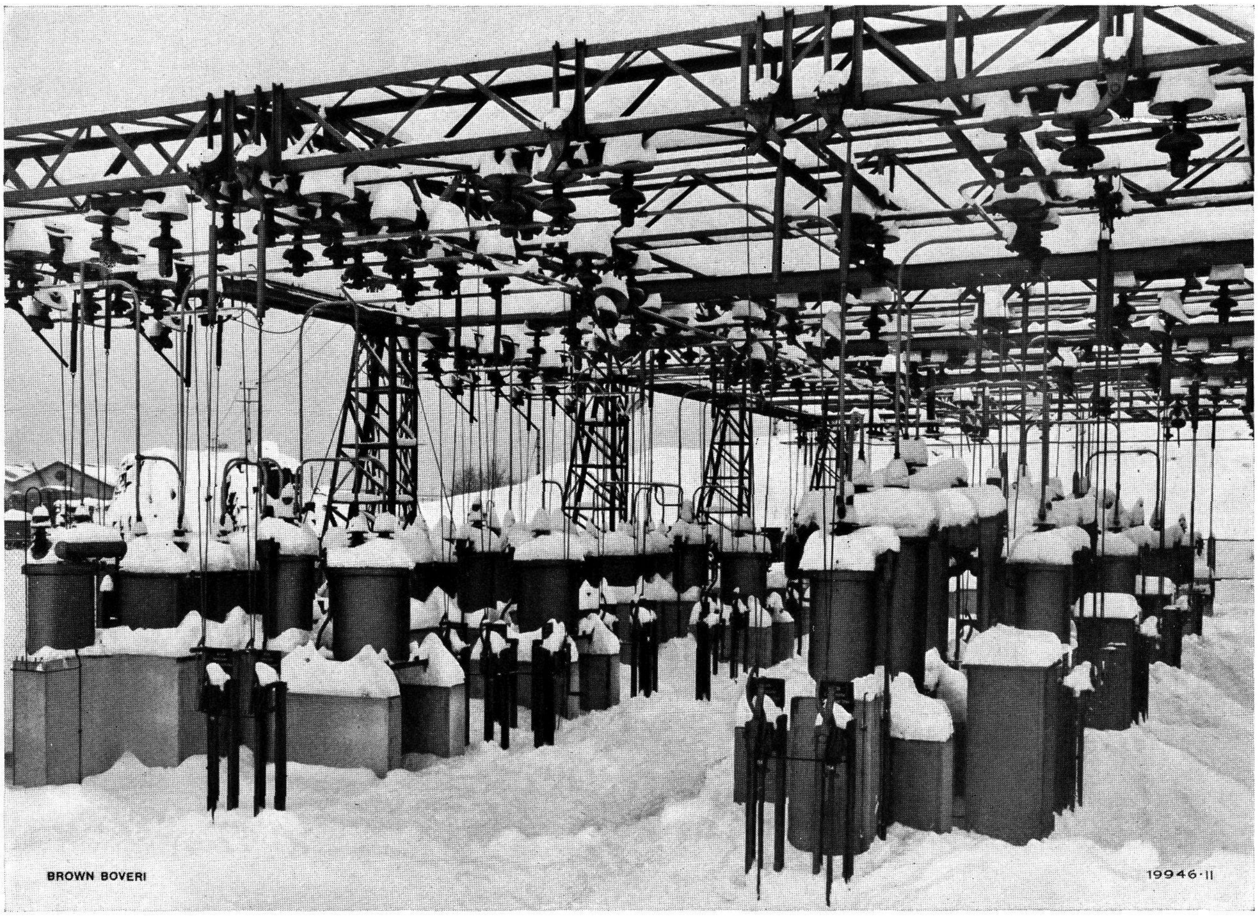
VOL. XIII MAY, 1926 No. 5

THE BROWN BOVERI REVIEW

EDITED BY BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND)



PART OF THE BRUGG SUBSTATION OF THE SWISS FEDERAL RAILWAYS, AFTER THE HEAVY SNOWFALL IN JANUARY, 1926.

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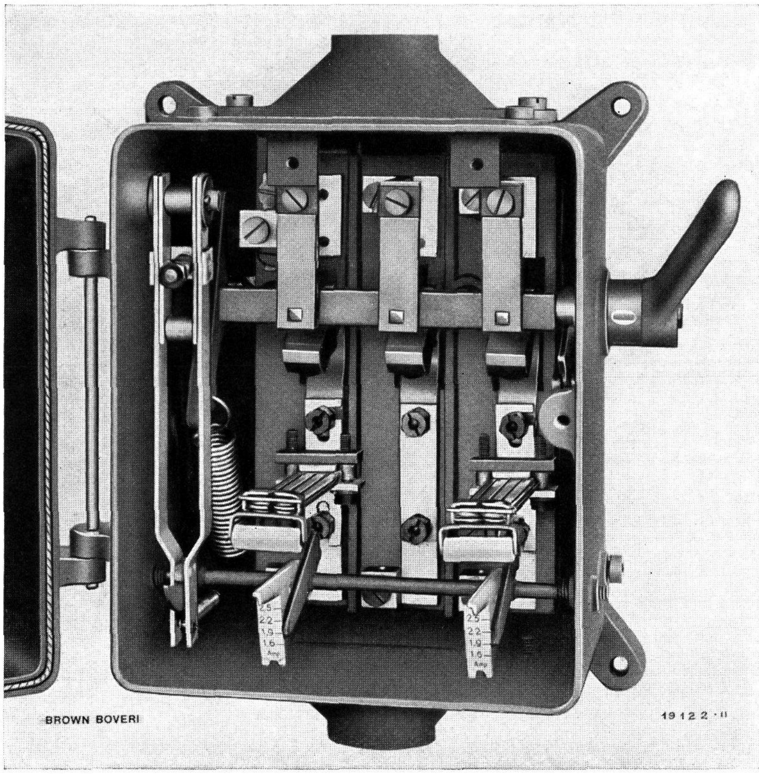
SWITCHBOXES TYPE L

WITH

COMPOUND STRIP TEMPERATURE RELEASE

PERFECT PROTECTION FOR ELECTRIC MOTORS



SWITCHBOX TYPE L WITH COMPOUND STRIP TEMPERATURE RELEASE,
rated pressure 660 V, rated current 64 A, breaking capacity 250 kVA.

ACCURATELY SUITED TO THE CHARACTERISTICS OF THE MOTOR

ADJUSTABLE TO ANY DESIRED TRIPPING CURRENT

NO FUSES - NO REPLACEMENTS

PROTECTION AGAINST SHORT CIRCUITS AND DAMAGE FROM OVERHEATING

SIMPLE CONSTRUCTION - RELIABLE IN SERVICE - LOW PRICE

THE BROWN BOVERI REVIEW

THE HOUSE JOURNAL OF BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND)

VOL. XIII MAY, 1926 No. 5

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BREAKDOWNS IN INSULATING MATERIAL.

Decimal Index 621. 319. 37.

I. INTRODUCTION.

VERY little is known to-day of the occurrances accompanying the breakdown of a solid insulation. One of the causes of the breakdown is reported in the following article. A practical explanation of this phenomenon has been found from the research work which has been carried out during recent years in the Brown Boveri testing laboratories. The fundamental principles for the calculation of the breakdown stress of a solid insulator under continued strain, are repeated in this article, and some mention is also made of the tests on which the theory has been based[1], and the verification of it which has taken place.

It is known that a solid insulation does not behave as a pure capacity. On the application of an alternating pressure, a current having a phase displacement of less than 90^0 flows in the insulating material. The watt component requires an output which is continually turned to heat in the insulator, i. e., the dielectric loss.

For a long time, measurements of dielectric losses have been carried out in the Brown Boveri high-tension testing laboratories. The measuring apparatus used is described in the Brown Boveri Review, 1923, No. 8, p. 152. Hard paper materials known as Bituba products were principally tested.

[1] See also Bulletin des S. E. V., 1926, No. 2.

II. THE DIELECTRIC LOSSES.

In order to form an idea of the occurrances present when an insulating material breaks down through heating, the magnitude and the degree to which the dielectric losses of the field strength depend upon the alternating current, frequency, and the temperature will be mentioned.

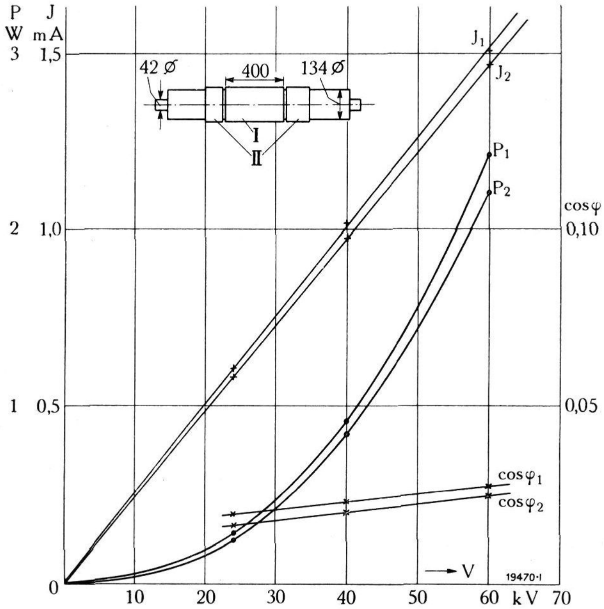

Fig. 1. — Dielectric loss P, current J, and loss factor cos φ as a function of the pressure, for two Bituba tubes tested at 18° C, 50 cycles.

I. Measured covering. II. Protection covering.

1. *Relation between dielectric losses and strength of field (pressure).*

Fig. 1 shows the results of measuring the losses in two Bituba tubes, dimensioned as shown; these were tested at 18^0 C under alternating current at 50 cycles. In addition to the loss and current, the loss factor

$$\cos\varphi = \frac{\text{loss}}{\text{current} \times \text{pressure}}$$ has also been plotted.

As shown in Fig. 1, cos φ increases slightly with the pressure. The losses increase rather more rapidly than the square of pressure. This has been established for many cases, not only for Bituba but also for shellac-micafolium and other insulating materials.

For this phenomenon, two explanations are possible.

(a) Air pockets are enclosed in the wound insulator tubes and these begin to become luminous at high field strengths. The corona involves a more rapid loss in the insulator. It is to be assumed that the air layers occur in different thicknesses. With an increasing pressure, at first the thicker, and afterwards the thinner, air pockets become luminous, owing to the greater dielectric strength of thin air layers. This loss caused by corona in the enclosed air spaces, was measured on a model. The corona was produced between two glass plates having a thickness of about

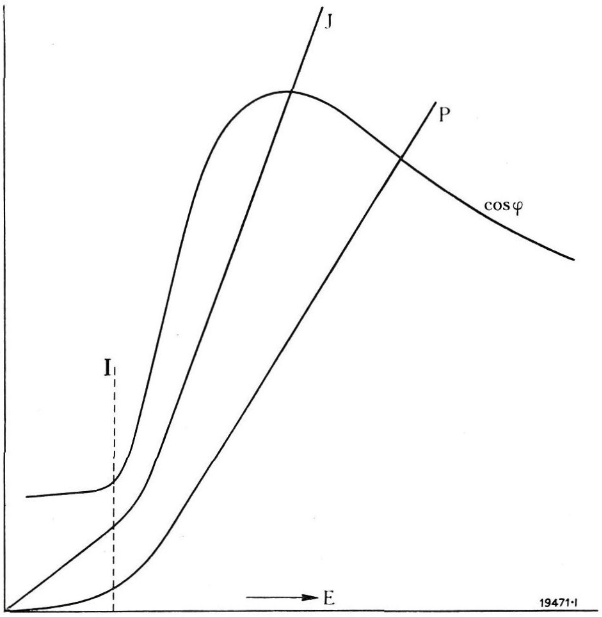

Fig. 2. — Loss P, current J, loss factor cos φ as a function of the pressure E, for series connection of two glass plates with an air gap between them, at 20° C, 50 cycles.

I. Initial pressure for corona.

three millimetres, and set up about 0·6 mm apart. A large increase in cos φ was noticed when the corona started, the characteristic being as shown in Fig. 2. The losses and current increase with a nearly lineal relationship to the increased pressure, while cos φ reaches a maximum and then falls again. The curves reproduced in Fig. 2 were obtained with an alternating current of 50 cycles; if a current with a frequency of 100 cycles had been employed the curves would have been similar but the maximum value of cos φ would not have been so well defined. It is also possible to explain the increase in cos φ with the pressure by means of the corona effect of the enclosed air gaps. The presence of various thick air layers flattens the rise of cos φ and displaces the maximum for still greater values of the pressure, hence the general behaviour is similar to that observed when using Bituba. F. Dubsky[1] has investigated the height of the corona pressure for thin layers of air. Attention is drawn to the fact that the corona pressure is essentially below the theoretical value for a clean material if the surface is covered with salt or is dirty. The surface of a Bituba tube, which was not absolutely clean, was shown to glow after the intervening air had been stressed to an effective pressure of 11 kV/cm, while that between clean electrodes requires a stress of 21 kV/cm before it breaks down; sensitised paper was used as a recording medium.

(b) A second explanation for the losses increasing more rapidly that the square of the pressure, at constant temperature, is that moisture is present in the fabric.

The researches of S. Evershed[2] have shown that moisture-containing fabrics have an increased capacity for conducting at increased pressure. Exceptionally interesting and valuable conclusions which have already been partly confirmed in the Brown Boveri laboratories, have been drawn from this work. By corona effects and enclosed moisture, the behaviour of Bituba under various pressures may be explained.

2. *The relation between dielectric loss and temperature.*

A large number of experiments have shown that the losses depend upon the temperature (Fig. 3). The dependency of the temperature can vary greatly between different fabrics and also between different series of fabrics. The ratio of the losses at 90° C as compared with those at 20° C or at 40° C, can be taken as a practical value. 90° C was chosen as a standard because this is the highest permissible temperature for the transformer oil. Good hard paper has a small value for the ratio $\frac{P_{90}}{P_{20}}$, whereas a poor quality paper has a correspondingly higher value. It has

[1] F. Dubsky, the dielectric strength of air films. Proceedings of the A. I. E. E. 1919, Vol. 38.

[2] S. Evershed "The characteristics of insulation resistance". Journal of the Institute of Electrical Engineers 1913/1914 No. 52.

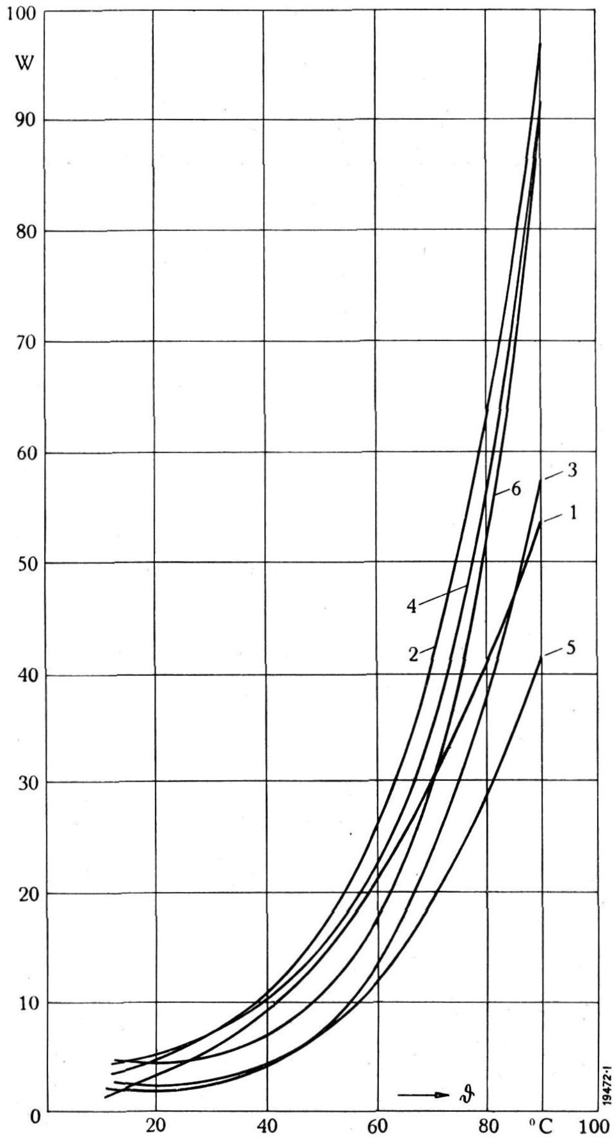

Fig. 3. — Dielectric losses as a function of the temperature for three hard paper tubes.

1. Losses in tube No. 1 at 50 cycles
2. „ „ „ „ „ „ 100 „
3. „ „ „ „ 2 „ 50 „
4. „ „ „ „ „ „ 100 „
5. „ „ „ „ 3 „ 50 „
6. „ „ „ „ „ „ 100 „

not yet been decided how the increase of the losses with rise of temperature may be explained physically. The property is present with all electrolytes. The ohmic resistance of these materials have negative temperature coefficients. A possible explanation results from the analogy that hard paper contains water which involves losses. The resistance of the water falls considerably at higher temperatures, therefore the losses increase. However, even with pure Bakelite there is an appreciable increase in the losses with increasing temperatures.

3. *The relation between the dielectric losses and the frequency.*

Measurements were also made with frequencies of 50 and 100 cycles at different temperatures. The test pieces were completely immersed in oil at a constant temperature. At first a current with a frequency of 50 cycles was applied to the test piece and measurements taken, then it was immediately changed-over for current at 100 cycles. With current at a frequency of 100 cycles the mean value of the losses was 1·7 times those with current at 50 cycles for the same pressure and temperature. If the losses in the same test piece are measured when direct current is applied, they are only a few per cent of the value obtained with a current of 50 cycles frequency. The actual leakage losses are therefore not important. Almost all of the losses arise through the reversal of the polarity.

The best explanation of the occurence of these losses is probably that of hysteresis of the dielectric. This hysteresis has been evaluated by two mathematical processes. Firstly, the Maxwell theory on layered dielectrics as expounded by K. W. Wagner's theory for non-homogeneous and layer dielectrics.

Secondly, by applying the theory of molecular movement. Many pairs of electrical poles do not instantly adjust themselves to agree with the electrical field. This theory has been discussed by E. v. Schweidler.

Actually, in view of the above theory, the values of the dielectric losses calculated by Wagner seem to agree with the measured results, as shown in the article by F. Tank[1].

III. DESCRIPTION OF BREAKDOWN THROUGH HEAT.

The occurence can be explained by using a hard-paper bushing as an example, as shown diagrammatically in Fig. 4. The tests have shown that such a material approximately retains it homogeneity. The losses at

[1] F. Tank. Annalen der Physik, Vol. 48 No. 3, and Dissertation, Zurich, 1915: "Ueber den Zusammenhang der dielektrischen Effektverluste und Kondensatoren mit den Anomalien der Ladung und der Leitung."

places, at the same temperature and field strengths, in different elements of volume may be considered to be equally large. For simplicity the heat resistance of the insulating material will not be taken into account. The whole resistance is assumed to be present only on the surface. The insulator under these conditions is at a uniform temperature all over; only at the edge there is a temperature gradient to the surrounding air. An alternating pressure, applied between the flange F and the stud D, causes a current to flow (Fig. 4), and electrical energy passes into the insulator. This energy is partly stored up as energy of potential and partly converted into heat, as change of polarity is always accompanied by losses. The insulator is assumed to have successfully withstood the first pressure impulse. Very soon a stationary state is established, and a wattmeter which measures the electrical losses in the insulator indicates an approximately constant input.

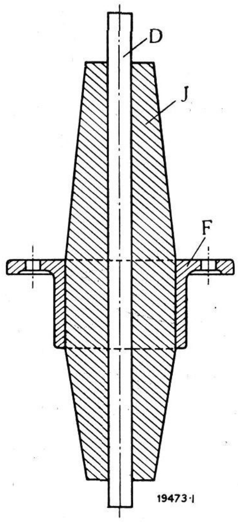

Fig. 4. — Diagrammatic view of bushing.
D. Lead-in stud.
J. Insulating material.
F. Flange.

This loss may be greater or smaller, according to the temperature of the material; generally, it increases with the temperature. Further occurrences in the bushing are represented in Fig. 5. If the bushing is left alone its temperature is ϑ_a °C. Soon after the alternating pressure E_1 is applied the dielectric losses may be shown by P_{10}, and the heat dissipation is zero. The electric losses P_{10} thus serve exclusively for heating the bushing. The temperature continues to rise and the losses increase as shown by the curve P_1. At the same time the bushing commences to disperse part of the heat generated, as shown by the curve Q. The difference between the ordinates of the two curves, P_1—Q, represents the output which heats the bushing. This continues until there is no difference in the output. At S the heat produced is completely dissipated i. e., the condition is stationary. This position is also stable, as a slight accidental increase of the temperature would produce a negative difference P_1—Q, therefore the bushing would again cool to the point S. The temperature attained by the bushing is given by ϑ_s. The dielectric losses produced by the pressure E_1 are continually carried off at this pressure; the temperature is in a state of stable equilibrium.

Assuming that the pressure is increased from the value E_1 to E_2. The losses corresponding to the pressure, also increase, as shown by the curve P_2. The losses increase to P_{21}, to a point depending on the point S in the previous case. The difference now between curves P_2 and Q represents the further heating of the bushing. At first this difference decreases with increasing temperature, but it never reaches a zero value, i.e., the bushing still heats up and the losses continue to increase. The heat dispersed also increases, and from a definite point, the two curves separate without crossing each other. The dispersal of heat becomes more inadequate and the material rapidly becomes self heating. The losses (the watt current) increase so that the material assumes the properties of a conductor subjected to a heating

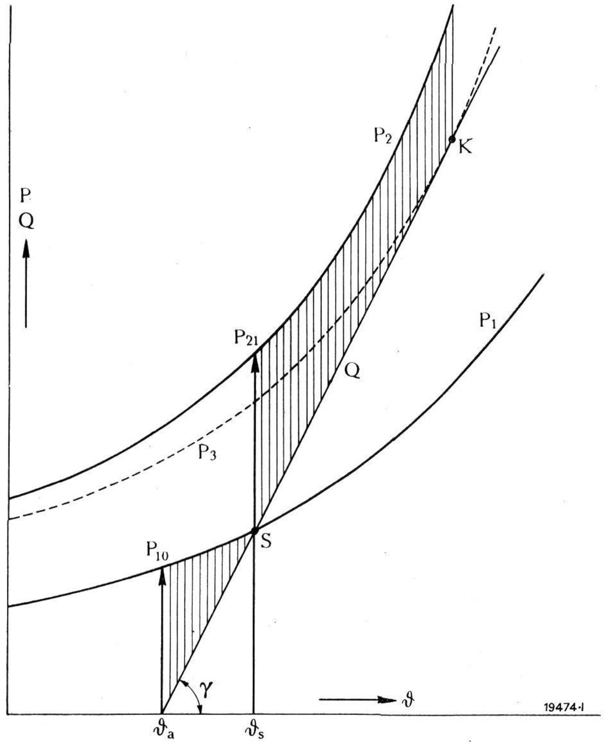

Fig. 5. — Dielectric losses P and dispersed heat Q as a function of the temperature.

P_1. Dielectric losses of the bushing with pressure E_1, as a function of the temperature.
P_2. Dielectric losses of the bushing with pressure E_2, as a function of the temperature.
Q. Heat dispersed by bushing, also as a function of temperature.
ϑ_s. Temperature of bushing.
ϑ_a. External air temperature.

current, with the result that the temperature rises and finally the insulating material breaks down, i.e., chars or melts. The occurrence is similar to that of the magnesium strip in a Nernst lamp.

If current flowed through the stud, heat would be developed there, and if the stud were not liberally dimensioned, part of the heating current would tend to pass through the insulation. In a high-tension cable the total heating current is forced to act in this manner, hence a loaded cable will not withstand so high an alternating-current potential for such a long time as a cable on no-load. These facts have been proved by experience.

In order to judge whether an insulating material is suitable for given conditions, i. e., heating current in the conductor and external temperature, it must be known whether a balance of heat can be obtained, i.e., the relation between the losses, temperature, and the resistance to heat; the latter determines the angle γ in Fig. 5, while cot γ gives the heat resistance. The highest pressure with which balance is possible is shown by the curve P_3 to which the line Q is tangential. The tangent point, however, does not represent a stable condition, as with a slight accidental increase of temperature the losses increase more rapidly than the rate at which the heat generated is dissipated. The difference between the two quantities is very small and the conditions only get worse slowly. The point K is the limiting point at which a condition of balance may obtain. The values of the pressure, loss and temperature as given by K are the limiting pressure, limiting loss, and limiting temperature. This temperature may be regarded as the upper limit of temperature above which a stationary heat balance cannot be realised for continuous service. It is thus easy to see that an insulation can withstand, for a short time, a considerably higher pressure without sustaining damage, if during continuous service it is stressed with less than its limiting pressure. It is a question of the heat capacity of the material.

IV. VARIOUS KINDS OF BREAKDOWN DUE TO HEATING.

The example given shows that the following points are of vital importance when dealing with insulation breakdowns:—

(a) The magnitude of the losses produced.
(b) How they depend on the temperature.
(c) How they are distributed in the insulator.
(d) How the heat is removed from the insulator.

The first two conditions are dependent upon the nature of the insulating material, the pressure and external temperature. It is difficult to determine by measurement how the losses in the insulating material are divided among the small elements of volume, assuming constant temperature and field strength. In a moulded material, or porcelain, or in a very thin layer, bad places may occur, usually as threads, bubbles etc. Examination of such pieces has shown that the breakdowns mostly occur along fine cracks or threads. In a hard paper tube, however, composed of many layers wound one on the other, it is extremely improbable that defects in the paper finally coincide. A wound tube may be considered as a comparatively homogeneous material, having an equal distribution of the losses at constant temperature and field strength.

The distribution of the field strength of the insulator also influences the distribution of the losses. For example, this is different in cables carrying direct, or alternating current, as soon as a temperature difference is formed. With direct current, the pressure distribution is determined by the ohmic resistance of the various layers, but with alternating current it depends largely on the partial capacities. The hot spots in a direct-current cable are automatically relieved from the pressure and losses; in a cable carrying alternating current, however, this is less likely to be the case, because the ohmic resistance depends much more on the temperature than the dielectric constant.

The fourth point, the dissipation of the heat, comes into consideration when referring to the varying division of the losses. When dealing with a heated thread of bad material enclosed in a non-homogeneous substance, chiefly the heat resistance in a direction perpendicular to the thread is considered but, on the contrary in a homogeneous material the internal resistance to heat, as well as that on the surface, must be considered. Various theories, as shown in the following table, have been based on these starting points.

Author	Distribution of the losses	Direction of flow of heat	Resistance to heat	Suitable for
Wagner[1]	In threads (canal theory)	Normal to the thread and to electric field	In the insulating material	Direct current and alternating current
Rogowski[2]	Uniform	Parallel to the electric field	In the insulating material	Direct current
Dreyfus[3]	Uniform	Parallel to the electric field	In the insulator and on the edge	Alternating current

V. THE RELATION BETWEEN THE ALLOWABLE CONTINUED PRESSURE AND THE THICKNESS OF THE INSULATING LAYER.

The choice of the thickness of the insulating layer to withstand a continuous stress is undoubtedly one of the most important technical problem. The canal theory of Wagner assumes that a thread of bad material in an insulator, considered as a plate, produces large losses. A good example is furnished by a long continuous specimen composed of insulating material and placed, in oil or air, under the influence of a constant field. A definite amount of energy, which is radiated in all directions, is converted into heat for each centimetre of the thread. The output of heat depends upon the strength of the field and the temperature. Should the temperature or pressure increase beyond a certain value the losses become so great that they can be dissipated no longer, as shown in the example under III. If the thickness of the plate, i.e., the length of the thread, and also the applied voltage be doubled, the field strength at each point remains unchanged. The losses per centimetre and also the cooling conditions remain the same. It is possible to obtain a balance of heat if such conditions previously existed. The admissible pressure increases proportionally with the thickness of the layer, or expressed mathematically $E = k_1 \cdot d$ where E is the permissible pressure,

k_1 is a constant depending on the material and the external temperature.

d is the thickness of the plate.

In this case an admissible field strength results, which is independent of the thickness of the insulating layer; this has been established by experiments for thin layers.

A second instance arises when a homogeneous material is considered, in which the heat resistance is situated on the surface of the plate (see the example in section III). It was established that the losses may reach a given value but still be dispersed. If the thickness of the layer is doubled the field strength falls to a half and the losses per unit volume to a quarter. The layer of double thickness, owing to the doubled volume, produces only a half of the losses which occur in the single layer for the same applied pressure. In order that the plate may dissipate the same amount of the losses as before, the pressure applied to the layer of double thickness may be increased to $\sqrt{2}$ times of that applied to a plate of the previous thickness. It follows that with the heat resistance on the edges, the flow of heat parallel to the electrical field, the admissible continued alternating-current pressure is proportional to the square root of the thickness of the layer.

$$E = k_2 \sqrt{d}$$

where k_2 is a new constant dependent upon the material, the external temperature, and the properties of the surface and surroundings for the dispersal of heat.

A third example occurs when considering a homogeneous material in which all the heat resistance is in the inside of the insulation, the surface being maintained at constant temperature e.g., by immersion in oil. As previously, the heat will flow in the direction of the electric field. A complicated temperature gradient is set up inside the insulation, which is determined by the size of the losses traversing each point, and produced in the insulating material itself.

If the sum of all partial losses is considered as produced in a middle layer, it is seen that the occurrence must remain essentially the same as in the example in section III. If the thickness of the layer is again doubled the losses are once more reduced to a half, assuming that the applied voltage remains unchanged. Nevertheless the heat resistance does not remain the same, but has also been doubled. The critical temperature distribution, for which it is possible to disperse the heat, remains independent of the thickness of the layer, if the applied pressure is constant. In other words in spite of the thicker plate no higher pressure may be applied. The highest admissible pressure is independent of the plate thickness. $E = k_3 \cdot d^0$ where $d^0 = 1$, and k_3 is a new constant

[1] Journal A. I. E. E., 1922, Vol. 41, p. 1034.
[2] Archiv für Elektrotechnik, 1924, p. 153.
[3] Bulletin des S. E. V., 1924, No. 7.

depending on the material and external temperature. By means of improving the material, the bad threads in the direction of the electrical field practically vanish, as, for example in a wound insulation. The heat resistance at the edge of the material may be eliminated in many cases by immersing the insulator in oil, as in the last example considered. This evidently represents the upper limit for the pressure which a large undivided plate may be expected to withstand continuously.[1]

VI. CONCLUSIONS.

Beyond a certain limit it is of no use thickening the layer of insulation. Continuous and good insulating properties against high pressures can only be attained by improvement of the material or by more effective cooling. According to the above considerations and conclusions, which have been established by tests, a second device for determining the dielectric losses, especially for the insulation factory, has been installed in the Brown Boveri workshops. All of the usual insulating material can be measured there.

As the watt measurement is the best modern method of determining the value of an insulating material, guarantees can be given for the uniformity of the insulating material to reliably withstand the continuous stresses at high temperatures, such as occur in service.

(MS 377) *K. Berger. (J. R. L.)*

[1] For the results of the calculations and tests on this important case, see the publication mentioned on p. 115.

POWER FACTOR CORRECTION AND SPEED REGULATION OF INDUCTION MOTORS.

Decimal index 621.317.4:621.313.64.

IN recent times, new kinds of cascade connections for polyphase induction motors and Scherbius machines have been developed, which in certain cases ensure a simplification of the previous Brown Boveri Scherbius system[1] used for phase compensation and speed regulation, and in addition, permit fresh problems to be overcome. The theory of the previous methods was somewhat complicated because the resultant impedance of the excitation circuit of the Scherbius machine changes very rapidly with slip frequencies, i.e., with the speed of the main motor. When the slip frequency is zero, it is equal to the ohmic resistance, but when the slip frequency increases it is almost entirely determined by the inductance which is proportional to the slip. With the new methods which are really extensions of one of the first-known forms of cascade connection the difficulty is avoided by inserting, in the exciter circuit of the Scherbius machine, a resistance which is appreciably greater than the inductance of the circuit at the maximum slip frequency. The inductance, therefore, can be neglected over the entire range without introducing any appreciable errors. In this way the exciter current is always in phase with the pressure applied, and its magnitude is obtained by dividing the pressure by the constant resistance of the excitation circuit. The losses in the additional resistance are generally small; however, should they become excessive with the usual arrangement, they can be reduced by special connections.

I. PHASE ADVANCER FOR INCREASED SLIP.

These phase advancers are employed with induction motors which operate with increased slip, in order to utilise the flywheel masses, and ensure full compensation of the main motor at no-load and also on load besides effecting a partial recuperation of the slip energy. Furthermore, over-compensation can often be attained. With the connections described in the Brown Boveri Review, 1925, No. 2, p. 40 for ensuring series characteristics where the main induction motor also operated with additional slip, it was not possible to obtain phase compensation at no-load and it therefore serves primarily for recuperating the slip energy, whereas the new system is equally suitable for power factor correction.

The phase advancer for increased slip is worthy of special importance since all other systems of power factor correction, with which a rotary machine is connected in the rotor circuit of the main motor,

[1] See Brown Boveri Review, 1925, No. 2, p. 29.

exhibit serious disadvantages if the resistance of the rotor circuit is increased in order to produce increased slip, as has been hitherto customary. All kinds of synchronous motors are inherently unsuitable for such cases. The shortcomings of the other methods hitherto used are due to the following reasons:—

In Fig. 1, O A is the stator pressure and O B the rotor pressure of an induction motor with a given slip, O C is the rotor current of the motor at full load and with the power factor advanced to unity; hence all of the magnetisation current of the motor is taken over by the rotor. O C_1 is the watt component of the rotor current and $C_1 C = OE$, the wattless component, which corresponds to the magnetisation current of the motor. When the load decreases the watt component OC_1 falls off proportionally. The changes in the wattless current differ with the various methods of power-factor correction employed. For example the wattless current can also vary in proportion to the load so that with a falling load the end of the rotor current vector OC travels along a straight line from C towards O. It can, however, with an output falling from full-load change slower than the load, and only falls rapidly with very small loads so that the extremity of the rotor current vector describes the curve CDO. In both cases, the degree of correction of the main motor decreases with the load, but in the second case this decrease takes place much slower than in the first. The first example corresponds to an unsaturated phase advancer without stator, whereas the second is for the highly saturated phase advancer of the Brown Boveri type. If the wattless current remains constant, independent of the load, the end of the rotor current vector, with falling load, travels from C to E on the straight line CE; hence complete power factor correction is obtained at all loads and also for no-load. This applies also to the frequency changer made by Brown, Boveri & Co. The greater the power factor correction required with partial loads the greater are the current and heat losses in the rotor circuit.

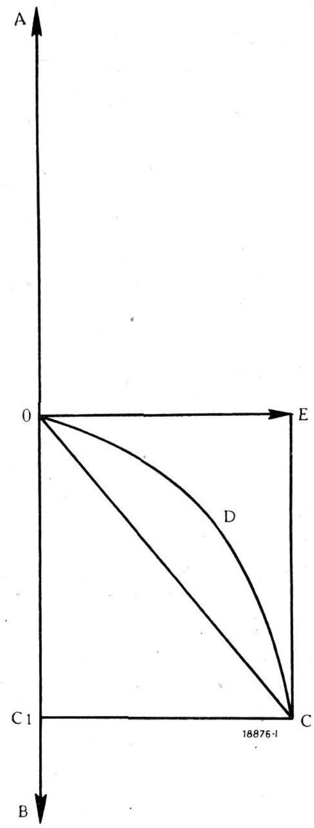

Fig. 1. — Rotor current of an induction motor with various loads and varying degrees of power factor correction.

The various power factor correcting systems differ also with regard to the watt output of the machine which is connected in the rotor circuit of the main motor. Certain machines such as the Brown Boveri phase advancer operate with a phase displacement of 90° between the current and pressure. Their watt output is zero and in this article they are referred to as wattless phase advancers.

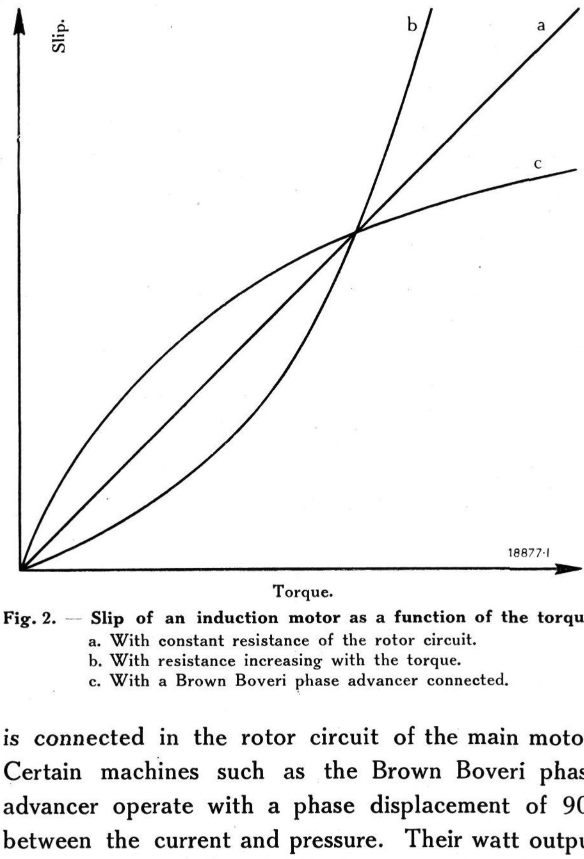

Fig. 2. — Slip of an induction motor as a function of the torque.
a. With constant resistance of the rotor circuit.
b. With resistance increasing with the torque.
c. With a Brown Boveri phase advancer connected.

Frequency changers and other systems operate as generators and make good the copper losses due to the magnetising current of the rotor circuit. As long as the rotor of an induction motor receives no power from external sources, the slip is equal to the total copper losses in the rotor circuit divided by the output of the motor. The copper losses for a given output increase, however, with the degree of power factor correction attained as explained above. For the wattless phase advancers the slip of the main motor on partial load is therefore all the greater for a given value of the full-load slip the greater the degree of power factor correction attained.

The curves a to c in Fig. 2 show the way the slip varies in relation to the torque. The slip at normal torque is assumed to be equal for all three curves; it is proportional to the torque when the straight line a is followed as is the case of uncompensated motors as well as compensated motors with wattless phase advancers, if the rotor current with falling load changes according to the straight line OC (Fig. 1), with the result that the power factor with falling load decreases quickly. A slip curve having these characteristics is favourable, but better still is one occurring according to curve b, in which case heavy load peaks are taken up to a great extent by the flywheel masses. If, finally, the wattless phase advancer is so dimensioned that it also gives a high power factor correction with partial loads, and the full-load slip remains unchanged, the slip at partial loads is greater than if the phase advancement at partial loads were less. The slip curve is given by c, and the largest load peaks are compensated the least. Where a frequency changer makes good the ohmic losses due to the magnetisation current externally, the slip depends only on the ohmic losses of the watt current, which are the same as with uncompensated motors. In such a case complete power factor correction can be obtained even at partial loads, the slip being as shown by the straight line a in Fig. 2. The efficiency is very unfavourably influenced by the compensation when the slip resistance is connected. As long as the resistances of the stator and rotor, referred to the same pressure, have approximately the same value it is almost immaterial if the magnetisation current flows either in the stator or in the rotor. If, however, the rotor resistance is artificially increased to produce additional slip, considerable additional losses are incurred if the magnetising current is carried exclusively by the rotor; they must then be made good externally by the frequency changer, with the result that the efficiency is adversely effected. With the wattless phase advancer, any additional losses would be borne by the stator as well as the watt losses, the efficiency rarely differs from that of an uncompensated motor, since as a result of the power factor correction; the required additional resistance for a definite additional slip is smaller.

If the main motor runs with increased slip owing to the extra resistance in the rotor circuit, the systems employed hitherto produce either an unfavourable slip curve, or decrease the efficiency. The phase advancer for increased slip avoids both these disadvantages and furthermore compared with the uncompensated motor it operates with a notable increase in efficiency. The connections are shown in Fig. 3, a is the main motor with slip rings b connected to the commutator machine c, which has two shunt excitation windings d and e on the same poles. The winding d (resistance excitation winding) is connected to slip rings b by the ohmic resistance f, and the winding e (inductance excitation winding) to the slip

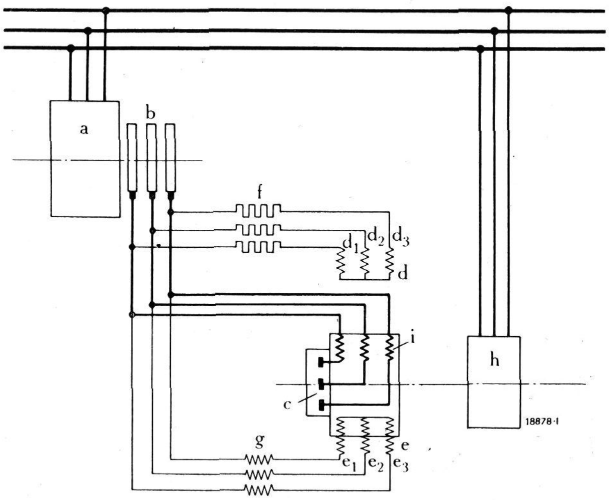

Fig. 3. — Normal connections of an induction motor with phase advancer for increased slip.

rings b of the main motor by way of a choke coil g. By coupling the commutator machine to the induction machine h (Brown Boveri Scherbius System) the speed is kept contant. The resistance and choke coil are so dimensioned that for each load of the main motor the voltage drop in the resistance and choke coil are essentially greater than the pressure applied to the terminals of the inductance excitation winding. The principle mentioned in the introduction is also applied to the resistance excitation circuit. For a given slip-ring pressure the value of the current in the resistance and in the choke coil would scarcely change if the terminals of the excitation coils d_1, d_2, d_3 and e_1, e_2 and e_3 were short-circuited. This implies that with correct connections the current in the two windings is almost independent of the behaviour of the commutator machine and only affected by the resistance and inductance of the choke coil. As the slip-ring pressure which feeds the two excitation circuits is proportional to the slip, the current in the resistance excitation is also approximately proportional to the slip. The current of the inductance circuit is practically constant because the inductive resistance of the coil is proportional to the slip. The resultant excitation field of the commutator machine is given by the sum of these two excitation currents, hence the armature pressure of the Scherbius machine is composed of a part proportional to the slip-ring pressure and also a constant component.

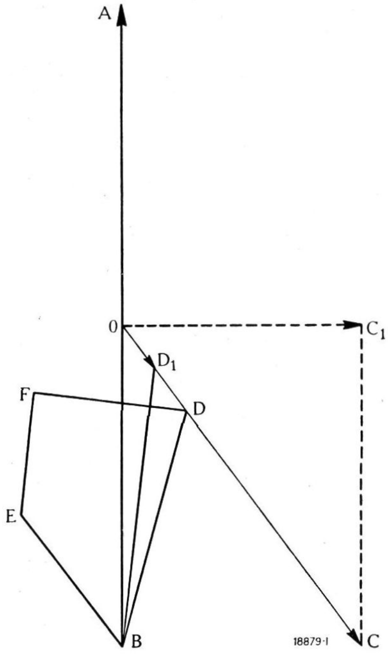

Fig. 4. — Pressure diagram for the rotor circuit of an induction motor with phase advancer for increased slip.

The resistance circuit is so dimensioned that the component of the armature pressure proportional to the slip-ring pressure is smaller than the latter and opposed to it. The resulting pressure is consequently only a fraction of the slip-ring pressure. The rotor current and torque of the motor for a given slip-ring pressure and therefore for a given slip are smaller than without the commutator machine; a definite torque is consequently only attained with increased slip. The additional slip thus obtained is further augmented by means of a compound excitation winding i, traversed by the armature current of the commutator machine, which induces a further pressure in this machine, proportional to the rotor current but opposed to it. The pressure necessitated by means of the inductance excitation winding lags 90^0 behind the pressure of the resistance winding and effects phase advancing.

In Fig. 4, OA is the induced pressure in the stator of the main motor, OB the induced pressure in the rotor corresponding to a definite slip, OC is the rotor current with phase advancement, OD is the corresponding total pressure drop in the complete rotor circuit, and OD_1 the drop in the rotor of the main motor alone. D_1B is the pressure across the slip rings whilst BD is the resulting induced pressure in the advancer. This pressure consists of the pressure BE in the opposite direction to the current and is due to the compounding winding EF, which corresponds to the resistance winding and is almost opposed to the slip-ring pressure and FD in quadrature with EF, and produced by the inductive excitation winding. The pressure components of the rotor circuit acting in the direction of the slip pressure are approximately proportional to the load, thus also the slip pressure OB and the slip must be proportional to the load. The pressure FD, perpendicular to slip pressure, is approximately constant, the same applies to the magnetisation current OC_1 taken over by the rotor, which is independent of the slip. From Fig. 4, it appears that the greater the number of the compound turns the greater the pressure BE, and consequently also the pressure FD, and therewith the choke coil, whilst the pressure EF, caused by the excitation resistance circuit in armature, becomes smaller. The object of the compound winding is primarily to reduce the losses in the resistance circuit, moreover, to damp out the effects of disturbances liable to occur.

As FD, the pressure component of the commutator machine, is nearly in phase with the magnetising current, it covers the heat losses in the rotor circuit (see page 123); complete phase correction with small loads is attainable without interfering with the proportionality between the load and slip. The unfavourable influence upon the efficiency experienced with certain of the previous methods is avoided. Moreover the increased slip is produced by means of the phase advancer and not by switching in a resistance. A considerable reduction of the total losses results through utilisation of the slip energy when this kind of installation is compared with an uncompensated motor. The resistance (f in Fig. 3) is connected in the excitation circuit of the commutator machine, the current of which is very much smaller than the rotor current. Its losses are thus much smaller than those caused by a slip resistance connected in the rotor circuit.

The phase advancer for increased slip runs as a generator for as far as it is called upon to cover the magnetisation losses in the rotor circuit, whereas it runs as a motor when taking up the slip energy of the main motor. The magnetisation losses are approximately constant, and independent of the slip; the slip energy is proportional to the square of the slip if the slip is proportional to the load. The magnetisation losses preponderate with small loads. The advancer then runs as a generator and its driving motor takes power from the system which can exceed the power saved by phase advancing in the stator of the main motor. In this case, small additional losses are involved owing to the phase advancing.

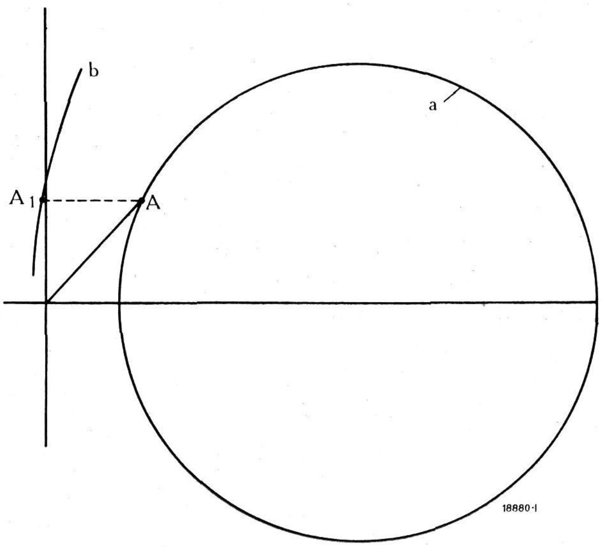

Fig. 5. — Stator current of an induction motor.

a. Without phase advancer.

b. With phase advancer for increased slip.

These, however, are always notably smaller, even with the main motor on no-load, than those of a synchronous motor running light, by means of which the same amount of wattless power is returned to the system. Often the basic load of the main motor provided by the friction losses is so large that even at basic load the slip energy greatly exceeds the magnetisation losses, the commutator machine runs therefore as a motor and returns power to the system which must be added to the power saved in the stator. In this case a saving of energy is effected concurrently with phase advancing even with the main motor practically on no-load. Since the slip energy recuperated increases proportionally to the square of the slip, the size of the auxiliary machine for taking up the slip energy coupled with the commutator machine is principally determined by the working conditions on overload. Protection against running away on unexpectedly high overloads is afforded by a centrifugal switch. The advancer and driving motor are not generally completely loaded when the main motor is on full-load. In spite of this a considerable saving of energy is secured when compared with the resistance regulation method. With an additional slip of the main motor of about 6·0 to 10 % the overall efficiency of the motor is only 2·0—3·5 % smaller than when running without increased slip. If an equal slip were produced by inserting resistances the efficiency would fall off by 6·0 to 10 %. The larger the slip desired, the greater the energy saved.

The slip is proportinal to the load, up to about 30—60 % overload of the main motor. With higher loads, this usually no longer holds owing to saturation of the commutator machine. At 100 % overload, the slip amounts to about 1·7 times to twice the full-load value. Changes in the resistance excitation circuit produce a different degree of slip for a given load, thus the amount of the additional slip can be regulated. The exceptionally good results on the power factor obtained by use of phase advancer are shown in Fig. 5.

The circumference a gives the current diagram for a 880-kW motor without phase advancing; A is the full-load point. The power factor at full load is very poor owing to the low speed of the motor. The curve b shows the current diagram from measurements, a phase advancer for an additional slip of 8·0 % having been fitted. At full-load, A_1, the motor still runs with a slightly leading power factor. On overload the lagging wattless component increases much more slowly than for the uncompensated motor. This is brought about by an extremely favourable secondary action of the resistance excitation circuit. The inductive resistance depending on this slip is, however, small when compared with the ohmic resistance but is not entirely without effect with a large degree of slip. It causes a phase displacement of the exciter current and a corresponding lagging component of the rotor pressure EF, Fig. 4. Owing to this lagging, a pressure component is set up in the direction of the voltage of the choke coil; this increases with the slip and improves the power factor, especially on overload. An exceptionally large overload capacity of the motor, for a short time, accompanies the improved power factor, and it is considerably larger than that available with uncompensated motors. To use this in practice, the driving machine of the advancer must be amply dimensioned. It is usual to dimension the installation for 100 % momentary overloads.

With an uncompensated induction motor, the no-load speed is synchronous speed, the slip frequency and slip pressure being practically zero. If this speed was maintained, even after the phase advancer had been connected, this machine would become ineffective on no-load, as there would be no pressure in the rotor circuit, moreover the choke coil g (Fig. 3) would lose its inductive character with a zero frequency and only act as a small resistance. The choke coil excitation circuit is arranged, however, in such a manner that the main motor, even when entirely without load, still has a small slip (0·5—1·0 %), i.e., sufficient for the inductance of the choke coil to have effect. With no-load, therefore, complete, or nearly complete power factor correction is attained.

If the main motor runs above synchronous speed, owing to its being driven from an external source, although it then runs as a generator, the change from motor to generator does not affect the phase advancer which continues to effect the compensation, so that a switch is not necessary when passing through synchronism.

At the instant of passing through synchronous speed, the phase advancing diminishes, but this phenomenon is of little importance and can only be detected by careful observation of the instruments. The phase advancer, therefore, retains its favourable properties under all possible working conditions. It offers an exceptionally good solution, with simple connections, for problems relating to the phase advancing of induction motors which run with increased slip. Whereas phase advancing is otherwise almost always accompanied by increased losses, here it effects a considerable reduction of the total losses, hence the initial cost of the phase advancer for additional slip is repaid in a very short time.

With the methods dealt with hitherto, the no-load speed of the main motor is a little below synchronous speed, but by slightly changing the connections, however, this speed can be raised slightly above synchronism. Fig. 6 shows the magnitude of the pressure occuring in the rotor circuit, as far as it influences the speed. The components

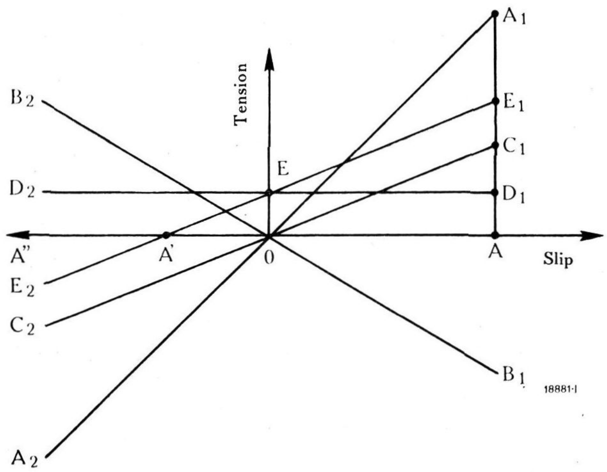

Fig. 6. — Pressures in the rotor circuit of an induction motor with phase advancer for increased slip and higher no-load speed as a function of the slip.

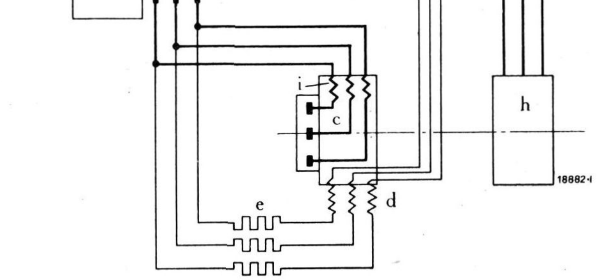

Fig. 7. — Connections of a phase advancer for increased slip and for higher no-load speed.

affecting the phase advancing are neglected; Fig. 7 shows the connections required to obtain this diagram. With reference to Fig. 6, AA_1 is the slip-ring pressure of the main motor with the sub-synchronous slip OA. If the slip varies, the point A_1 travels along the straight line A_1A_2. The portion OA_2 is that for the super synchronous running. The straight line B_1B_2 shows the pressure required in the resistance winding of the advancer; this pressure is proportional to the slip-ring pressure, but opposes it. C_1C_2 is the pressure in the rotor circuit resulting from the above two pressures. If the system of connections shown in Fig. 3 is used, the ordinate AC_1 is also a measure of the rotor current, and hence of the torque of the motor with the slip OA. If an additional and constant excitation current independent of the slip is introduced into the excitation circuit of the advancer, it causes another pressure component in the rotor of the advancer and can be represented by AD_1. When the slip varies the point D_1 moves along the straight line D_1D_2, parallel to the abscissae axis. The resultant pressure in the rotor circuit is now given by the vertical distance from the abscissae axis AA'' to the straight line E_1E_2 (where $C_1E_1 = AD_1$). The power with the slip OA is no longer represented by AC_1, but by AE_1, hence this also has increased. At synchronism the power is no longer zero, but is represented by OE. Zero is first obtained with the super-synchronous slip OA', where the line E_1E_2 cuts the abscissae axis. With a greater super-synchronous slip, and at a higher speed, the main motor runs as a generator. The variation of the speed from this no-load value is again proportional to the load; the main motor runs under similar conditions as obtained by the former connections, but with a higher no-load speed.

In order that a constant supplementary current may flow in the resistance excitation circuit of the advancer, a constant supplementary pressure must be applied to its circuit, which is effected by means of the frequency changer (f in Fig. 7) driven from the main motor[1]. The remaining connections are similar to those shown in Fig. 3. In both illustrations a to d, h, and i designate similar parts, e is the additional resistance in the excitation circuit and

[1] Brown Boveri Review, 1925, No. 2, p. 33.

g an auxiliary transformer supplying the frequency changer. Compared with Fig. 3, the inductive excitation circuit which is used for supplying a constant excitation has been dispensed with. In this case, this function is fulfilled by the frequency changer, which, apart from the current just mentioned, produces a constant pressure, having a phase displacement of 90^0 for the excitation circuit, whose effect is to correct the power factor independently of the load. The magnitude of the pressure AD_1 (Fig. 6) can be adjusted by changing the secondary pressure of the transformer g, and by varying the resistance e (Fig. 7); the inclination of the straight line E_1E_2, can be adjusted at will by simply altering the resistance e. The no-load speed and additional slip are also able to be adjusted. These connections can also serve to give the main motor a compound characteristic[1]; they are applicable only if slight regulation of the no-load speed, but a large speed drop, is required, thus affording another kind of speed regulation obtainable by the Brown Boveri Scherbius system.

Provided that only a single no-load speed above synchronism is required, it is best chosen so that the total speed range is approximately distributed about the synchronous speed. The maximum slip of the main motor, and its corresponding slip power, are thus only about half as large for an equal total speed range, as if the motor runs synchronously at no-load. The size of the commutator machine, its driving motor, the resistance in the exciter circuit, and the losses are consequently also appreciably reduced. A disadvantage of this system, when compared to that shown in Fig. 3, is incurred through use of the frequency changer, which must be driven by the main motor. It is, therefore, necessary to examine each individual case in order to decide whether it is advisable to use this somewhat complicated system; it is primarily applicable to instances requiring large speed ranges. Generally it is preferable to run the motor only below synchronism. Phase advancers for increased slip have already been manufactured in large numbers and have proved to be satisfactory in service.

(To be concluded.)

(MS 359) *Dr. W. Seiz. (J. R. L.)*

[1] Brown Boveri Review, 1925, No. 2, p. 38.

BROWN BOVERI GEARS.[1]

Decimal index 621. 833.

6. GEARS FOR MARINE INSTALLATIONS.

Apart from its applications on land, gearing is widely employed on board ship, as already mentioned at the beginning of this article. The course of the development of gearing for warships will be found described in an article in the Brown Boveri Review, 1922, No. 7, where it is stated that, at the commencement, gearing was only used for the small powers required by the cruising turbines, and after being perfected was used for a larger portion of the output until finally, the whole of the power was transmitted through gearing. Outputs up to 20,000 H.P. distributed over two or four pinions, have been transmitted by a single gear. Figs. 8 and 9 (February, 1926) show a gear wheel and pinion during the hobbing process, and Fig. 56 groups of marine gears and parts in the workshops of Brown, Boveri & Co. For warships which invariably require high speeds, and consequently a high number of revolutions for the propellers, single-reduction gears alone come into consideration. For merchant vessels, particularly with cargo steamers, double-reduction gears have become more and more common in recent years, since the most favourable propeller speeds for slow ships (80 r. p. m. and under) are low in comparison with the high speeds giving the best results with steam turbines. The high turbine speeds are due to the fact that the outputs are mostly small, and also that, for reasons of reliability the turbine is ordinarily subdivided into high and low-pressure parts. Owing to the considerable difference in speed between turbines and propellers, the gear ratio generally exceeds 30 to 1.

Figs. 57—59 show some types of marine gearing made by Brown, Boveri & Co.

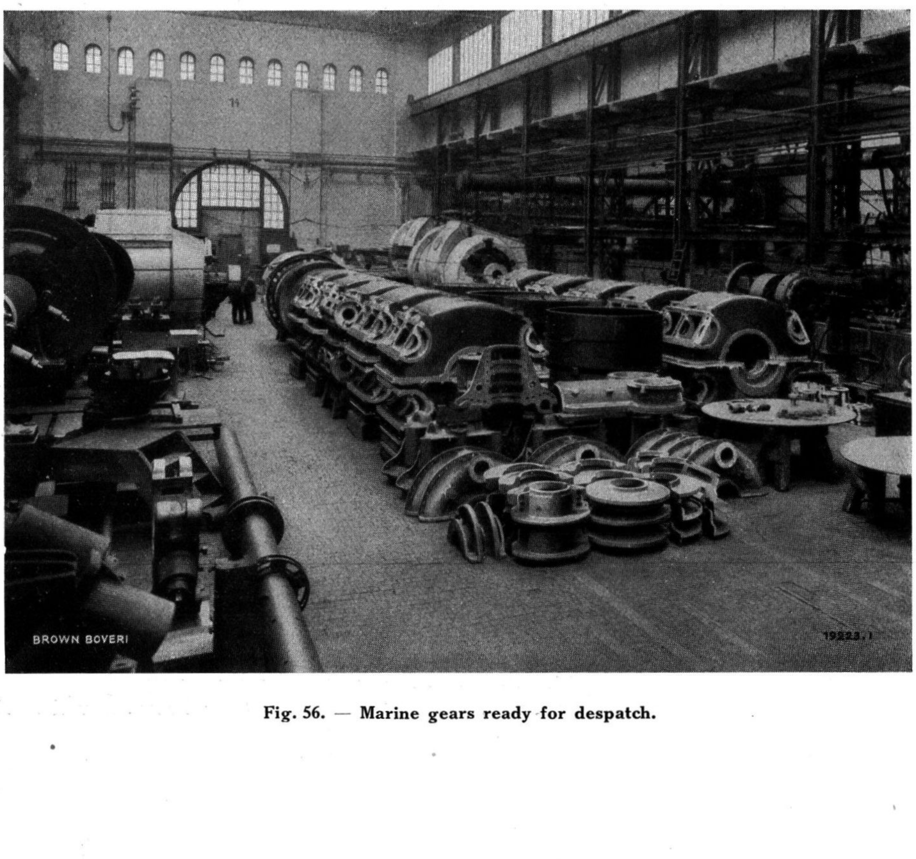

Fig. 56. — Marine gears ready for despatch.

In the set shown in Fig. 57 the two pinions coupled to the high or low-pressure turbine each drive two intermediate wheels, the shafts being connected to pinions, hence four pinions drive the gear wheel on the propeller shaft. All wheels have single-helical teeth.

The axial thrust of the first pinion serves to balance the thrust of the steam in the turbines, whereas that of the large gear wheel relieves the thrust bearing of the propeller. The axial thrust due to the intermediate gear wheels and pinions is mutually compensated because the teeth all slope in the same direction (since a driving and driven gear occur), and the spiral angles are chosen in such a way that their tangents are proportional to the diameters. The principles of compensating the axial thrust both on the intermediate and main shafts in plants of this description have been protected by patents by Brown, Boveri & Co.

Fig. 58 shows the propelling machinery of a ship with double-helical gearing. As in the foregoing case, two turbines drive a common propeller through a

[1] Continued from April, 1926.

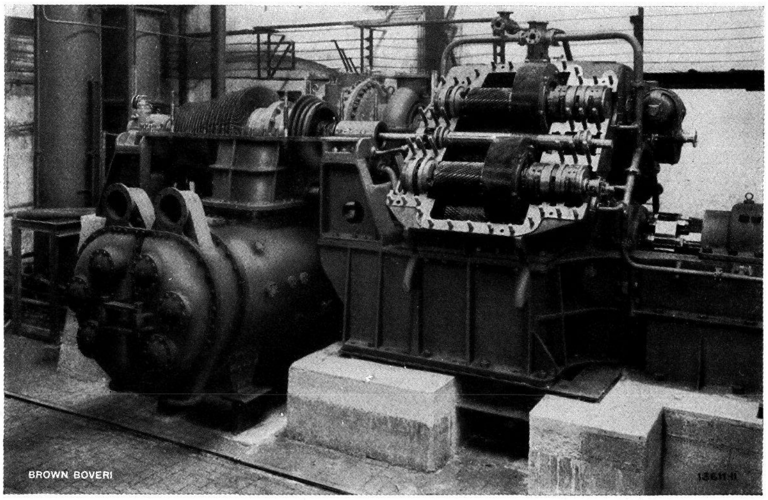

Fig. 57.

A double reduction gear, with double intermediate gearing and single-helical teeth, on the test bed.

Total power transmitted 3000 H. P., turbine speed 3000 r. p. m. speed of propeller shaft 75 r. p. m.

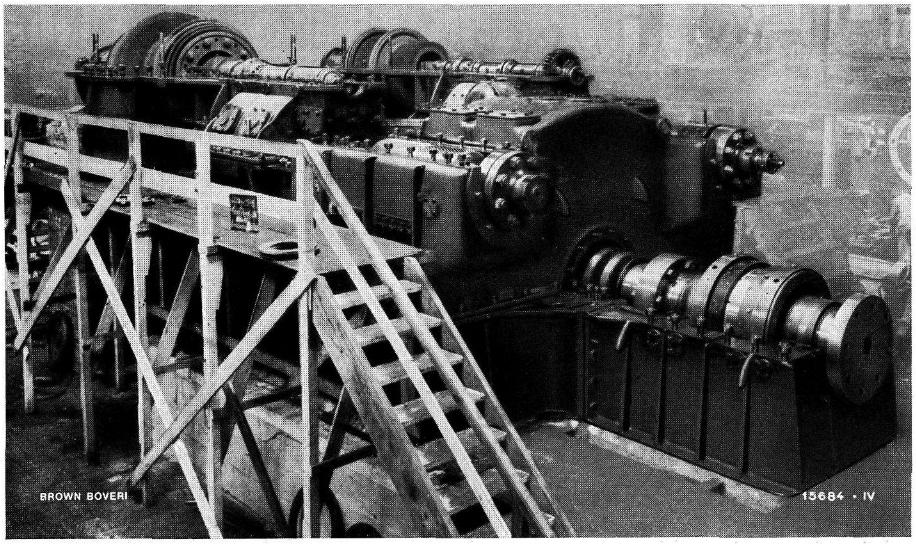

Fig. 58.

***Double-reduction marine gears* with double-helical gear wheels, on the test bed.**

Power transmitted 5000 H. P., speed of high-pressure turbine 3000 r. p. m., low-pressure 2300 r. p. m., propeller shaft 85 r. p. m.

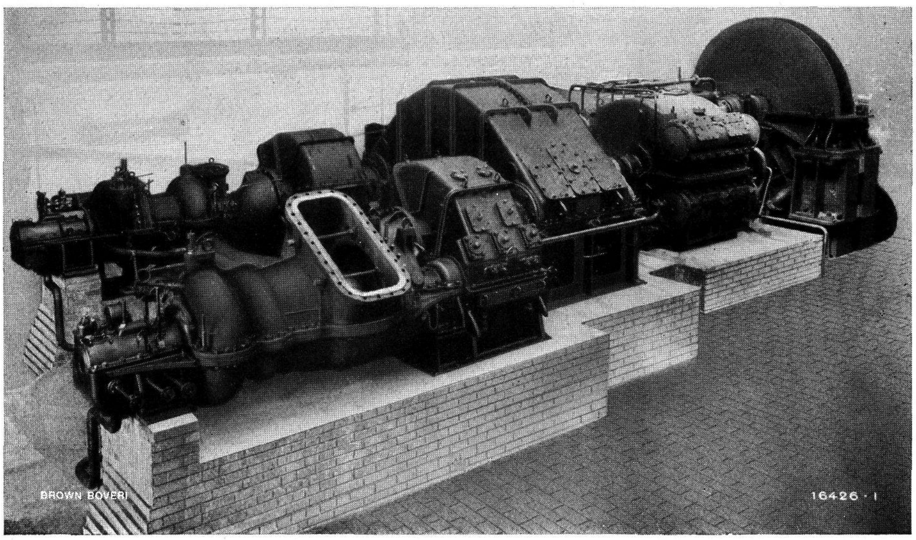

Fig. 59.

Turbine installation with double gearing for a paddle steamer, on the test bed.

Power transmitted 1500—1800 H. P., speed of turbine 3600 r. p. m., paddle speed 38 r. p. m.

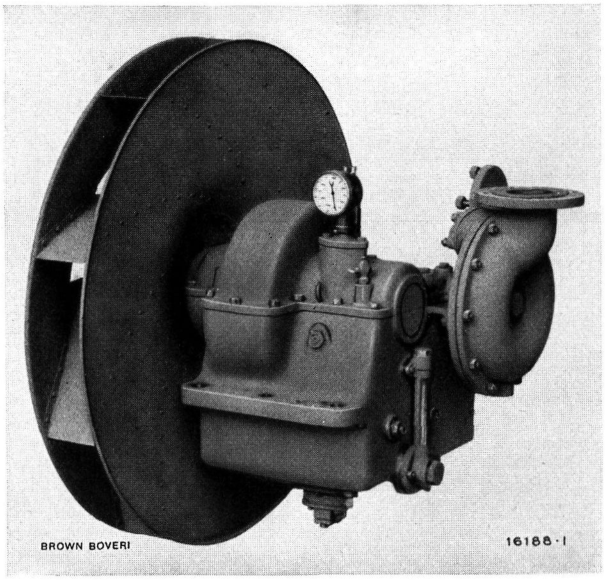

Fig. 60. — Geared turbine driven fan for a torpedo boat.
Power input 50 H. P., speeds 12,500/1200 r. p. m.

double-reduction gear. Apart from this common feature, the design of the two plants is entirely different, as a comparison of Figs. 57 and 58 will confirm. Each of the primary gears is located in a separate casing forward of the large secondary gear. The aim of this design is to place the turbine shafts as high as possible in order to obtain sufficient space for installing the condenser directly beneath the low-pressure turbine.

The double-reduction gear illustrated in Fig. 59 forms part of the drive of a paddle steamer. Both turbines have a speed of 3600 r. p. m., whilst the paddle shaft runs at only 38 r. p. m., so that the overall

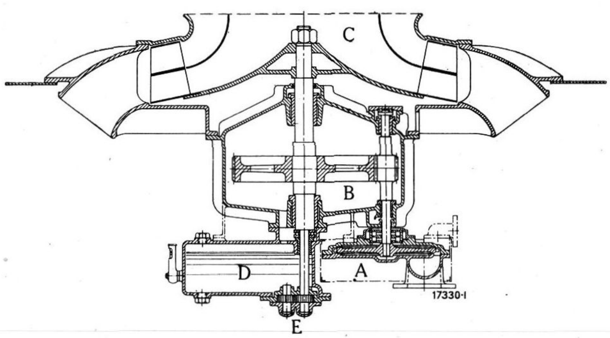

Fig. 61. — Vertical shaft fan, driven by a geared steam turbine.
Power input 60 H. P., speeds 12,500/1200 r. p. m.

A. Turbine
B. Gears.
C. Blower.
D. Oil reservoir.
E. Oil pump.

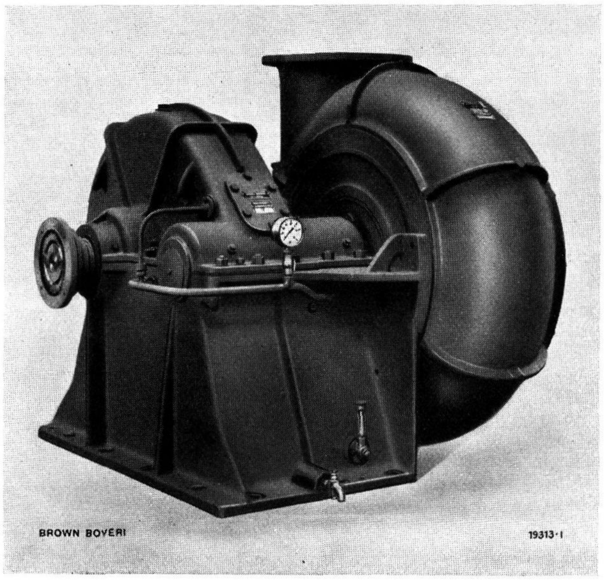

Fig. 62. — Gears and supercharging blowers for the main Diesel engines of a cargo boat.
The blower is driven by an auxiliary Diesel engine.
Output 75 H. P., speeds 300/3250 r. p. m.

reduction ratio amounts to 95 to 1. The plant is designed for 1500 H. P. normal rating, and 1800 H. P. maximum load. The illustration shows this gear on the test bed in the workshops. As the very low speed of the paddle shaft renders the exact determination of the output very difficult, a further gear was added between this shaft and the hydraulic brake so as to raise the speed again to 260 r. p. m. The output could then be measured with a torsion dynamometer.

Apart from the main gears forming part of the propelling machinery, gears can be used on board

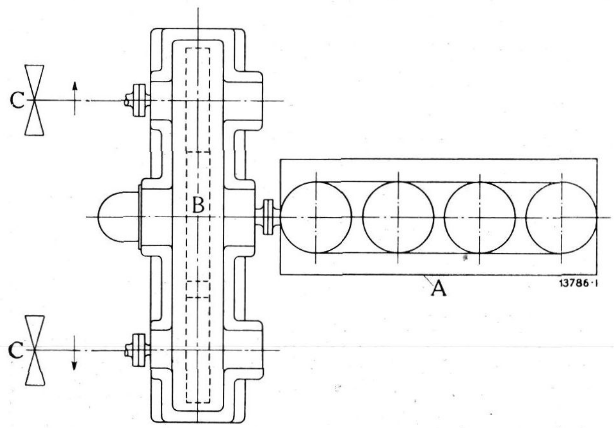

Fig. 63. — Geared Diesel engine for a river boat.
A. Diesel engine. B. Gear. C. Screw.

ship for a great number of widely different requirements in conjunction with the auxiliary machinery. Fig. 44 (April, 1926) shows a pump set, of which a considerable number has been constructed by Brown, Boveri & Co. for merchant vessels.

Pumps similar to those shown in Figs. 45 and 45 a, are extensively employed on board ship. Turbines and electric motors with intermediate gearing are particularly well adapted as prime movers for the numerous pumps required for various purposes.

Gears are often used between the direct-current generators on board and the driving machines to which they are connected.

Fig. 60 illustrates a turbine-driven fan for torpedo craft. The power required amounts to about 50 H. P., and the speed to about 12,500 r. p. m. for the turbine and 1200 r. p. m. for the fan. The fan shown in Fig. 61 has also a geared-turbine drive, but is intended for dealing with a rather higher power and is of the vertical-shaft type.

Fig. 62 shows, for example, the supercharging blower set for the main Diesel engines of a tanker; the blower is driven by a Diesel engine through gearing, special means being taken to compensate the cyclic irregularity.

The gearing, shown in Fig. 63, besides converting the engine revolutions to those required by the propeller, also distributes the power of the single-engine on to two propeller shafts since the specified shallow draught of the river steamer did not permit the use of a single screw.

(To be concluded.)

(MS 361) *J. Baasch. (J. R. L.)*

Centovalli Railway (Locarno-Domodossola); train on the bridge near Olgia.

NOTES.

The aerial-ropeway between Merano and Avelengo.

Decimal index 625. 25 (45).

EXPERIENCE with ropeways during the war has clearly shown the possibilities of this means of transport. A district in which this still rather unusual method of transport enjoys considerable popularity is found on the southern slopes of the Alps in the Tyrol. Ropeways showing novel features both as regards service and construction are installed between Merano and Bolzano. The economy of this kind of installation has been considerably improved, both as regards construction and maintenance of the service by the practical use of the interesting test results obtained by Herr Zuegg, an engineer in Merano, who ascertained that installations in which the rope is stretched taut offer a greater resistance to rope break, hence the life of the rope is longer than in installations of the slack rope type. This conclusion depends on the properties of wire to withstand large tension stress better than fluctuation,

Fig. 1. — The aerial ropeway between Merano and Avelengo.

although the bending moment may be smaller. It is easy to realise that as the rollers pass slack ropes are subject to greater deformation than tight ropes. These facts enable very large spans to be bridged, and the high speed which is necessary with this means of transport, to be attained.

Some years ago a plant of this description was installed between Merano and Avelengo, the electrical equipment being reconstructed by the Tecnomasio Italiano Brown Boveri, Milan.

The chief particulars of the railway are:—

Length of cable (approximately)	2600 m
Difference in altitude of end stations . .	890 m
Largest span	1700 m
Speed	3·6 m/sec.

The speed of this ropeway may ultimately be increased to 5 m/sec.

The adjacent cables are only fixed to three supports in the entire length between the two end stations. Reinforced concrete towers are used for the supports, each of which contains a store room for auxiliary material. The propelling cable is of the endless rope form, and runs over two pulleys installed in the terminal stations. Owing to the use of nickel steel, the cars which hold 16 passengers, are very light and are slung from the cable. They are provided with electric lighting from a storage battery.

Much care was spent on the safety measures of this railway. The cars are sprung to damp out any shocks which may be received when passing over the supported parts of the cable and on the towers and end stations lateral guide rails are fitted, to prevent excessively large oscillations arising. In view of the possibility of the propelling rope breaking, an automatic brake is provided which acts on the suspension cable. This brake can also be released by the conductor of the car. An auxiliary car, with a reserve motor, connected to a spare cable, is provided in order that the trip may be completed at reduced speed, in the event of the propelling cable of the main installation breaking. A reserve petrol motor, which can be rapidly started will also be installed in the driving station, hence the journey could be completed in the event of the electric power failing during a trip. The cars are equipped with telephone installations which use the propelling and suspension cables as conductors.

The driving station is equipped with an ordinary three-phase motor supplied with power at 190 V with a frequency of 50 cycles. The circuit breaker is fitted with an overload relay, no-volt release, and remote control. An alarm bell gives warning to the operators when this switch opens. A drum-type starting and reversing controller with auxiliary contacts for interlocking with the limit reversing switch is provided. If the position of the limit switch does not correspond to the direction of travel, the circuit breaker is tripped and the safety brake applied. The starting resistance, composed of cast-iron elements, is specially designed to give smooth starting of the driving motor. An auxiliary resistance is provided to enable trips to be made at a reduced speed, e.g., for examination of the cable. The motive power is an induction motor with four poles, having a one-hour rating of 35 H.P., which is extraordinarily small when compared with other telpher lines for similar conditions. A second motor of equal power is provided as a stand-by. It can be put into service in a very simple manner.

The safety brake is provided with the usual tripping devices which operate automatically in the event of the maximum permissible speed being exceeded, or if the car runs too far into either terminus. It is worthy of note that the brake is fitted with a direct-current braking magnet.

A special device is provided to prevent the car entering a terminus except under the control of the driver. By changing-over the limit switch before the arrival of the incoming car, an alarm bell is automatically sounded for a short period and the circuit breaker tripped, if the mechanic omits to keep it closed by means of an auxiliary contact operated by a pedal, at the correct time. The driving mechanism may also be stopped from the car by means of an emergency relay.

The chief features in this installation are the moderate constructional and running costs, an efficient service, and a long life of the materials together with the greatest possible safety of operation. A new ropeway between Oropa and the Mucrone lake is under construction. The Tecnomasio Italiano Brown Boveri, Milan have undertaken to supply the electrical equipment which is very similar to that of the line between Merano and Avelengo.

(MS 376) *F. Balestra. (J. R. L.)*

Isolating switches for heavy current.

Decimal index 621. 317. 32.

ISOLATING switches are usually included in switchgear installations for breaking circuit when no current

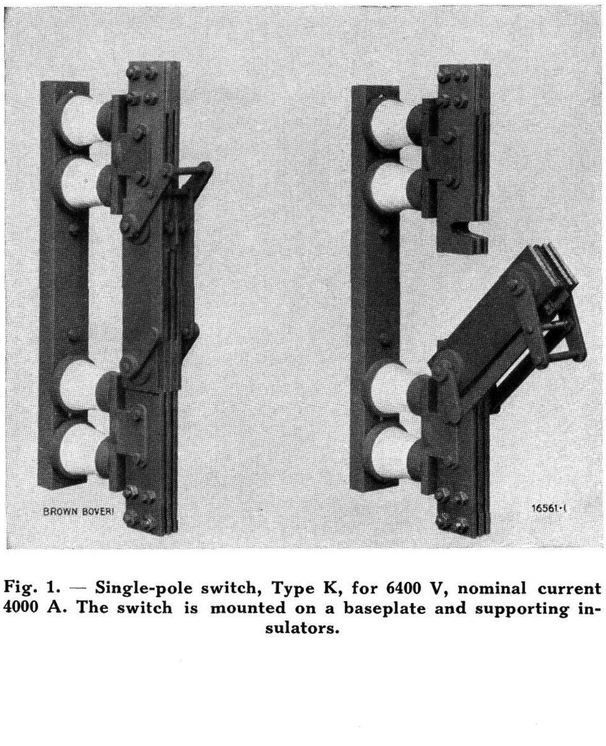

Fig. 1. — Single-pole switch, Type K, for 6400 V, nominal current 4000 A. The switch is mounted on a baseplate and supporting insulators.

is flowing, with the object of providing reliable and absolutely certain isolation of parts from which, for any reason, the pressure must be removed. This apparatus, therefore, though simple in itself, constitutes an important component for low-pressure installations as well as for high and extra-high-tension plant, and demands careful attention in all respects. Rated currents up to about 1000 A, and short-circuit currents up to about 20,000 A, do not necessitate any special constructional arrangements. In addition to good insulation, sufficient pressure between the blades and the contact-jaws is one of the chief requirements to ensure efficient working.

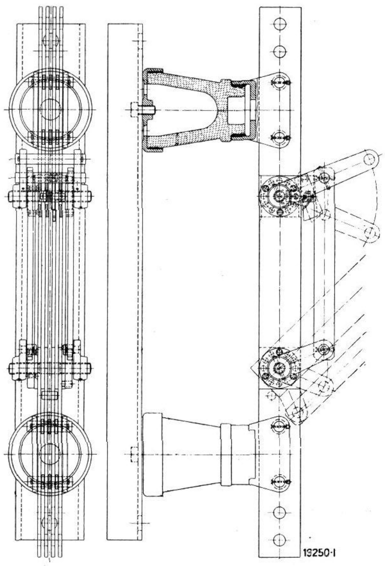

Fig. 2. — Type K, single-pole isolating switch, for 1600 A.

If, however, the currents to be carried exceed the above limits, the demands made on the isolating switches are very much more severe. When dealing with currents of considerable magnitude, electro-dynamic forces are set up which must be allowed for by very massive construction and counteracted by a suitable arrangement of conductors. When the conductors on isolating switches are not well arranged, it may happen that with heavy short-circuit currents, the moving switch blade is flung away from the contact position by the "throw-off effect", or should there be a self-locking catch provided, this, or indeed, the whole switch may be destroyed. For mechanical reasons, the switch blades cannot be introduced between the compressed contact springs without difficulty owing to the high contact pressure necessary with heavy currents.

As a result of these considera-

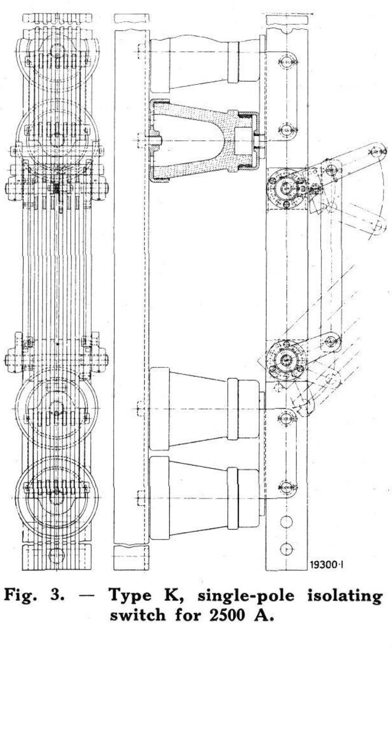

Fig. 3. — Type K, single-pole isolating switch for 2500 A.

tions, as well as of many years experience, Brown, Boveri & Co. have developed isolating switches for heavy currents which electrically are short-circuit proof, and from the mechanical point of view are reliable and are very simple in operation.

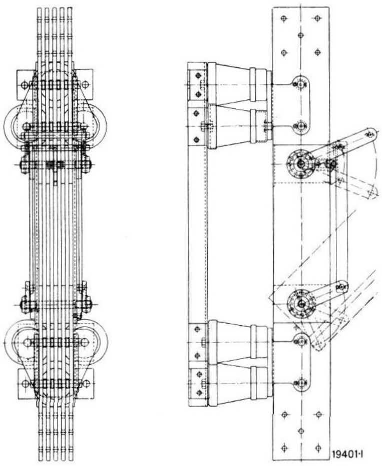

Fig. 4. — Type K, single-pole isolating switch for 6400 A.

In the following, the construction is described and the method of operation explained.

In the design of the K-Type isolating switches for rated currents of 1600, 2500, 4000 and 6400 A at 6400 V, every endeavour has been directed towards securing the most direct passage of current possible. By this means the effect of the dynamic force of short circuits causing the "throw-off effect" can be reduced to a minimum. With this arrangement (Fig. 1), the characteristic simplicity as well as great mechanical strength is guaranteed. The clamping device employed allows the blades to be inserted in their jaws with practically no friction. By exerting a moderately high pressure upwards on the operating rods; which, on account of interlocking arrangements, is only possible with closed switches, the clamping nuts at the pivot and contact jaws are tightened and a very powerful clamping effect is produced. Both closing and clamping are effected by a single movement, so that the operation of the isolating switch is very simple and easy to perform, owing to screw-clamping being used. The direct combination of the switch blade with the jaws avoids soldering and reduces the number of electrical joints to a minimum so that hot spots in the conductors are avoided. The contact arms to which the incoming and outgoing leads are screwed are supported on loose bolts which allow the necessary movement on heating without straining the supporting insulators.

The contact pieces of the isolating switch are, according to their size, fixed on one, two or three insulators as shown in the illustrations. The whole apparatus rests on massive insulators which in turn are carried by a strong channel iron.

The switch described above has proved to be very reliable in operation and can be used without risk in plants which are often in danger of short circuits.

(MS 366) *O. Zingg (J. R. L.)*

Experience obtained from operations at the Brugg Substation of the Swiss Federal Railways.

Decimal index 621.312.63.0064 (49.4) : 621.331.32 (49.4).

THE Brugg Substation was put into service in January 1925; the 60-kV overhead transmission line is connected to the Steinen Substation and to the Hendschiken Distribution Station. The substation supplies the contact line for the Zurich-Olten Section, which was opened during the month in which the station was put into service.

As mentioned, in the Brown Boveri Review, 1925, No. 11, in the article dealing with the transformers and electrical apparatus at this substation, the outdoor plant at present consists of four transformers, each of 3000 kVA, 60/15 kV, $16^2/_3$ cycles; in Fig. 4, three of the transformers may be seen. As with the transformers in the Swiss Federal Railway Substations at Melide, Seebach and Bussigny, no over-potential devices are provided, i. e., protection choke coils or horn gap arresters are not fitted. The neutral point of the windings of these transformers is connected to earth by means of a 60,000-ohm resistance. Up to the present there have been no disturbances due to the lack of protective devices. The complete installation, that at 60 kV, as well as the 15-kV switchgear has completely fulfilled all the stipulations of the Swiss Federal Railways, and under all weather conditions.

Fig. 1. — The outdoor installation of the Brugg Substation from the 15-kV side, *after* the fall of snow on January 18, 1926.

These conditions took into account the difficulties under which railway services have to be maintained.

During the first year of operation, heavy currents, due to earths, short circuits of the contact wires, or overheated transmission lines, have been broken by the 15-kV feeding-point switches of this station without any noticeable defect occurring in the switches.

This substation remained in service, without one interruption, both during and after the heavy snow fall on January 18, 1926. Illustrations in this number show photographs of the outdoor installation at that time. The frontispiece shows the insulators of the 15-kV switchgear completely covered with snow. No short circuit, earth connection, flashover, break in the service, or damage to the installation was caused by the snow. On examination of the oil of the 15 and 60-kV oil switches as well as that of the track switches, measuring instrument, and test resistance, no trace of ice or of dampness was found. It may be mentioned that it is customary to examine and filter the oil after the switches have operated 45—50 times under heavy short circuits. The breakdown strength of the oil, even then amounted to more than 25 kV. Fig. 3 shows the track switches of the outgoing lines for supplying the contact lines; although the switches, as well as the whole plant, were completely covered with snow, they were absolutely reliable in service.

(MS 389) C. Giudici. (J. R. L.)

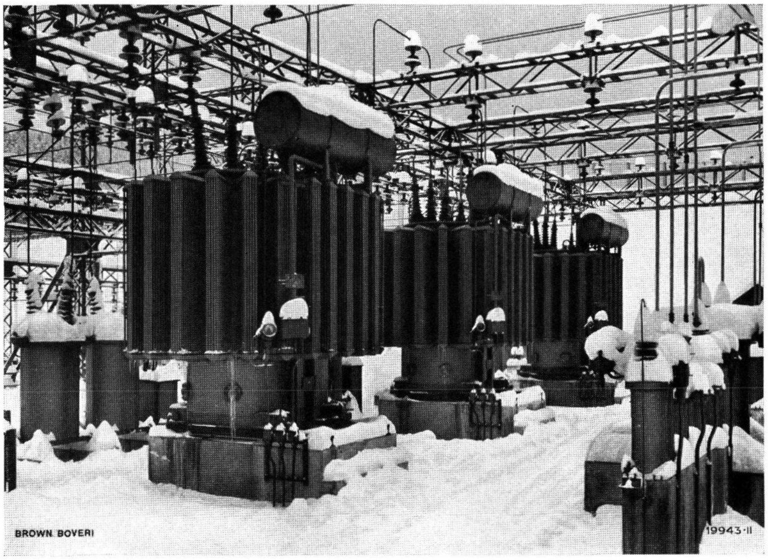

Fig. 2. — Three transformers, each 3000 kVA, 60/15 kV, 16²/₃ cycles, seen from the low-tension side.

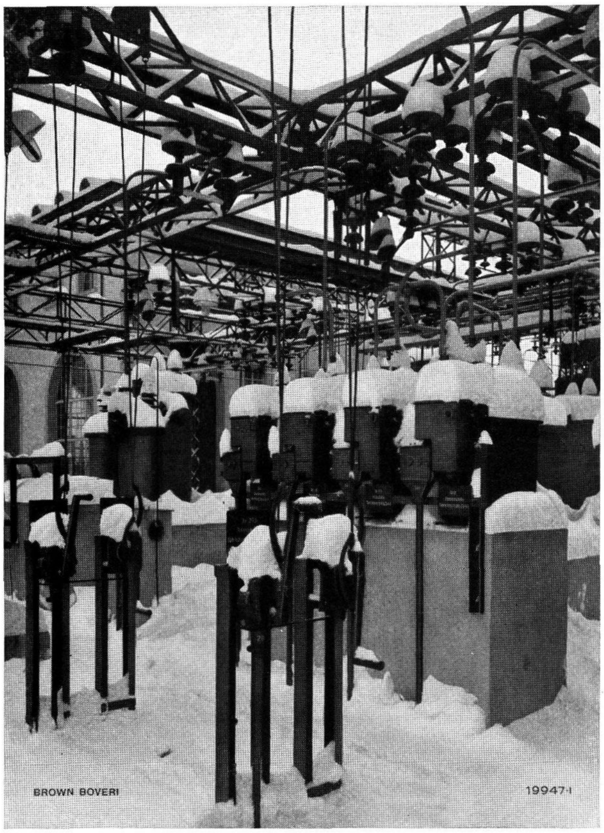

Fig. 3. — Track switches of the outgoing 15-kV lines, under snow.

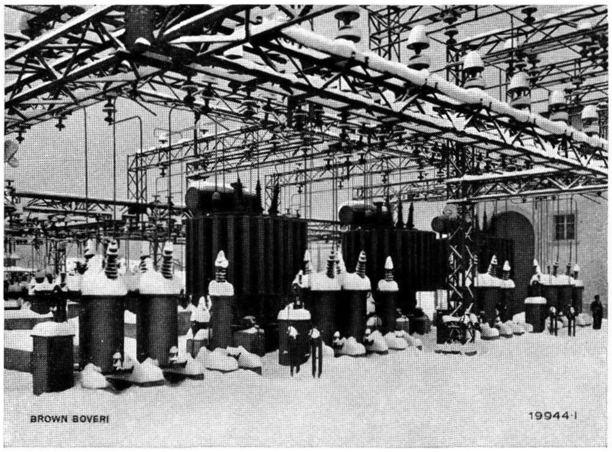

Fig. 4. — The three transformers each 3000 kVA, 60/15 kV, 16²/₃ cycles and the oil switches of the 60-kV side.

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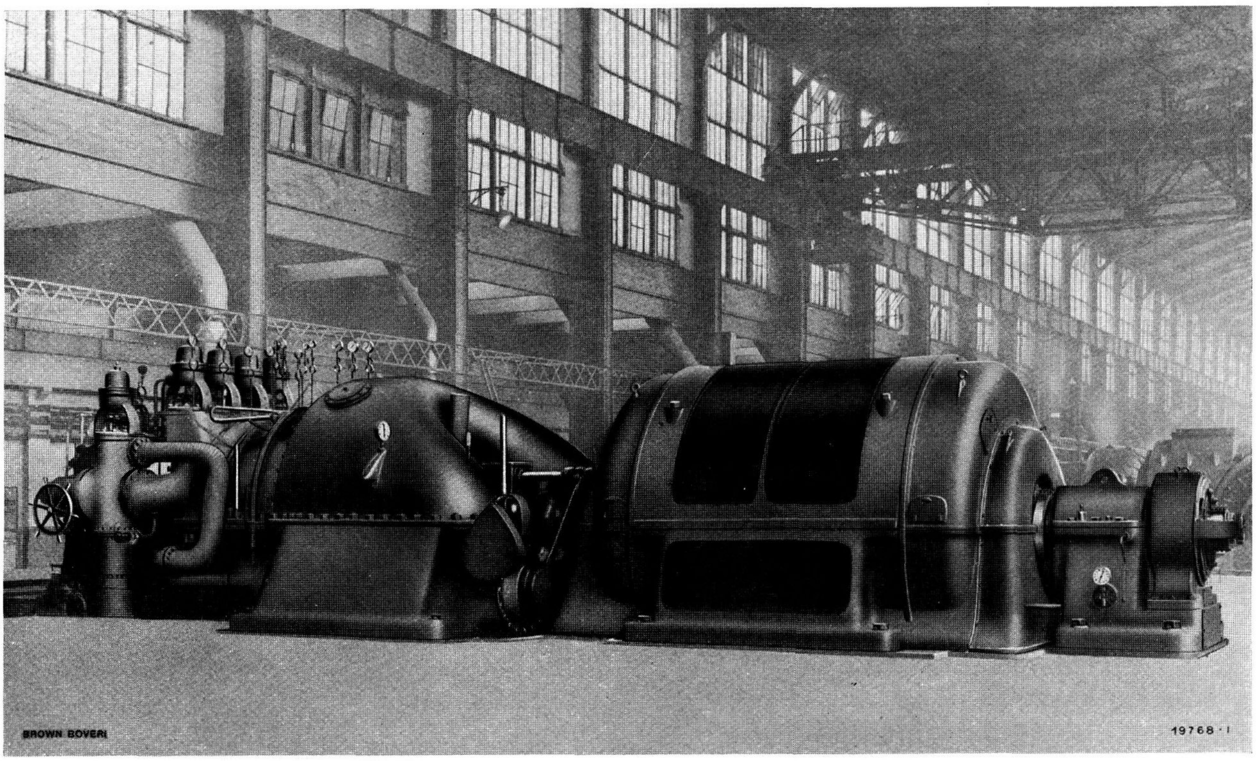

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