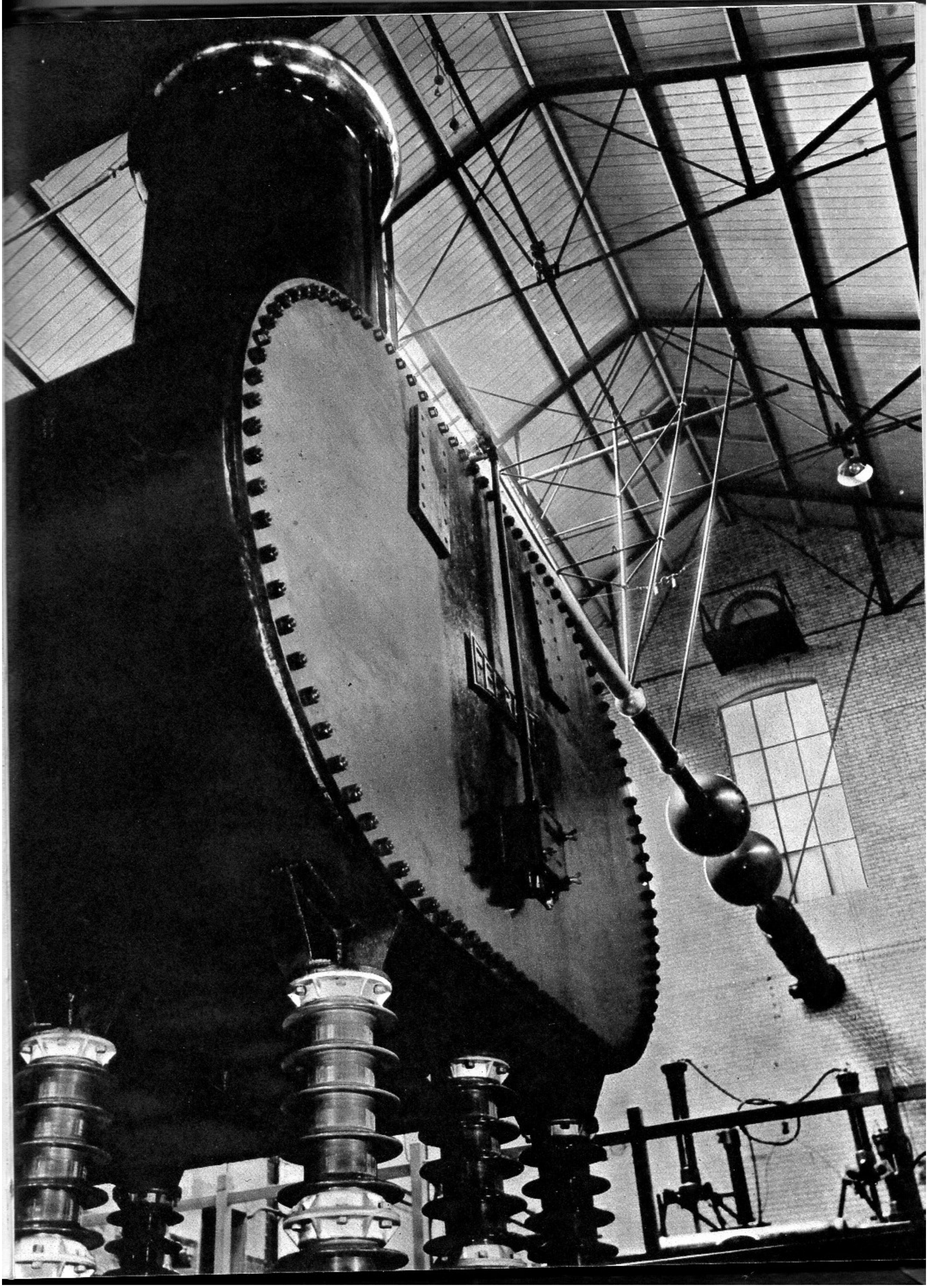
RESEARCH LABORATORIES

1934
CALLENDER'S
CABLE & CONSTRUCTION CO. LTD.

Plate I (*Frontispiece*)

TRANSFORMER

The photograph shows a view of No. 2 high voltage transformer and the 1,000 mm. sphere gap, which is used for high voltage measurements. The sphere gap has been mounted in a horizontal position to leave the floor space of the laboratory clear for experimental work. No. 2 transformer is mounted on porcelain insulators with a clearance to ground of 10 ft. to enable the two transformers to be connected in cascade. When testing in this manner at 1,000,000 v. the tank of No. 2 transformer is itself raised to 500,000 v. by No. 1 transformer.



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INTRODUCTION

It is probably true that in no other engineering field does the designer receive so little instruction and guidance from the application of established general principles and basic theory as in the practice of electrical insulation. Industry is impatient, and has had to progress without waiting for the slow formulation of fundamental theory. As a result, the insulation engineer has in the past found himself responsible for vast expenditures, with little but empirically gained experience for his guidance. The insulation engineer has generally not only no very definite theoretical guidance as to what kind of failure will occur, but he has also found that empirical test provides him with no well-defined boundary beyond which breakdown will arise. Failure is not a function solely of the stresses introduced, but is a function, as well, of the time over which the forces are applied. The insulation engineer has found in the past that the safe working stress in any particular case can only be determined by patient series of observations over a long period of time.

In these circumstances it is not surprising to find that in many respects it is the problem of electrical insulation which is holding back the fullest development of high voltage engineering for the transmission of large blocks of electrical power. These difficulties have almost prohibited the use of cables on the very highest voltage transmission systems and have rendered commercially unavoidable the use of overhead lines in positions and circumstances for which they are not entirely suitable.

Even in the case of transmission systems which are not of the very highest voltage, the difficulties and uncertainties facing the designer necessarily result in a cautious outlook which is reflected, ultimately, in the cost of cables relative to that of overhead lines.

It is in these general conditions that there have been assembled at Wood Lane research laboratories organised and equipped in a manner which will enable investigations to be carried out in any field related to the transmission of electrical power. The equipment provides for the highest voltage testing of extra high voltage cables, and of porcelain insulators, both A.C. and D.C., as well as for long time testing of lengths of buried cable under conditions exactly simulating those occurring in practice. The Dielectrics and Physics Laboratories enable bench studies to be made of dielectric behaviour on small samples of a wide variety of dielectrics, and the Chemistry Laboratory is available for the study of all chemical problems that arise. At the same time, the organisation of the laboratories provides for all kinds of research work, from an *ad hoc* test in the case of an urgent practical application, to prolonged investigations of a fundamental character, where it can be anticipated that the results will have a bearing upon transmission problems.

GENERAL ARRANGEMENT AND ORGANISATION

The laboratories occupy the buildings of the old Kensington and Notting Hill Power Station. The two main easterly buildings (H.V.1 and H.V.2) are occupied by two high voltage transformers (T.1 and T.2), each of 500 kv., 500 kvA. These laboratories are devoted to high voltage life tests on cables and auxiliary apparatus and flashover tests on porcelains. A corridor to the north contains the switchgear and motor alternators supplying the transformers.

The corridor on the south side is occupied by the high voltage D.C. equipment of the outside testing section. This section is concerned with the high voltage D.C. testing of completed contracts, and also with the location of faults in transmission systems. It also provides the equipment for any high voltage D.C. which may be required in the research sections.

The building in the south-west corner contains the cable life testing laboratory (H.V.3). This laboratory is concerned with long life tests on buried cables, the cables being tested with excess voltage and superimposed heat cycles. The cables are buried in loops of about 200 yards, to the south of the building in made-up soil, which is very representative of normal London conditions.

The building in the north-west corner (No. 4 Block) contains a medium-sized laboratory for general purpose investigations up to 120 kv. This is normally occupied by investigations into joint and sealing end design and in tests on short lengths of high voltage cable, and in addition with work which is

GENERAL PLAN OF LABORATORIES

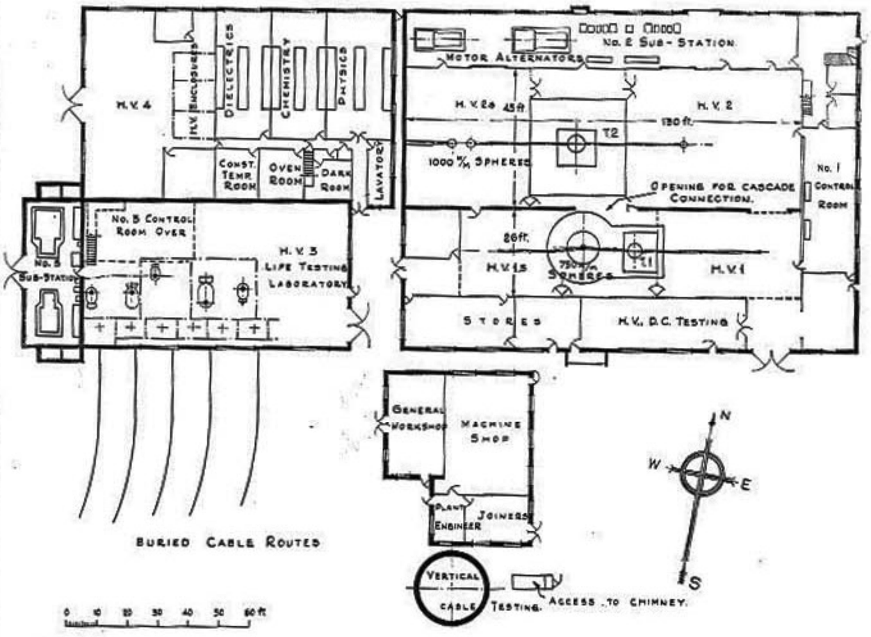
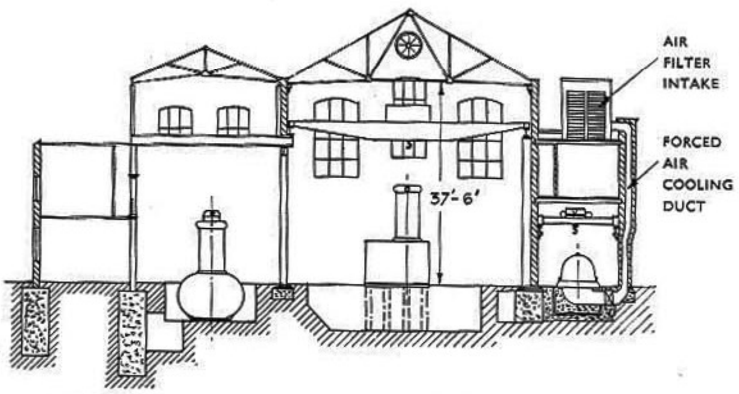


Fig. 1



SECTIONAL ELEVATION OF H.V. LABORATORIES.

LOOKING FROM EAST TO WEST.

0 10 20 30 40 50 60 ft.

Fig. 2

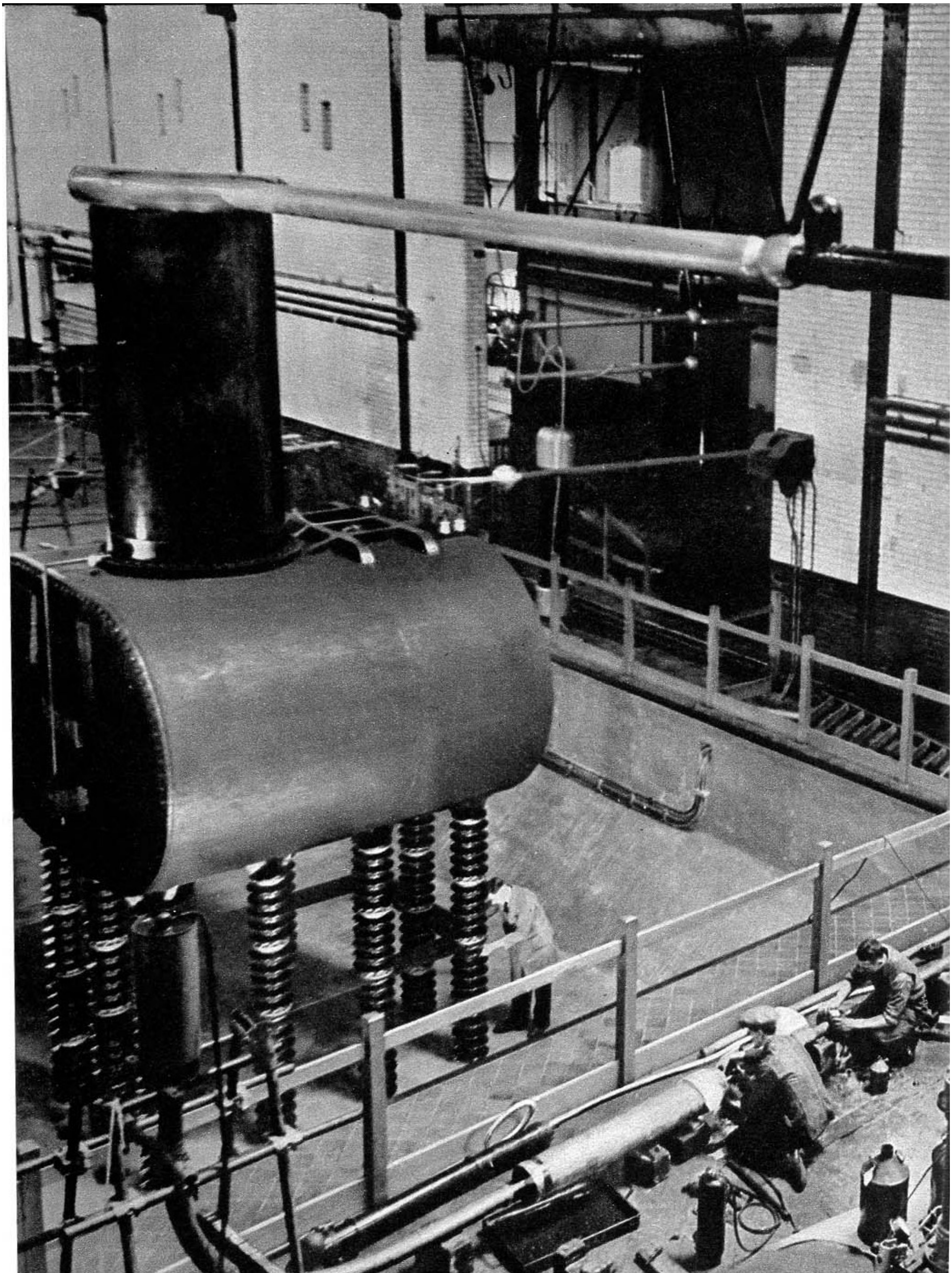
generally concerned with the theory and mechanism of breakdown of cable dielectric. The remainder of the building is cut up into smaller laboratories for dielectrics, chemistry and physics, together with a constant temperature room, oven room and dark room.

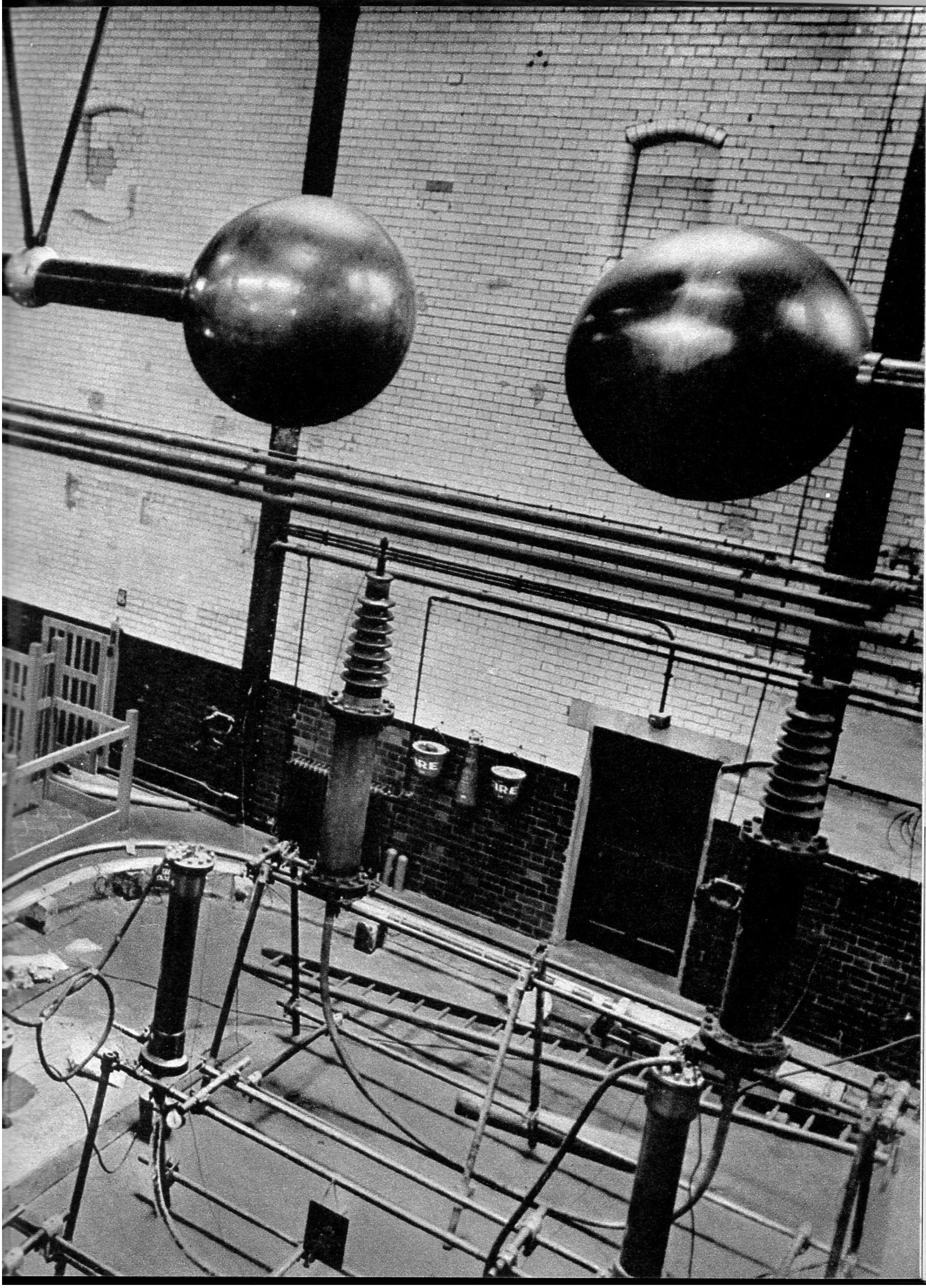
The main chimney shaft has been converted for use as a vertical cable testing laboratory. An internal staircase has been run up to a height of 120 ft., together with skeleton platforms at intervals of 20 ft. By these arrangements it is quite easy for clear vertical runs of 100 ft. of high voltage cable to be installed and tested. This laboratory is connected by duct line to the life testing laboratory, so that the tests can be carried out either by transformers located in the base of the chimney or by transformers located in H.V.3.

PLATE II

GENERAL VIEW OF HIGH VOLTAGE LABORATORY

The photograph shows the relation of the two high voltage transformers. No. 1 transformer can be seen through the large opening in the wall, which is necessary for bringing through the high voltage connections between the two transformers when they are operated in cascade. In the foreground a number of cables are being prepared ready for test.





EQUIPMENT

High Voltage Transformers

The two 500 kv., 500 kvA. transformers have been supplied by Messrs. Ferranti Ltd. The second transformer has been installed on porcelain insulators, with a clearance of 10 ft. in all directions to earth, so that the two transformers can be cascaded to give 1,000 kv., 1,000 kvA. In this case, the primary supply for the second transformer is obtained from a suitable winding which is located at the high voltage end of the secondary winding of the first transformer. This winding accounts for the difference between the tops of the bushings of the two transformers. In addition, the transformers can be operated in parallel, giving 500 kv., 1,000 kvA. In all cases the overload capacity of the transformers amounts to twice normal full load for two hours. This long time constant arises from the large proportion of insulating material and oil which is necessary for the high voltage insulation. The motor alternators, cabling and switchgear have, however, all been designed for the same overload capacity. It will be seen, therefore, that the transformers provide very large kvA. testing capacities. It is believed, in fact, that they are the largest transformers of this voltage available in the industry. The transformer capacity is also reflected in the transformer impedance figure, which has been brought down to the very low figure of 8·5 per cent. This low impedance is very important in enabling the effect of high-powered arcs to be studied.

The size of the transformers has, of course, been determined by considerations of the cable tests to be carried out.

As an example, the American Commonwealth Edison specification for 66 kv. single core cable calls for a test at 270 kv. At this voltage, one transformer would be fully loaded by a test on an 80 yard length of cable.

The lay-out of the transformers represents a departure from the normal high voltage laboratory practice. Instead of the transformers being located at the end of the available building, as is usual, each transformer has been located in the middle of its own laboratory. Each transformer can, therefore, command two working spaces. This feature is of very great importance in obtaining a good load factor on the testing time of the transformer. It is a common experience in a high voltage laboratory that the majority of the time is spent on preparations for test. In fact, it is quite feasible for the testing time to amount only to a few minutes per day. With the present arrangements, however, while the transformer is testing in one of its working areas, three or four tests are under preparation in the remaining area. Even with the greatest experimenting skill, it is not always possible to foretell whether any particular test will last a few minutes or, say, 200 to 300 hours. In these circumstances, therefore, an arrangement of this kind is of enormous

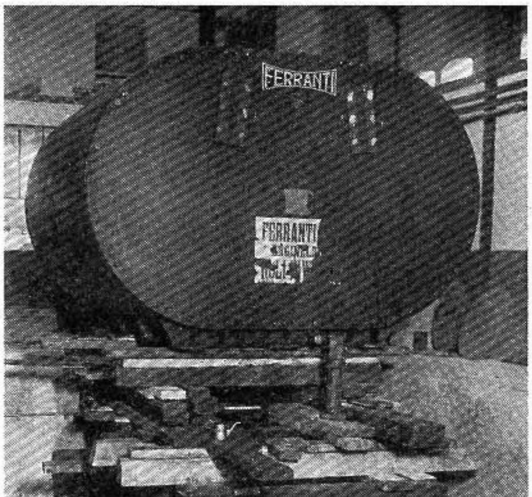


Fig. 3 *No. 1 Transformer in Course of Erection*

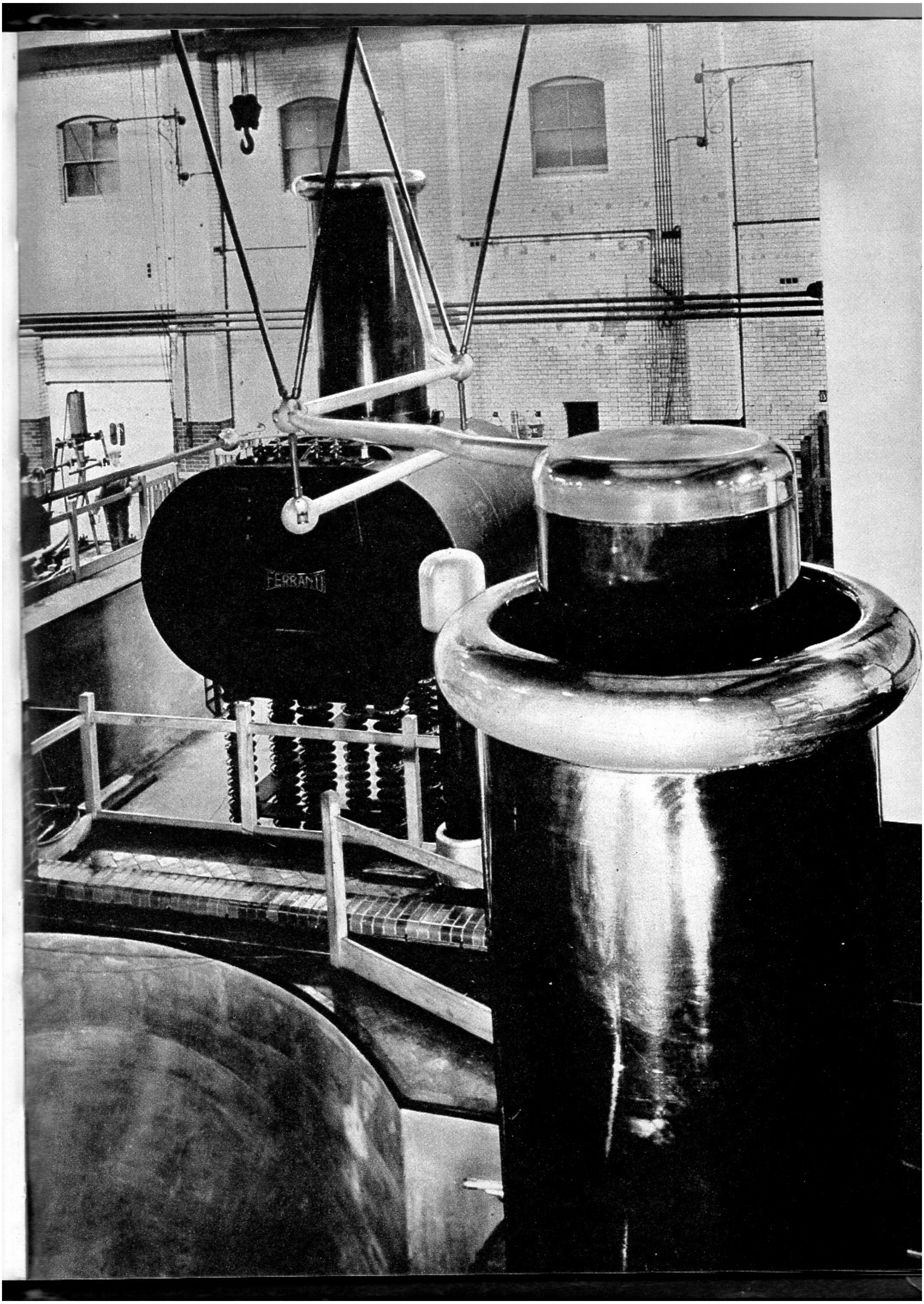
importance in keeping up the load factor not only of the transformers, but also of the whole of the laboratory organisation and personnel. It is interesting that with this arrangement it has proved possible for the two high voltage transformers to run for many weeks on end at a time load factor calculated on the actual testing periods of over 90 per cent.

Transformer Supply

Each transformer is supplied by a 3,000 volt single phase alternator driven by a synchronous motor which is connected to the alternator through a fluid gear, which provides an infinitely variable gear ratio over the range from 25 cycles to 75 cycles per second. The choice of this drive was determined largely by consideration of the measurements to be made on cables and other materials under test. One of the most important measurements is of the dielectric loss angle or power factor. This is carried out with a Schering bridge arrangement and a vibration galvanometer which has an extremely sharp response curve. A departure of 0·5 per cent. from the frequency to which the galvanometer is tuned results in a complete loss of galvanometer sensitivity. In routine testing, too much time is occupied if the galvanometer has to be continually tuned during the process of taking measurements, and it was therefore desirable that the frequency during a series of measurements should be held constant to about 0·1 per cent. This can, of course, be accomplished by utilising a synchronous motor if the incoming supply is drawn from one of the large grid systems. At the same time, it was desirable that other frequencies besides the supply frequency should be available for testing purposes. After consideration of a large number of alternatives, it was concluded that a synchronous

VIEW OF BOTH HIGH VOLTAGE TRANSFORMERS

The photograph shows the two transformers with the paralleling high voltage connection joining the two terminals. With this connection the two transformers will give an output of 1,000 kVA. *at 500* kV. *with an overload capacity of 2,000* kVA. *for two hours. In between the two transformers can be seen the compressed gas condenser suitable for continuous operation at 500* kV. *which is used as the standard capacitance for high voltage measurements of dielectric loss angle.*


FERRANTI

motor with a variable ratio fluid gear was the most suitable method to meet these requirements. For 50 cycle work the fluid gear can be locked, giving a straight through connection between the motor and the alternator. When the fluid gear is not locked, however, the frequency of the alternator output can be continuously varied; it can be brought to any required frequency within the precision of frequency measurement; and for any gradual or sudden changes of load it will hold this frequency within an accuracy of 0·1 per cent., with a time of recovery after any sudden change of load of about 2 secs.

Variable Ratio Fluid Gear

The fluid gears have been designed and manufactured by Messrs. Haslam & Newton Ltd., who were also responsible for the synchronous motors and alternators. The general idea of the continuously variable fluid gear has, of course, been known for a long time. A fluid pump is arranged with a variable crank throw or some other arrangement to enable the output of the pump to be varied. The output of the pump is then used to drive a fluid motor, and the gear ratio depends upon the adjustable output from the pump. The special feature of the Haslam & Newton design is that the surfaces of what are effectively the pistons and cylinders of the fluid pump and motor are so arranged that the pressure difference drives the surfaces into intimate contact in such a way as to form a complete oil seal.

The detailed mechanical design of the fluid gear is exceedingly complicated, but the main lines upon which it operates can be seen from Fig. 4.

The arrangements for remote control of the alternator speed and for automatic speed control during sudden changes of load are shown in Fig. 5. An extension of the alternator shaft carries the disc of a continuously variable friction gear. This gear is only required to drive a miniature differential, so that the load on the gear is negligibly small. The speed of the second member of the friction gear is matched by means of a mechanical differential against a miniature synchronous motor, which can be driven either from a tuning-fork or from the time-controlled supply if the latter holds a sufficiently constant frequency.

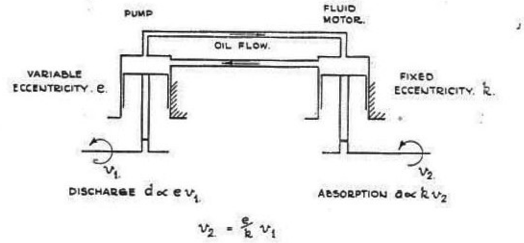
If the alternator speed, after correction in the ratio determined by the friction gear, differs from that of the miniature synchronous motor, a motion is communicated to the differential member of the differential gear. This motion is communicated, by means of electrical contacts, solenoids and a high pressure Servo motor, to the valve which operates the change of ratio of the main fluid gear. The fluid gear ratio will thus be changed until there is no differential motion between the two parts of the differential gear. It is of theoretical importance that a clutch is introduced between the differential member and the electrical contacts. If this clutch was not present, the arrangement would amount to positional matching between the two members of the differential gear. In this case, after any transitional drop in speed, it would be necessary for the speed to be raised above the equilibrium speed in order to recover the original positional relationship; and this introduces a serious risk of hunting occurring. The introduction of the clutch ensures that the ratio of the fluid gear is only altered when the speed of the alternator cannot be matched exactly against the reference speed.

The main synchronous motors and alternators are cooled by forced air ventilation. The ventilating fans and filters are

Fig. 4

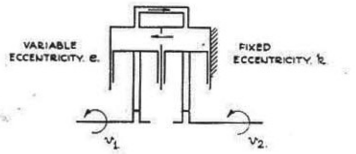
EVOLUTION OF THE FLUID GEAR.

1



$$v_2 = \frac{e}{k} v_1$$

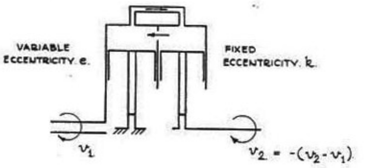
2



THE TWO CASES CAN BE COMBINED INTO ONE FIXED BODY, AND AS BEFORE:-

$$v_2 = \frac{e}{k} v_1$$

3

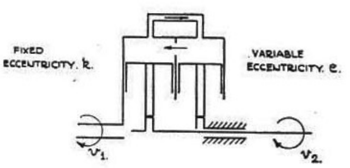


NOW GIVE THE WHOLE SYSTEM A ROTATION $-v_1$ i.e. OPPOSITE TO THE CRANK DIRECTION OF 1 & 2 THEN THE FIRST CRANK BECOMES THE STATIONARY FIXED BODY.

$$\text{THEN } v_2 = -\left(\frac{e}{k} v_1 - v_1\right) = v_1\left(\frac{k-e}{k}\right)$$

WHEN THE ECCENTRICITY $e = 0$, $v_2 = v_1$, i.e. BY REDUCING THE ECCENTRICITY TO ZERO THE TWO PARTS v_1 & v_2 ROTATE AS A SOLID BODY LOCKED BY THE INCOMPRESSABLE FLUID; THE 1 : 1 TRANSMISSION IS THUS ACCOMPLISHED WITHOUT ANY FLUID PUMP OR FLUID MOTOR ACTION.
THE FLUID TRANSMISSON ONLY HAS TO ACCOMPLISH THE DIFFERENCE BETWEEN THE OUTPUT SPEED v_2 AND THE INPUT SPEED v_1.
IN ADDITION THE MECHANISM FOR VARYING THE ECCENTRICITY HAS NOW ONLY TO BE DESIGNED FOR A FIXED CRANK INSTEAD OF A MOVING CRANK.

4



IN ORDER TO ENABLE THE MECHANICAL DESIGN TO BE ACCOMPLISHED REVERSE THE POSITIONS OF THE FIXED AND VARIABLE ECCENTRICS.

housed on the roof of the building. After passing through the motor alternators, the filtered air is passed into the main laboratory. In this way there is a continual supply to the laboratory of 13,000 cu. ft. per minute of filtered air, which contributes materially to the general cleanliness and to economy in the cleaning of insulators and bushings.

Safety Arrangements

In view of the large amount of preparation work it was required to carry out in the laboratory without interrupting the use of the transformers, it was necessary to give very careful consideration to the question of safety for the laboratory personnel. Complete safety has been achieved by connecting

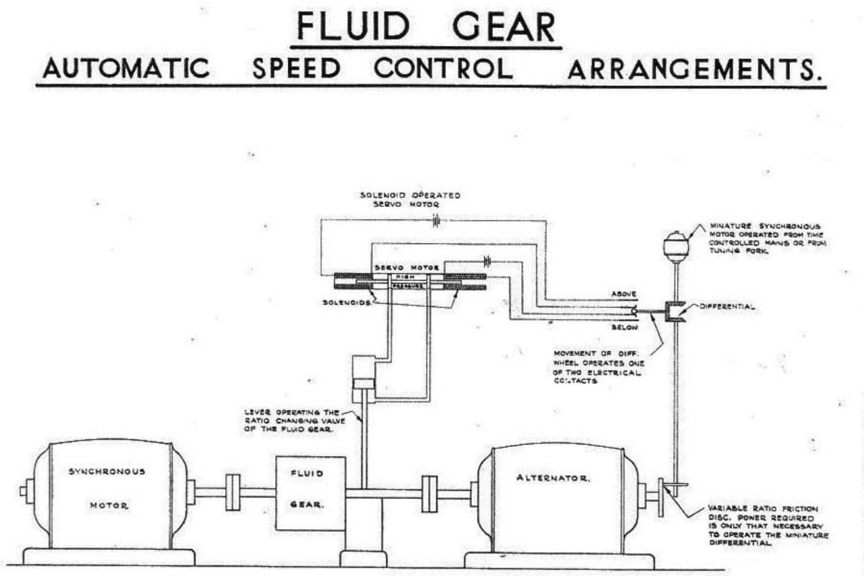


Fig. 5

each transformer into its working areas, one on each side of the transformer, by means of removable busbar links. Any particular section, therefore, can be made into a safe working area by removal of the link forming the high voltage connection. There are the usual arrangements by which the doors giving access to the laboratory are interlocked with the circuit breaker between the alternator and the transformer. In addition, however, arrangements have been made by which removal of the high voltage link on any one side of the transformer results in the door switches on that side of the transformer becoming short-circuited. In this way free access is given only to those portions of the laboratory which have been rendered safe by removal of the high voltage link.

Control Room

A single control room for the two laboratories has been obtained at a level 8 ft. above the laboratory floor level by opening a large window across nearly the whole width of the two laboratories. The two control desks provide for remote control of the A.C. solenoid operated circuit breaker between the alternator and the transformers; push button control with key-lock of the voltage by means of a motor-operated resistance potentiometer which is mounted in the circuit breaker cubicle in the substation; push button control with key-lock of the gap between measuring spheres; push button control of the shutting down of the motor alternators; and a night-switch which, if left in operation, ensures that in the event of a failure bringing out the circuit breaker the whole of the running machinery is automatically shut down.

In addition to the usual instruments, the following special instruments are embodied in the control desks. A gap indicator for the gap between spheres by means of a decade counter which gives a direct reading of the gap in millimetres. This is operated by means of contacts on the driving worm of the earthed sphere. In view of the high performance of the variable ratio fluid gear and the necessity of knowing accurately the frequency in order to make dielectric loss angle measurements, considerable attention was given to the question of frequency indicators. The final arrangement consists of a miniature alternator mounted on an extension of the main alternator shaft. This drives a miniature synchronous motor mounted under the control desk, which in turn drives a Bonniksen type of speedometer which is directly calibrated in frequency. This type of instrument is arranged to make more than one complete revolution of the pointer. This results in a very high reading sensitivity, while the main

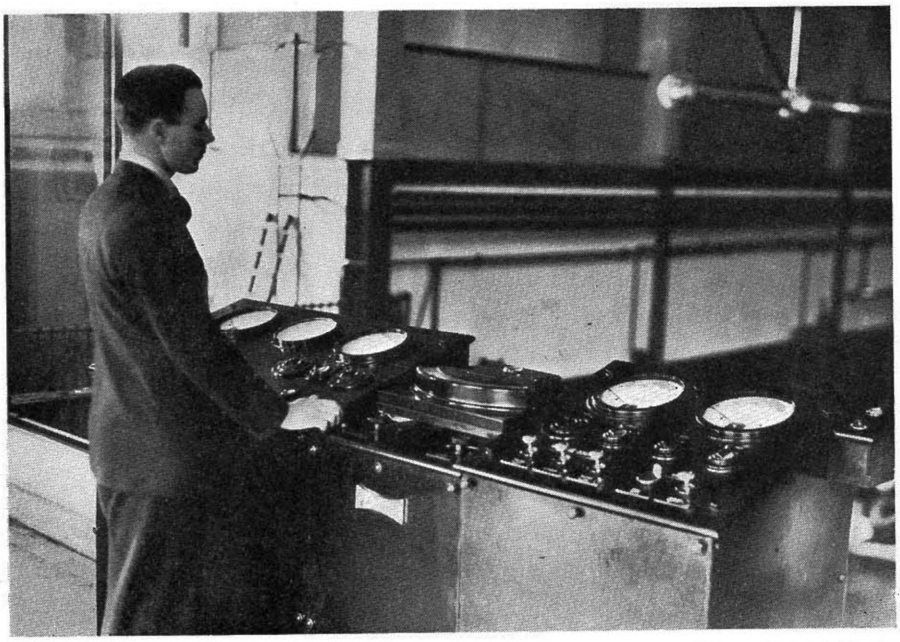


Fig. 6 *No. 1 Control Desk*

principles upon which the instrument is based ensures a high degree of absolute accuracy.

Measurement of High Voltage

A tertiary winding is embodied in the transformers which is connected to a direct reading voltmeter on the control desk. This ensures that a good approximation to the secondary voltage is always immediately available to the control engineer, but it is naturally not possible to rely upon the ratio between the tertiary and the secondary windings holding for different voltages and different loads. For accurate high voltage measurements, therefore, two other methods are used.

In the peak rectifying voltmeter, the secondary voltage is applied to a high voltage condenser. The laboratory contains a compressed gas condenser suitable for continuous running at 500 kv. R.M.S. This condenser is of the guarded type and is normally used for dielectric loss angle measurements up to this voltage. It is, however, of course, always available for voltage measurements when required. The capacity current passing through the condenser is then rectified and measured on a D.C. instrument. It can then be shown that apart from certain exceptional cases, the D.C. current is a true measure of the peak voltage whatever the wave form of the voltage may be. In publications made from the laboratory,* it has been shown that with suitable arrangement of the circuit including over-biasing of the rectifying valves the method can be considered to give an absolute measurement of the high voltage with an accuracy

*STARR, A. T., "The Rectifying Peak Voltmeter as a Standard Instrument," *Proceedings of the Physical Society*, Vol. xlvi, Part 1, No. 242, Jan. 1, 1934, page 35.

dependent only upon the accuracy with which the capacitance of the high voltage condenser is known.

Normally, however, it is of greater interest to know the R.M.S. value of the secondary voltage. For this purpose, a method of utilising the Schering bridge which has been developed in the laboratory is extensively used. This method is shown in Fig. 7.

The secondary voltage is applied through the high voltage condenser to one arm of the Schering bridge, while at the same time the tertiary voltage or even the primary voltage is applied through a much larger capacitance (which, however, need, of course, only be a low voltage condenser) to the

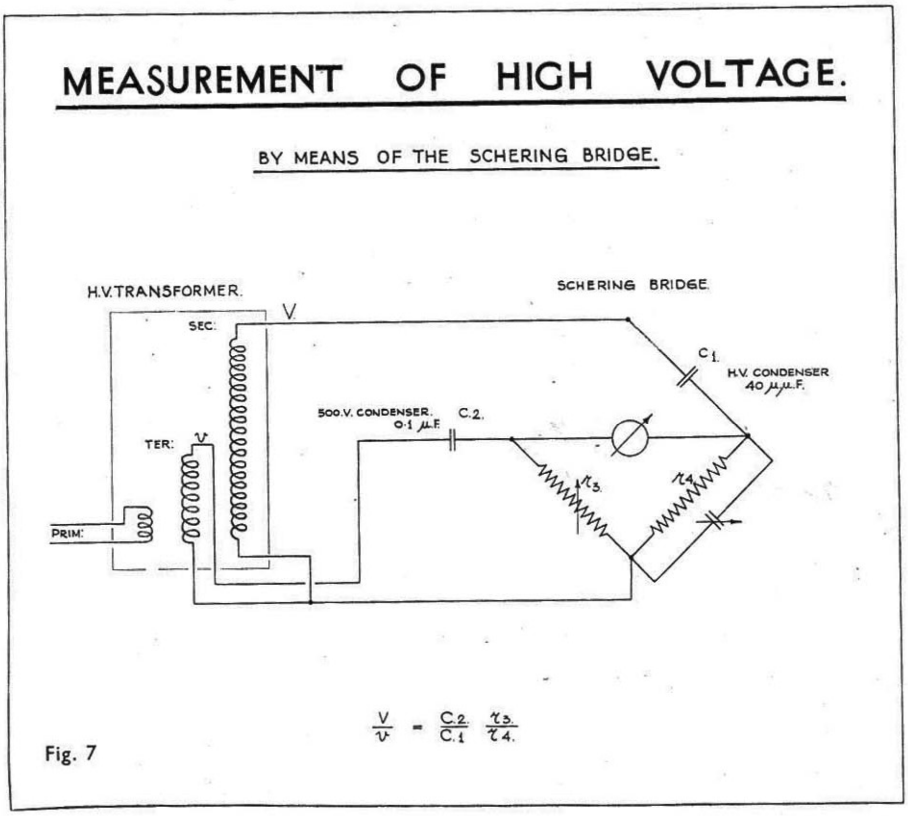


Fig. 7

other arm of the Schering bridge. When the bridge is balanced, the ratio of the secondary to the tertiary voltage is given in terms of the bridge resistance readings, and the ratio of capacitances of the two condensers. As all these quantities can be measured with a high degree of accuracy, it is quite easy by this method to get a knowledge of the ratio of the two voltages to within an accuracy of better than 1 part in 1,000. The voltage ratio calibration can be carried out with any condition of loading on the transformer. It is, moreover, of great practical convenience that the voltage ratio calibration can be carried out without carrying out accurate measurements of any voltage at the same time. Subsequently, during actual testing operations, the tertiary voltage is measured with any required degree of accuracy, and the previously determined voltage ratio then gives the secondary R.M.S. voltage.

Protection

In investigating the cause of the breakdown of cable dielectric, it is of great importance that the supply circuit breaker should be brought out with the minimum delay after the dielectric has failed, in order that the evidence provided by the dielectric is not destroyed by general burning of the cable. For this purpose, therefore, protection arrangements provide for continuously variable settings from 1 per cent. of full load up to twice full load. Two relays are provided, one in each core of the supply to the transformer. These are fed by tapped current transformers, which provide for coarse adjustment, while the relay itself is continuously variable for fine adjustment between transformer tappings. Ammeters are provided to show the control engineer the current flowing in the relay coils, and in this way it is always possible for the relay to be adjusted to a position which is only very slightly in excess of the testing condition at any particular moment. This extremely sensitive protection has proved of the very greatest importance in the study of the mechanism of cable failure.

Temperature Measurements

A knowledge of the temperature distribution along a cable under test is extremely helpful for enabling incipient faults to be arrested at any desired stage of development. It also provides advance indication of cable failure, which greatly facilitates the organisation of the work of the laboratory. For this reason, over 100 thermocouple points have been run out to connection points situated in various parts of the laboratory, so that thermocouples fitted on to any cable can easily be connected through to the control room. By means of an interchange board, any fifty thermocouples can be connected through to a 50-way rotary switch. This rotary switch is a standard telephone manufacture, but it has been developed in the laboratory to meet these particular requirements. The rotary switch connects one thermocouple on to a standard thread recorder for one minute intervals, the rotary switch being impulsed one step forward by operation of the chopper bar. In this way, the thread recorder will keep under constant record all the cables that may be under test in the laboratory. The thread recorder record gives a repeated series of small patterns, each of which represents, in effect, a curve of temperature distribution along a particular cable. Arrangements are made by which any positions on the rotary switch which it is not required to record are left out by the wipers, so that

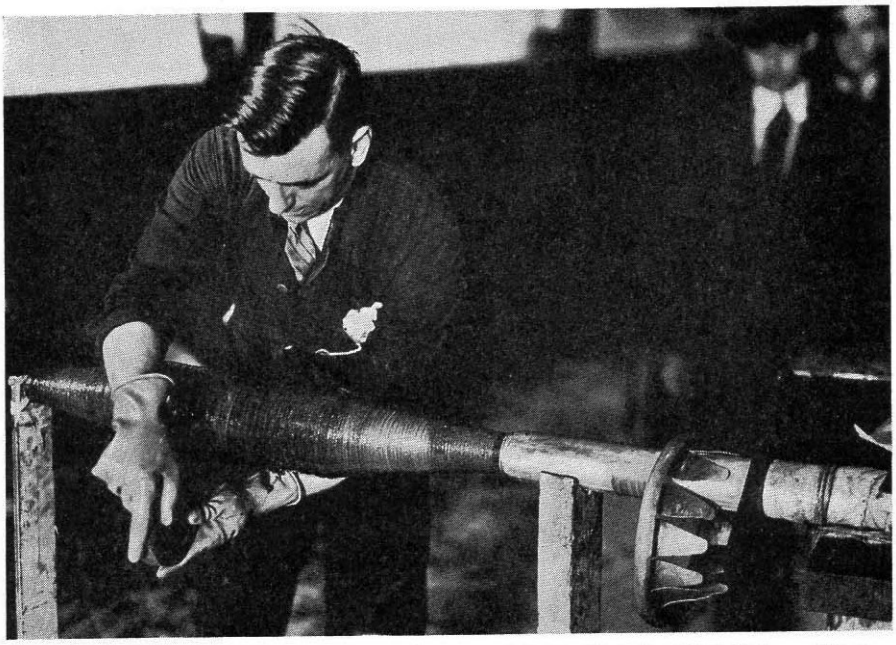


Fig. 8 *Preparation of Cable End for High Voltage Testing*

time is not spent in searching over these. The switch can be brought immediately to any particular thermocouple which it may be required to observe specially, and can be left continuously on this position. Many other circuit arrangements can be effected by this system, which has proved to be extremely convenient and flexible in use.

In addition, a double bridge resistance-measuring circuit is run round to various points in the laboratory, so that resistance measurements for the purpose of temperature estimation can easily be carried out at any position in the laboratory.

Schering Bridge Measurements

Low capacity leads, suitable for Schering bridge measurements of dielectric loss angle, have been run out to various positions in the laboratory and completely screened interchange boxes have been developed which enable the control engineer to plug into any cable under test and to make measurements of the dielectric loss angle without interruption of the test in any way.

The Control Room is equipped with a Coe harmonic analyser, a low voltage cathode ray oscillograph and a three-element Duddell-Mather Cambridge oscillograph.

CABLE LIFE TESTING TRANSFORMERS

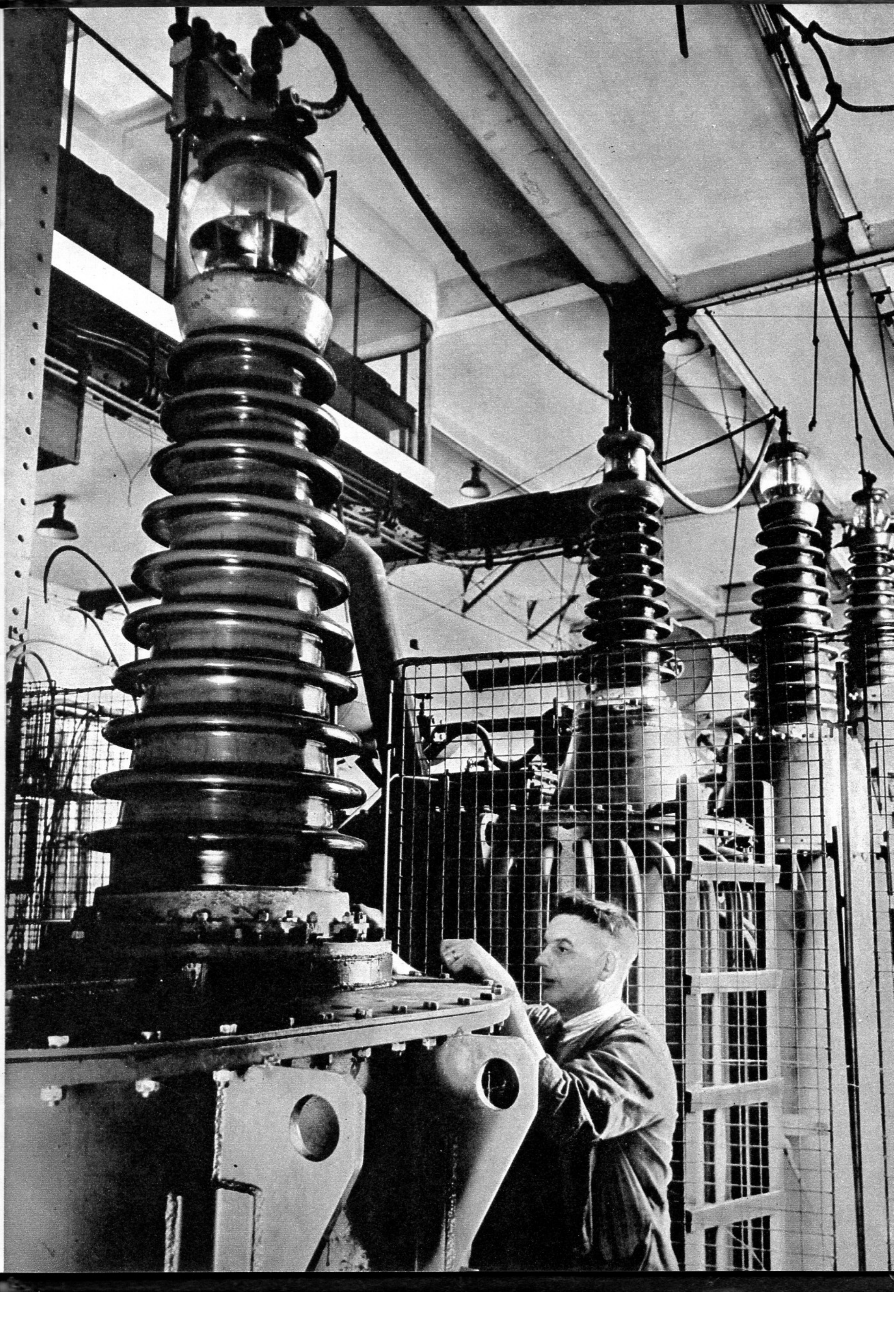
In the cable life testing laboratory, equipment has been installed to enable long life tests to be carried out on 66 kv. and 132 kv. cable at twice working voltage. Here again the capacity of the transformers has been determined by the consideration that it was desirable to test 200 yards of cable at these voltages. The two high voltage transformers are for 1,000 kVA. at 170 kv., and 500 kVA. at 85 kv. In addition, in order to supply the superimposed loading current for submitting the cables to heat cycles, there are two transformers supplying 750 amps. at 76 volts, the secondary winding, however, being completely insulated for 170 kv. in both cases. This enables the two transformers to be operated together in parallel or series on the highest voltage tests. In addition, there is a potential transformer, ratio 170,000/110, for the measurement of high voltage. These five transformers are of particular interest in that two electrostatic screens have been introduced between the primary and the secondary windings. For reasons which have been set out in publications from the laboratory,* it is not possible when dielectric loss angle measurements are to be made on cables which are buried, and in which the lead sheath is, therefore, compulsorily earthed, for measurements of high accuracy to be made unless the transformers are equipped with double screens in this manner. Apart also from accuracy, the arrangement has the great advantage in routine working that measurements can

*Brazier, L. G., "Dielectric Loss Angle Measurements of Multi-core High Tension Cables, with special reference to the Schering Bridge," *J.I.E.E.*, June, 1931, page 757.

Plate IV

CABLE LIFE TESTING EQUIPMENT

The photograph shows some of the cable life testing transformers. Equipment has been installed which will test under working conditions with superimposed heat cycles, 66 kV. cable and 132 kV. cable at twice working voltage. These equipments are for 500 kVA. and 1,000 kVA. respectively. The cable heating current transformers provide a total of 1,500 amperes, insulated for a voltage of 170,000 v. to earth.



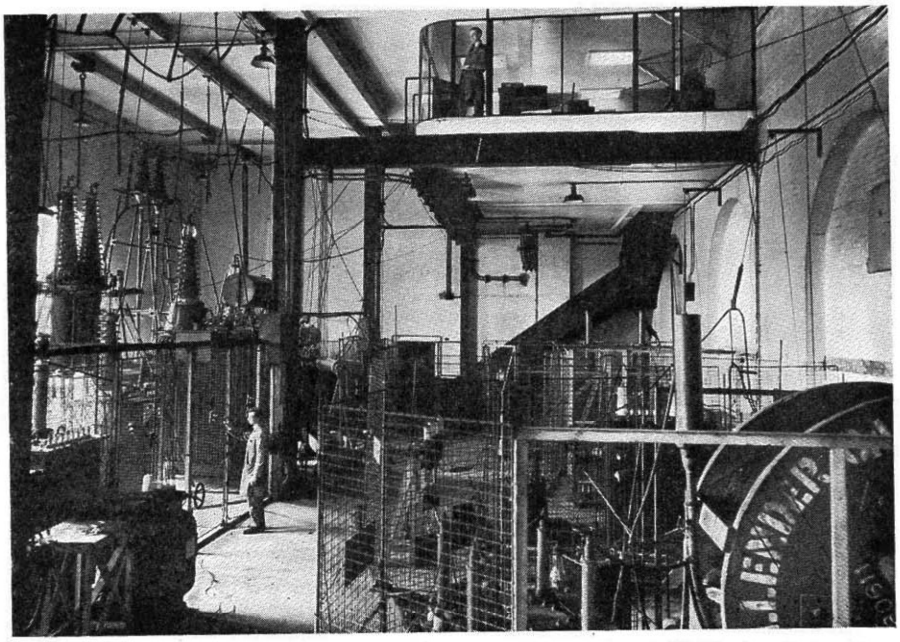


Fig. 9 *General View of Cable Life Testing Laboratory*

be made on buried cables without the necessity of taking a preliminary measurement of the transformer and lead losses, and vectorially subtracting these from the total result. Thus, for routine working, the number of measurements to be made is reduced by half.

The high voltage transformers are supplied from single phase alternators, and, as before, these are driven by synchronous motors. The primary voltage is 3,000 volts, as in the case of the high voltage transformers, so that the equipment is interchangeable, should such a desirability ever arise.

The loading current transformers are supplied at 800 volts from buck and boost induction regulators, operated direct on the 400 volts supply. The control room of this laboratory has been suspended under the roof, in order to provide the maximum head-room in the space below. The control desks provide for push button release of the main high voltage circuit breakers, hand control of the voltage regulators and remote control of the loading current circuit breaker and regulators.

The protection arrangements of the high voltage transformers include not only adjustable current relays as in the case of the main high voltage transformers, but also a relay which is operated by a watt movement. The purpose of this feature is to ensure that the circuit breaker is brought out in those cases where a fault on a long length of cable will not result in an increase of the current to the primary of the transformers.

The whole of the cable life testing equipment has been supplied by the British Thomson-Houston Company Limited.

MEASUREMENT OF DIELECTRIC LOSS ANGLE OF A BURIED CABLE WITH SHEATH EARTHED.

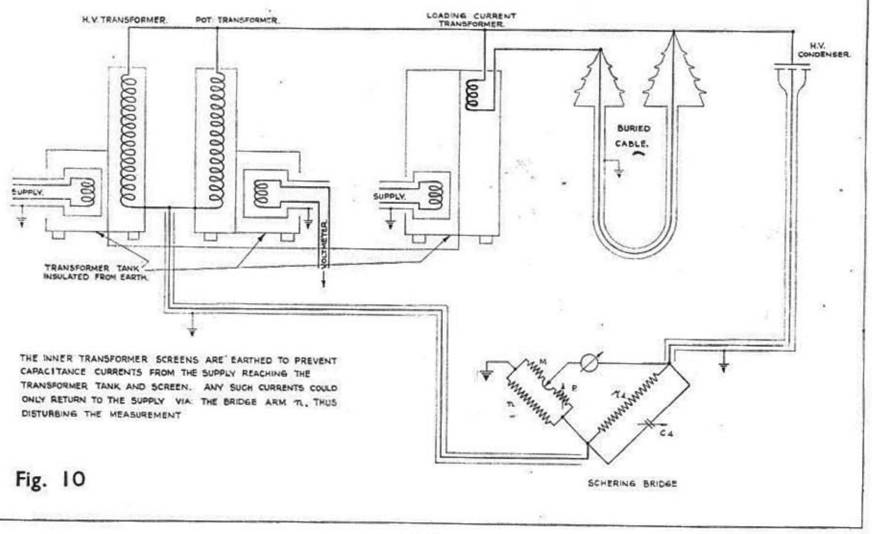


Fig. 10

The control room is equipped in the same manner as the control room of the main high voltage laboratory, with thermocouple connections and recorders, with centralised resistance measuring arrangements and with centralised arrangements for dielectric loss angle measurements on all cables.

HIGH VOLTAGE D.C. EQUIPMENT

A special system has been developed in the laboratory for the production of high D.C. voltage from an alternating current supply. This equipment has been developed by the section of the laboratory which deals with the testing of completed contracts. It has the special feature that all the units required are very small, so that they can be carried into any position in the field. In addition, the units are largely interchangeable. The arrangement, therefore, has the additional advantage that sets for a low voltage can be adapted for a higher voltage by the addition of further components, and not by the substitution of a completely new equipment.

The method depends, as is usual, on the cascading of rectifying valves, but the special feature of the Callender-Smith connection is the inclusion of isolating transformers in various parts of the circuit, the purpose of which is to separate the A.C. stresses from the D.C. stresses, so as to enable these to be taken on suitably designed insulation.

The equipment available in the laboratory gives a supply of 400 kv. D.C. to earth, but there is no difficulty, when the need arises, for further stages to be added, giving voltages to at least double this figure. The circuit arrangement of the Callender-Smith connection is shown in Fig. 11 and a photograph of the equipment in Fig. 12.

The high voltage D.C. equipment is also used by the section of the laboratory which is concerned with the location of faults on long cable routes and transmission lines. In the case especially of London underground cables, the enormous cost of excavation and reinstatement makes high precision location of the very greatest financial importance. The methods developed in the laboratory aim at localisation to an accuracy of 1 yard in 1,000 yards; and at the present time, the accuracy achieved in practice is only limited by factors which are outside the control of the locating engineer, such as an accurate knowledge of the cable length and the uniformity of the copper conductivity.

Where a fault occurs on one core of the feeder and the insulation completely breaks down, location of the fault is a comparatively easy matter. In practice many difficulties arise which have required special methods to be developed for their solution. It is of general experience in high voltage cables that a fault does not completely break down the insulation, but the fault retains a resistance of perhaps

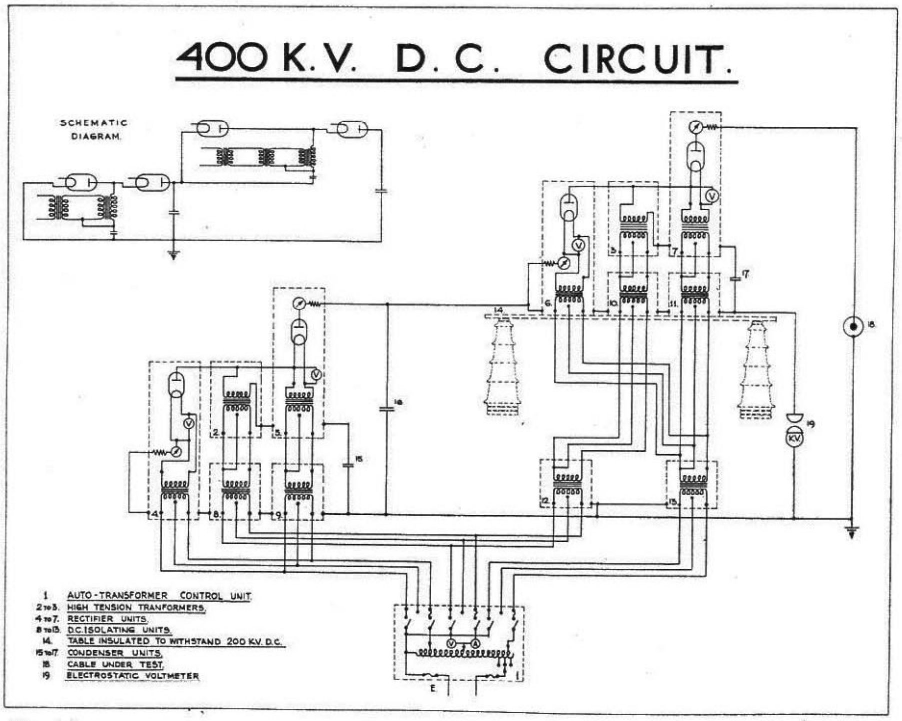


Fig. 11

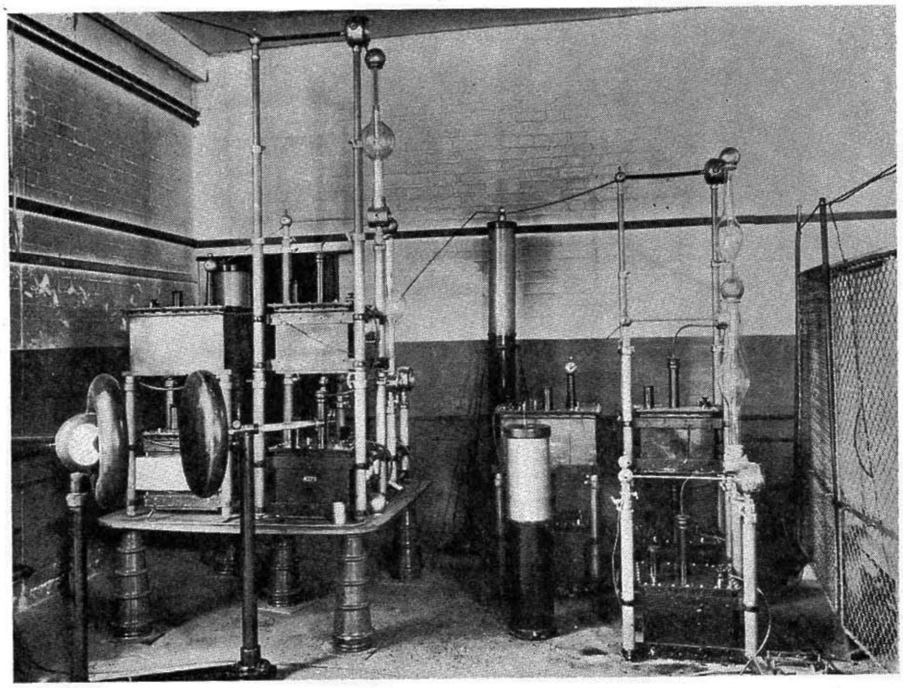


Fig. 12 *High Voltage D.C. Equipment*

100 megohms. In these circumstances, a high voltage bridge is used in which the bridge and controls are all raised to a voltage which may amount to 60 kv. for the purpose of getting sufficient current through the fault to make measurement possible. Other types of faults occur in which all three cores may be completely disconnected, and special methods, described in publications from the laboratory,* are necessary in this case. These methods are of special importance at the present time, because as a result of the interconnection of large power stations by means of the National Grid, there has been an enormous increase in the magnitude of fault currents,

*URMSTON, J., "The Electrical High Pressure Testing of Cables and the Localisation of Faults," *J.I.E.E.*, Vol. lxix, 1931, page 983.

with the result that complete disconnection of the conductors tends to occur more frequently. As a result, it has been found desirable to develop suitable apparatus for the rapid practical application of the principles described in the paper quoted above.

Joint failures may also be particularly difficult in those cases in which the breakdown takes the form of an intermittent flashover with no permanent impairment of the insulation. In these cases, the location has to depend solely upon measurements of the flashover current. It is satisfactory that it is now possible to say that all types of fault that can occur in practice can be located by measurements made at the feeder terminations.

GENERAL EQUIPMENT

The laboratory contains a number of other transformers up to a voltage of 120 kv., and these are utilised for the development of cable accessories, such as joints and sealing ends, and for general research into the theory and mechanism of cable dielectric failure, where this work can be carried out at medium high voltage.

In the Dielectrics Laboratory equipment has been installed for the purpose of testing condensers made of various dielectrics. The results obtained from this work depend very largely upon the control which is exercised in the conditioning

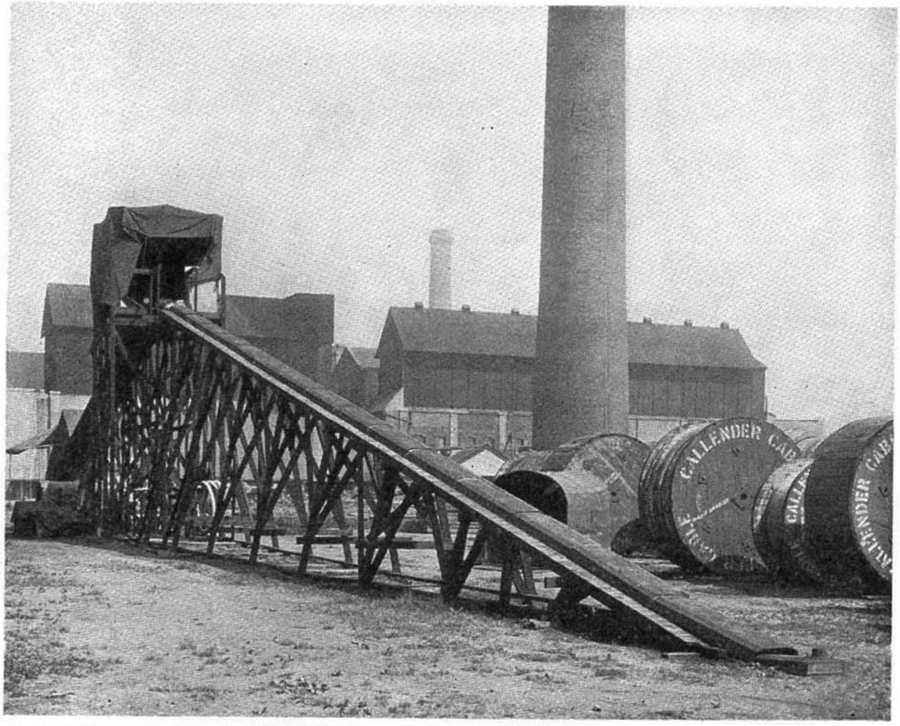


Fig. 13 *Ramp for Testing High Voltage Cables and Joints under difficult laying conditions. The chimney, which is used for testing high voltage cables suspended vertically, is also shown*

of the materials and the manufacture of the condensers. In the case of impregnated paper condensers it is necessary to control very carefully the drying time and temperature of the paper and oil, and the exact technique of the vacuum impregnation of the condensers. Several investigations are in progress to determine the improvement that can be obtained from the use of pressure in the case of a number of different dielectrics, and for this purpose a number of containers suitable for the preparation and testing of condensers in a pressure up to 250 lb. per square inch have been constructed. In association with the Dielectrics Laboratory is an oven room for the conditioning of the paper and compound, and a constant temperature room for the conditioning and testing of the condensers, and also for general laboratory use. All the testing enclosures of the medium high voltage laboratory (H.V.4) and of the constant temperature room are connected by means of low capacity leads to a completely screened interchange board in the Dielectrics Laboratory, so that any enclosure can be connected on to any of the measuring bridges in the Dielectrics Laboratory. The laboratory also contains suitable bridges and cylindrical condensers for the study of the properties of oils and compounds.

The Physics Laboratory houses various physical investigations as they arise from the main problems, from time to time. At the present moment, there is available a high frequency equipment, giving an output of 10,000 volts at 200,000 cycles. This is used in the study of the mechanism of cable dielectric breakdown. There is also, at the present moment, a supersonic equipment with which the efficiency of extremely high frequency elastic waves as a degasifying agent in compounds and oils is being studied. This laboratory is also the headquarters of various auxiliary investigations

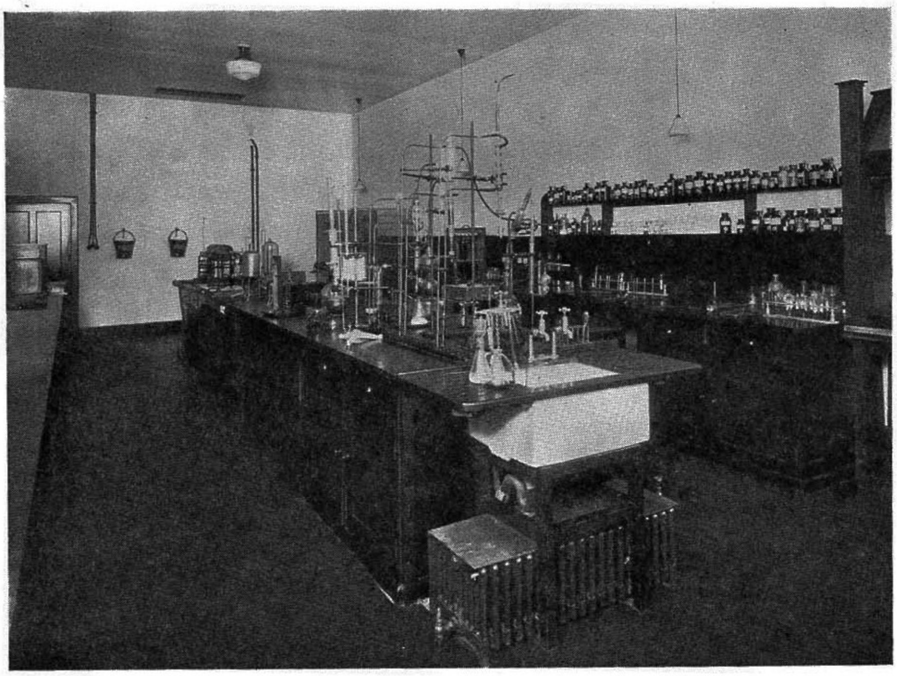


Fig. 14 *Chemistry Laboratory*

such as methods of determining the thickness of lead sheathing, without cutting the lead sheath, and the development of high performance fuses.

The Chemistry Laboratory is available for all chemical researches that arise in the course of the main investigations. Close co-operation between the Chemistry Laboratory and the physical section has resulted in the production of a technique which has proved to be of the utmost importance in the examination of cables after testing or after failures.

Factory Liaison

Close contact with the Factory is ensured by a section of the Research Department which is permanently located at the Factory itself. This section actually operates a high voltage laboratory located in the Factory grounds, which is employed for the type testing of cables and other Factory products which do not contain especially novel features. In addition, the section maintains a continuous series of investigations into the performance of the manufacturing plant and methods of improving the performance or the design. Regular meetings between this section and the research staff at Wood Lane ensure that the laboratories are in real contact with the problems arising at the Factory, and they also provide for the easy setting up of *ad hoc* investigations when these are found necessary to meet Factory requirements.

Statistical Section

Modern statistical analysis is largely devoted to methods of obtaining the maximum number of reliable conclusions from a minimum number of experimental results. In a high voltage laboratory where the cost of individual tests generally amounts to very large sums, a statistical section is therefore of the greatest possible importance.

A statistical section has therefore been set up in the laboratory. This section has the important duty of collating the test figures for all the Factory products. Small changes are necessarily made in the manufacturing specifications from time to time, and the test results of products immediately before and after these changes are scrutinised by the section and subjected to the latest method of statistical analysis for the purpose of determining whether any significant change can be attributed to the alteration of manufacturing procedure. In addition, the section is, of course, immediately available for all the research staff, and as a result much valuable work is done both in ensuring in advance that the research programmes will provide data in the most suitable form, and also by subjecting the conclusions from any research to a statistical scrutiny.