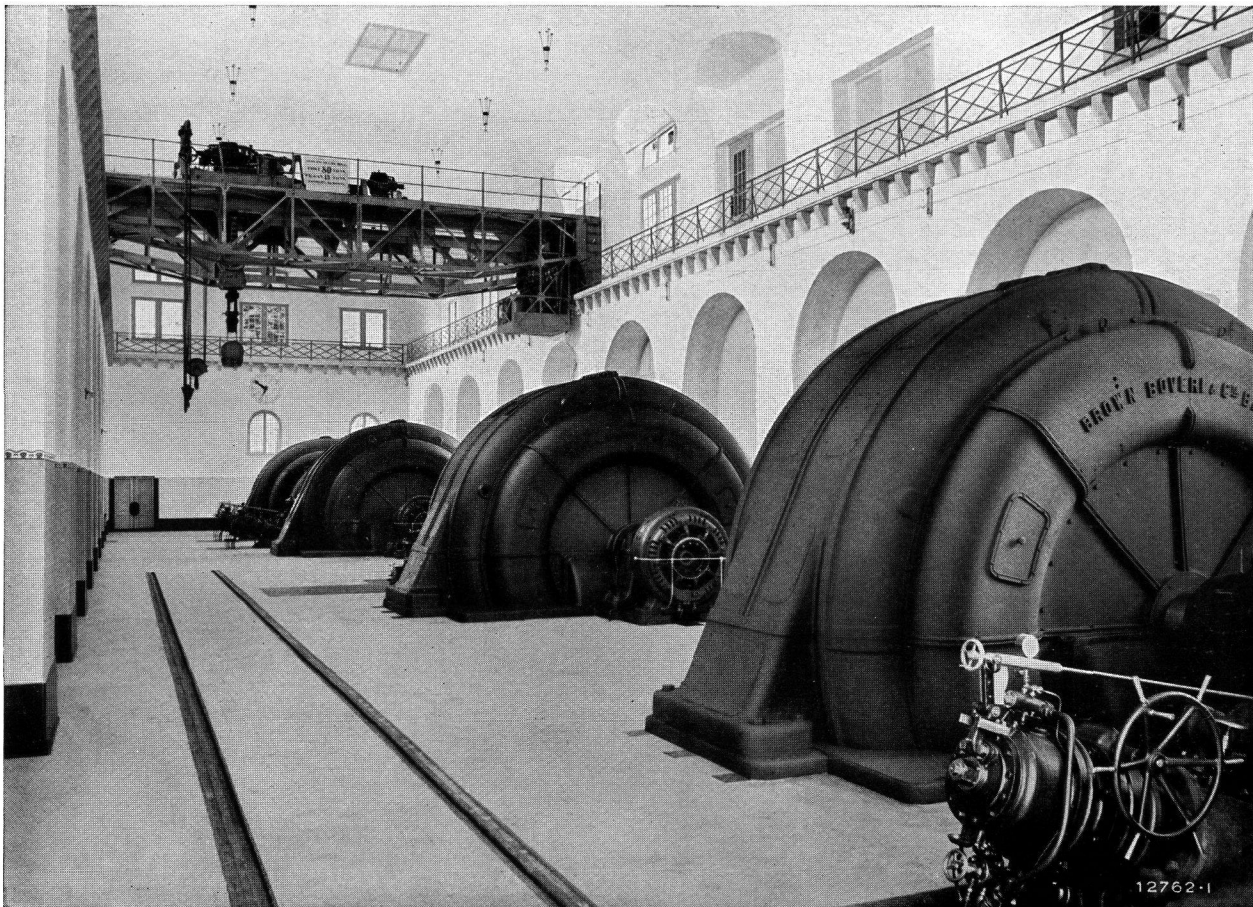


# THE BROWN BOVERI REVIEW

EDITED BY BROWN, BOVERI & CO., BADEN (SWITZERLAND)

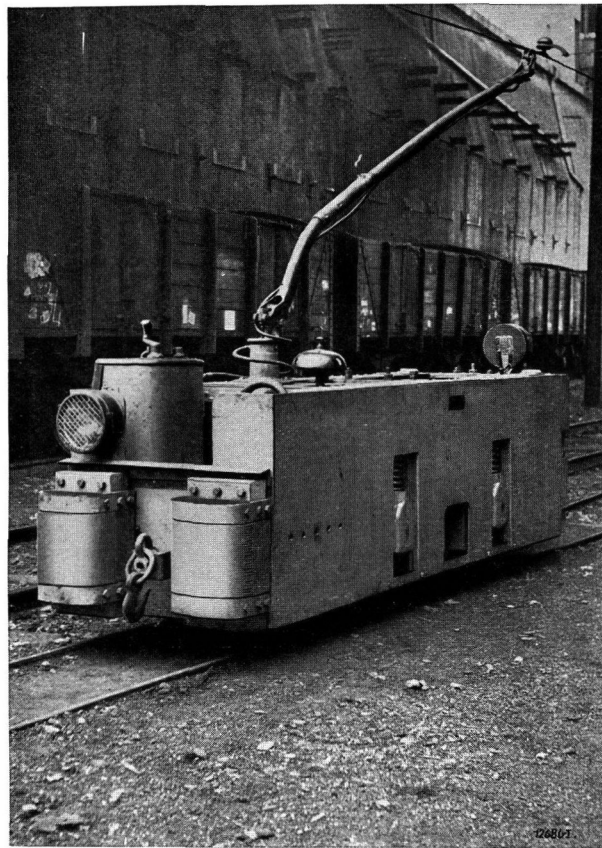


MACHINE ROOM OF RITOM POWER STATION, SWISS FEDERAL RAILWAYS.

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# COMPLETE EQUIPMENT OF INDUSTRIAL RAILWAYS FOR ELECTRIC TRACTION



ELECTRIC MINE LOCOMOTIVE OF THE SOCIÉTÉ DE MOUTIERS  
(FRANCE).

MINE LOCOMOTIVES - BATTERY LOCOMOTIVES  
BATTERY TRUCKS - RAILWAY MATERIAL

# THE BROWN BOVERI REVIEW

THE HOUSE JOURNAL OF BROWN, BOVERI & CO., BADEN (SWITZERLAND)

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## ERECTION AND TESTING OF THE SINGLE-PHASE ALTERNATORS FOR THE RITOM POWER STATION.

### General.

A NUMBER of important power stations are to be built for supplying the energy which will be required for operating the traffic as the electrification of the Swiss Federal Railways progresses. The first of these, the Ritom power station, was definitely put into operation in autumn, 1920, part of the alternators having already been put into service the preceding summer. The energy generated is required for operating the St. Gothard Section — the electrification of which was completed from Erstfeld to Airolo by 1920, and extended shortly afterwards from Airolo to Biasca. Valuable data and experience have been gathered from the operation of this power station, which will be of considerable use for subsequent single-phase plants of this description.

Ritom power station is situated on the south side of the Gothard tunnel, on the left bank of the river Ticino, 1010.5 m above the sea level, near the village of Piotta. Power is obtained from the fall of the Foss, a small stream which runs into the Ticino here. A vast storage reservoir having a capacity of 27.5 million cubic metres is formed by the Ritom Lake. The level of this lake has been raised to 1838.5 m above the sea by a dam, thus giving an available head of 828 m.

This power station is a typical example of an installation built for taking peak and winter loads. However, the Ritom station alone supplies the power required for the electrified lines of the Gothard Section until the Amsteg power station, at the north side of the Gothard tunnel, has been completed. Fig. 1 is a photograph showing the situation of the station, and Fig. 2 is a general view of the lake before the construction of the dam. The following article deals solely with the electrical equipment of the plant.

Only single-phase current for railway purposes with a frequency of  $16\frac{2}{3}$  cycles is generated in this station. The outgoing lines go in three different directions, namely:

(a) A feeder line which is connected to the contact wires at Ambri-Piotta railway station. The pressure of the current in this case is 15 000 V.

(b) To the substations at Giornico, Giubiasco and Melide in the south.

(c) To Göschenen substation in the north.

In the two latter cases, the power is transmitted at 60 000 V, the pressure being lowered to 15 000 V again at the substations. The power-station has been designed to accommodate six alternator sets; four sets have been installed up to the present.

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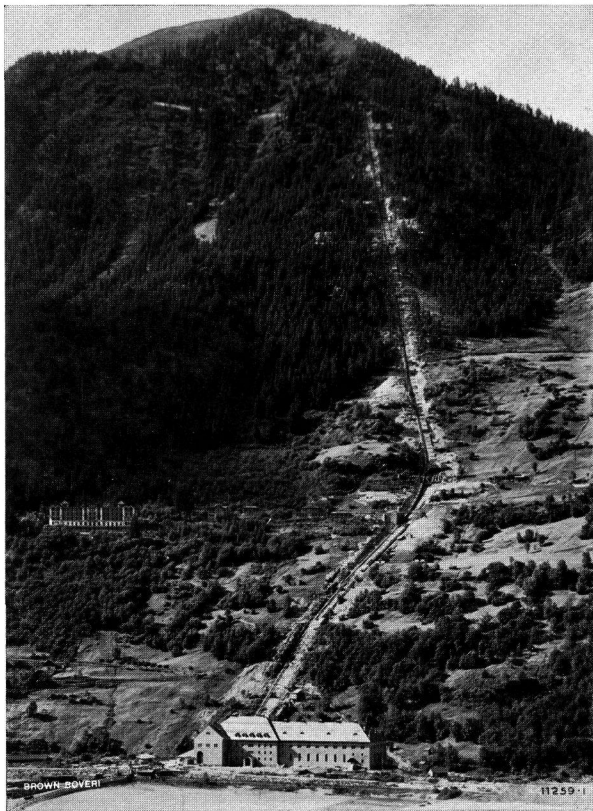


Fig. 1. — Ritom power station, showing pressure pipeline.



Fig. 2. — Ritom lake before the construction of the dam.

*Particulars of the alternators.*

The chief characteristics of one of these alternators are the following:<sup>1</sup>—

Continuous rating . . . . .	9000 kVA
1½-hour rating . . . . .	11500 kVA
Power factor . . . . .	0.75
Terminal pressure . . . . .	15000 V
Frequency . . . . .	16 <sup>2</sup> / <sub>3</sub> cycles
Normal speed . . . . .	333 <sup>1</sup> / <sub>3</sub> r. p. m.
Runaway speed . . . . .	630 r. p. m.
Total weight (including exciter) . .	222 met. tons
Weight of stator with core and windings	115 " "
Weight of rotor . . . . .	80 " "

Figs. 3 and 4 show the alternators in course of erection. Fig. 5 gives the arrangement of the connections for one alternator set.

The pressure regulation of the alternators is ensured by *Brown Boveri quick-acting pressure regulators*, connected as shown in Fig. 5, and having the following features:—

These regulators have a static characteristic, that is to say, they cause the pressure to be lowered when the load increases. Furthermore, they are compensated so that the terminal pressure augments with the power factor. For high values of the power factor, the effect of this compensating winding is opposed to that of the main winding, and can, in certain cases, neutralise or be superior to that of the latter. For instance, the pres-

<sup>1</sup> More detailed information has already been published in the *Revue BBC*, or *BBC Mitteilungen*, 1921, No. 9.

sure is made to increase with the load at unity power factor, as can be seen in Fig. 14. This mode of regulation causes the load to be evenly distributed amongst alternators or power stations (e. g. Ritom and Amsteg) working in parallel. A *maximum-pressure relay* (7, Fig. 5) is provided, which limits the pressure to 20 000 V by switching-in all the field resistances in the excitation circuit of the exciter whenever this value is exceeded. All danger due to the tension reaching excessive values should the turbines run away is thus removed.

A *Brown Boveri current-limiting device* protects the alternators against the effects of short circuits. Although the instantaneous value of the current can not

be limited, the device causes the lasting short-circuit current to be brought down to a predetermined value by diminishing the excitation. The current-limiting device therefore preserves the switchgear as well as the alternators. Moreover, it enables short-circuiting flashovers to be extinguished without necessitating the switching-out of alternators working in parallel.

Further protection against excessive currents is afforded by providing each alternator and each outgoing line with a secondary overload time-limit relay with independent time lag.

Protection against overpotentials on the 15000-V side is afforded by horn gap arresters with water resistances.

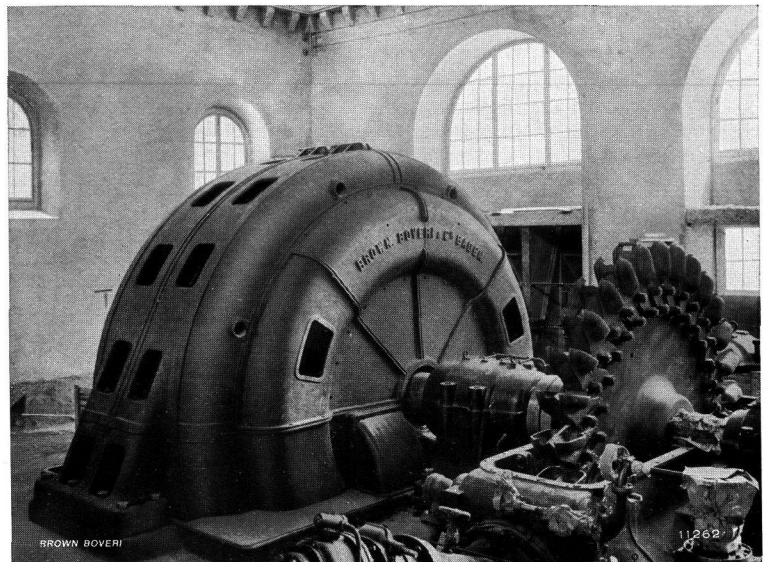


Fig. 3. — Single-phase alternator, Ritom power station. Output 9000 kVA, frequency 16<sup>2</sup>/<sub>3</sub> cycles. The Pelton water turbine, which is directly coupled to the alternator, is by the Ateliers des Charmilles (formerly Piccard, Pictet & Cie.), Geneva.

*Erection of the alternators.*

The erection of such large machines offers many interesting details, the chief of which will be briefly described. A 90-ton travelling crane is available in the power house. First of all, the soleplates and bearing pedestals are erected, and, once the position of the rotor shaft is correctly adjusted, they are embedded in concrete. Great accuracy is required for this work on account of the danger of the bearings running hot. Operations of secondary importance have to be carried out after this, such as, placing the pipes of the coolers for the bearings in position, etc.



Fig. 4. — General view of the first three alternators in course of erection.

The lower part of the stator is then assembled. The stator, in this case, is in four sections. As usual, the core is built up in the Baden workshops, so that it is only necessary to bolt the different sections together in order to assemble the stator. At the same time, the rollers for the stator and the main bedplate are put into position and embedded in cement. Whilst the cement is setting, the upper part of the stator is assembled and set up, and finally the rotor is erected.

Fig. 6 depicts a very interesting operation — viz. fitting the hub of the rotor spider to the shaft. It may be added that the shaft weighs 11 tons. The spider, as can be seen, is placed above a pit and heated so as to expand the bore, and the shaft is lowered with great care into the hub. The shrinkage of the latter on cooling and the pressure of shrink rings on the hub cause the shaft and spider to form one. This operation requires a great deal of skill, as it has to come off successfully the first time; moreover, it must be carried out rapidly, as a premature cooling of the spider may cause it to shrink on to the shaft at the wrong place. The pole pieces are next bolted on the spider (Fig. 7). After this, the stator winding is placed in the slots. The coils are ready for insertion as they have already been formed and impregnated in the workshops. This

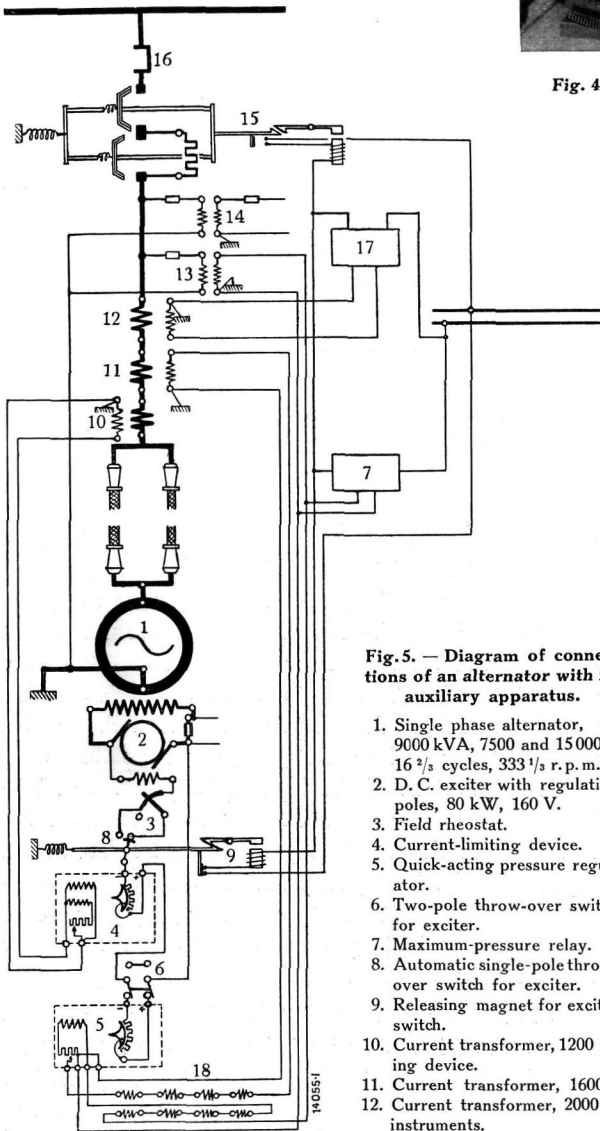


Fig. 5. — Diagram of connections of an alternator with its auxiliary apparatus.

1. Single phase alternator, 9000 kVA, 7500 and 15000V, 16 2/3 cycles, 333 1/3 r. p. m.
2. D. C. exciter with regulating poles, 80 kW, 160 V.
3. Field rheostat.
4. Current-limiting device.
5. Quick-acting pressure regulator.
6. Two-pole throw-over switch for exciter.
7. Maximum-pressure relay.
8. Automatic single-pole throw-over switch for exciter.
9. Releasing magnet for exciter switch.
10. Current transformer, 1200 (600)/1A for current-limiting device.
11. Current transformer, 1600 (800)/5A for stabilising.
12. Current transformer, 2000 (1000)/5A for relays and instruments.
13. Current transformer for regulators and relays.
14. Pressure transformer for instruments.
15. Oil-switch with protective resistances.
16. Isolating switch.
17. Secondary overcurrent-limit relay with independent time lag, 2.5 A.
18. Double stabilising coils.

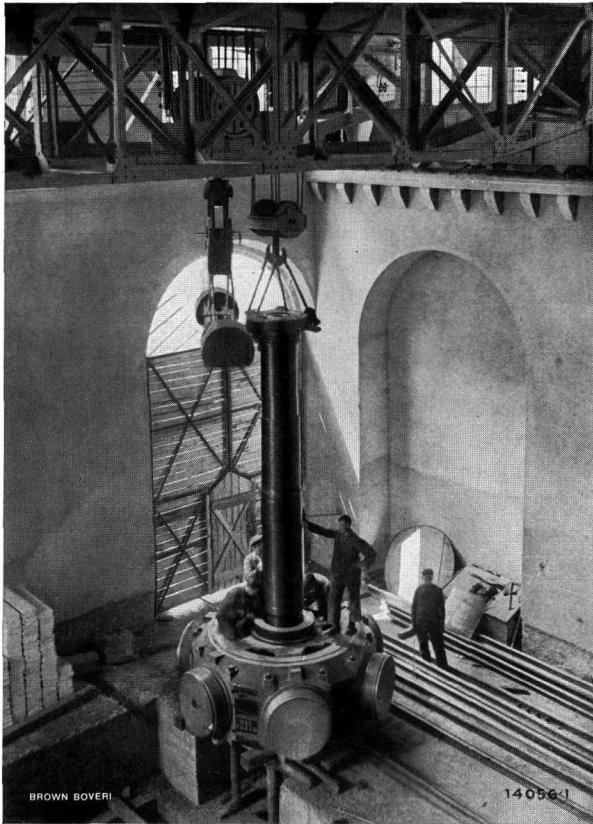


Fig. 6. — Assembling the hub of the rotor spider to the shaft.

undertaking is greatly facilitated by the rollers, which have been already mentioned, as they allow of the stator being rotated. A number of secondary operations are now carried out in the following order:— The feet are bolted on to the stator which can then be assembled to the bedplate; the rotor is inserted into the stator, and the covers are fitted. The alternator can finally be coupled to the turbine, and is ready for placing in service.

#### *Starting-up and tests.*

During the period of mixed steam and electric traction, the contact-wire pressure had to be lowered to 7500 V, as the normal working pressure of 15 000 V gave rise to insulation difficulties, especially in tunnels, on account of the fumes exhausted by the steam locomotives and of the soot deposited on the insulators. For this reason, the stator windings were temporarily connected so as to obtain a terminal pressure of 7500 V instead of 15 000 V. All traces of damp were removed before the alternator was energised by the flow of air produced by letting it run for about two hours without excitation. The pressure was then

slowly raised until 8000 V had been reached. The alternator was then allowed to run a certain time at this pressure, and kept under close observation. After this first trial, the current-limiting device and pressure regulator were adjusted, and the no-load and short-circuit characteristics of the alternator were determined. The alternators were then ready for service.

Further detailed tests were carried out in order to ascertain whether the guarantees had been fulfilled. Part of these were carried out under conditions which were artificially made to correspond to those met with in practice. The most important tests will now be briefly described.

The *no-load tests* showed the residual pressure of the alternator be about 300 V. This proves once more that it is dangerous to touch uninsulated wires connected to large alternators, even if the latter do not happen to be excited at the time.

The lasting short-circuit current, obtained by *short-circuit tests*, was found to be about equal to three times the normal current with full excitation. It will thus be seen, that these alternators conform with the latest practice, which consists of giving the machine a high internal reactance and of doing away with additional short-circuit reactances.

Great care was taken to determine the *efficiency curve*. For this purpose, the different losses (copper, iron, and friction and windage losses) were measured separately. In order to obtain the friction and windage losses, the alternator was made to rotate at its normal speed and then allowed to slow down, the alternator being speeded-up as described later on.

A water resistance, which had been provided by the Federal Railways for the acceptance tests, was able to dissipate the full load of an alternator, that is to say, 6750 kW continuously, or 9000 kW during short intervals. The tests carried out with this resistance enabled the maximum output of the turbine and alternator to be ascertained, and the influence of sudden alterations of the load to be found out. The tests with the alternator on load also permitted the variations of the terminal pressure to be determined experimentally. The power factor of the alternator to be tested was kept constant in a very simple manner by connecting it in parallel with another alternator which was more or less underexcited.

The experiments undertaken in order to measure exactly the friction and windage losses could not be carried out with the turbine coupled to the alternator, since the friction losses of the former were not known. On this account, the alternator to be tested

was uncoupled and made to run as a synchronous motor, which was brought up to its normal speed with the current generated by another alternator set. As no torque is developed by synchronous motors at rest, the difficulty of starting-up had to be overcome as follows:— The field coils of the two alternators were connected in series and fed with current from an independent supply. Before starting-up, the position of the machine to be run as a motor was adjusted so as to have the axes of the poles nearly coinciding with those of the stator coils. The alternators were then excited and the machine coupled to the turbine was started-up. The axes of the poles of the motor are then attracted, as would be a revolving magnet, towards the axes of the stator coils. The kinetic energy thus produced, together with the asynchronous effect of the damping winding and the vigorous impulses from the alternator generating the current as the axes of the poles approach those of the stator winding, cause the motor to gather speed rapidly. Oscillations of considerable magnitude occur on both machines when they are first set in motion, it may even happen that the motor begins to revolve in the wrong direction. By judicious manipulations of the water jet of the turbine, it was always possible to make the motor revolve in the right direction after a few trials in a very short time.

The values of the efficiency in per cent. obtained this way are given in the following table.

Output in kW	8600	6750	3500	1800
Unity power factor	%	%	%	%
Measured efficiencies	96.17	95.44	92.1	85.85
Guaranteed „	95.5	94.5	90.5	85.6
0.75 power factor	%	%	%	%
Measured efficiencies	95.24	94.7	91.7	85.7
Guaranteed „	94.7	93.8	90.0	82.6

It will be seen that the measured efficiencies are, without exception, higher than the guaranteed figures.

Measurements of the *output of cooling air* showed that 1500 cubic metres of air per minute could be supplied. This amount of air is amply sufficient for cooling under the most unfavourable circumstances possible at full load. The warm air is utilised in the winter for heating the machine room and switchgear.

Another series of tests were made to determine the time taken by the magnetic field, as well as the electrical energy of the alternator (stator and poles)

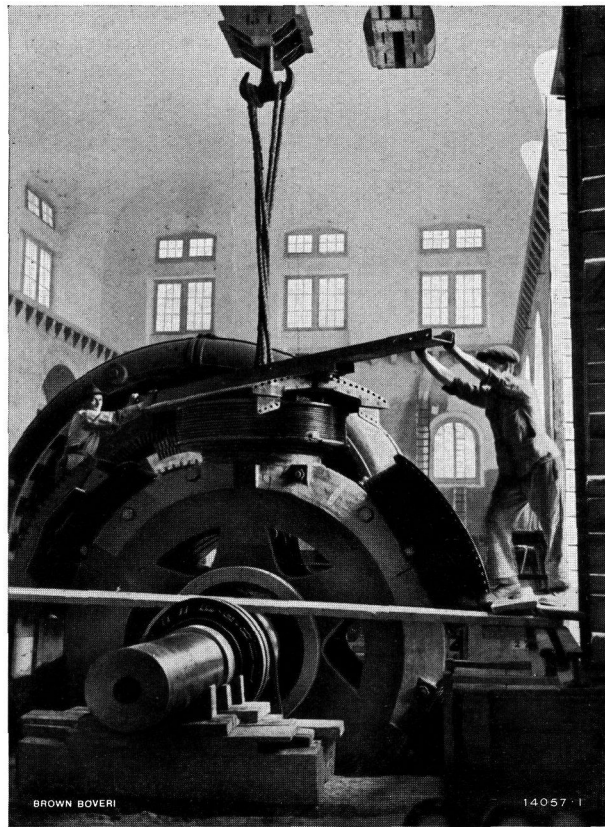
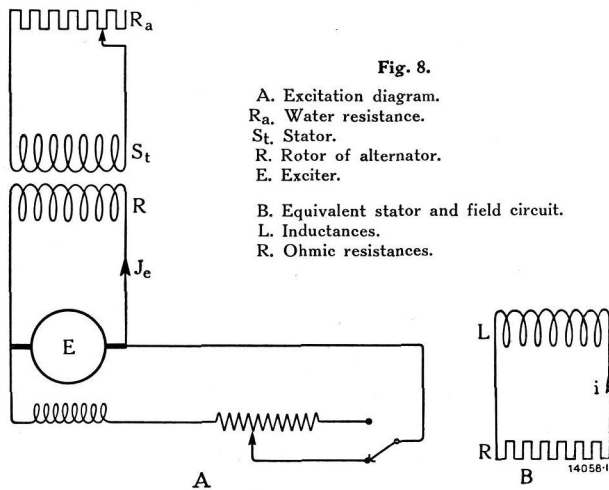


Fig. 7. — Assembling pole pieces on to the spider.

and exciter, to disappear when the switch of the exciter is thrown over, and to ascertain the influence of external resistances on this time interval, that is to say, the effect of resistances in the circuit of the alternator on short circuits coming from the line was found out. During a short circuit the energy of the



magnetic field and the electrical energy are stored by a system corresponding to the diagram, Fig. 8A. This system can be replaced by an equivalent circuit composed of inductances and an ohmic resistance,

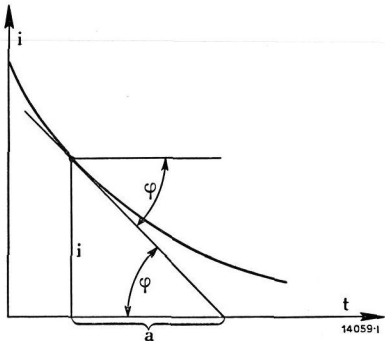


Fig. 9. — Exponential curve showing the diminution of current with the time.

converted into heat. The current  $i$  decreases with the time according to an exponential law given by

$$i = J_e e^{-\frac{R}{L}t}$$

where  $e$  is the modulus of Napierian logarithms,  $\frac{R}{L}$  the time constant of the system<sup>1</sup>.  $\frac{R}{L}$  can be easily determined from Fig. 9, as it is equal to the inverse of the subtangent  $a$ , which has always the same value with an exponential curve. The results of these tests have been plotted out in Figs. 10 and 11, where the pressure drop in volts per second and the time constant  $\frac{L}{R}$  are given as functions of the external resistance.

During these tests, the alternator was excited so as to obtain a terminal pressure of 7500V. The exact determination of the pressure variations at the terminals and the field current required by means of the experimental no-load characteristic, the measur-

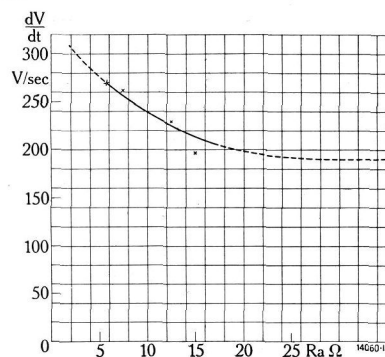


Fig. 10. — Pressure drop of stator in volts per second as a function of the external resistance when the exciter switch is thrown over.

<sup>1</sup> Account has not been taken here of the subdivision of the time constant into two components — one for the field winding and one for the stator winding — as sufficiently precise results are obtained without introducing this extra complication.

Fig. 8B. If a short circuit occurs, the energy of the magnetic field is dissipated in the ohmic resistances once the switch of the exciter is thrown over, that is to say, the energy stored in the system,  $\frac{i^2 L}{2}$ , is

ed values of the resistance and impedance and the construction of Potier's diagram is comparatively involved. Another graphical method, which is used for three-phase alternators, was found to give sufficiently accurate results with single-phase alternators, as the subsequent experimental determination of the pressure variations confirmed. The vector diagram necessary for this graphical method is given in Fig. 12. The impedance pressure  $E_z$ , which is in quadrature with the current  $J$ , is added to the terminal pressure  $E_t$ .  $J_{e_1}$  is the excitation current corresponding to the pressure  $E_1$ , the value of which can be obtained from the no-load characteristic of the alternator. To  $J_{e_1}$  is added  $J_{e_2}$ , which is the value of the excitation current corresponding to a given value of the current in the short-circuit characteristic. The total excitation current

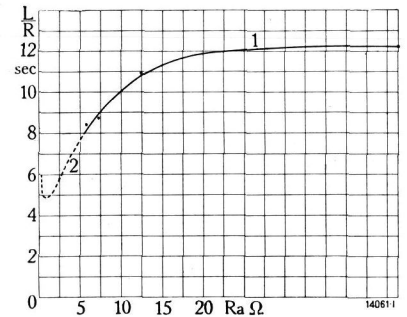


Fig. 11. — Time constant of the alternator as a function of the external resistances.  
1. Time constants for different values of the external resistances.  
2. Curve undefined.

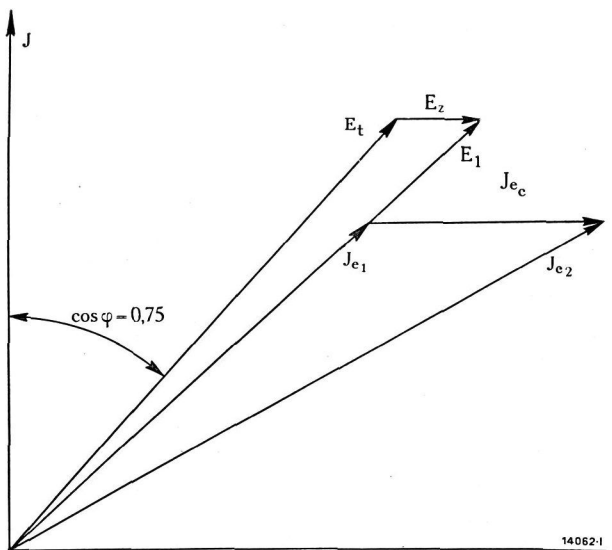


Fig. 12. — Vector diagram for obtaining the excitation current and pressure variations.

- $E_t$ . Terminal pressure,  $E_t = 7500$  V.
- $E_z$ . Impedance pressure,  $E_z = 1035$  V.
- $E_1 = 8250$  V.
- $J_{e_1}$ . Excitation current corresponding to  $E_1$ ,  $J_{e_1} = 317$  A.
- $J_{e_c}$ . Excitation current corresponding to  $J$ ,  $J_{e_c} = 162$  A.
- $J_{e_2}$ . Total excitation current,  $J_{e_2} = 435$  A.
- Experimental measurements gave  $J_{e_{2ex}} = 420$  A.

required enables the value of the pressure to be determined from the no-load characteristic. The text for Fig. 12 shows that the results obtained this way are sufficiently exact for all practical purposes. The

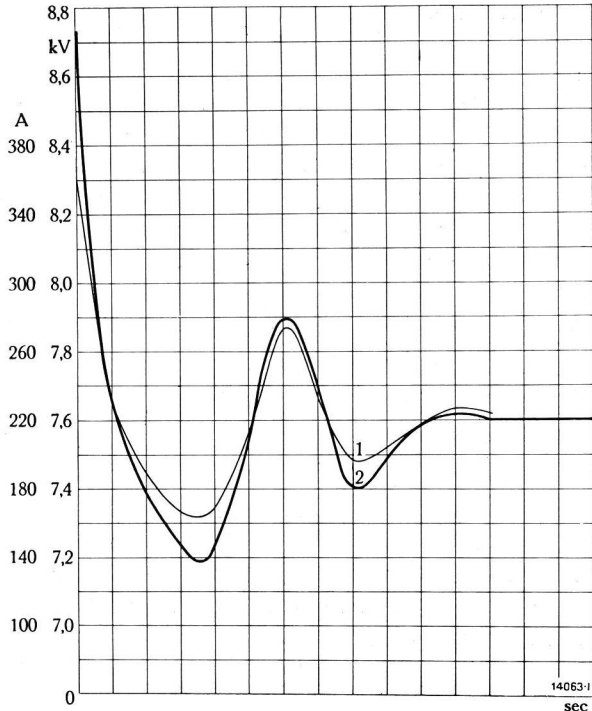


Fig. 13.— Regulation tests with pressure regulator when the pressure was increased 15%.  
1. Curve for when pressure is raised. 2. Curve for when pressure is lowered.

power factor ( $\cos \phi$ ) in this case was 0.75; with higher values of  $\cos \phi$  the accuracy of this method is still further increased.

**Pressure regulation.** The instruments recorded very clear results of the regulation tests. Fig. 13 shows that if the pressure is raised artificially about 15%, the regulation to the normal pressure takes place after very few oscillations. Fig. 14 shows the effect of a sudden removal of the load; the static characteristics of the regulation are distinctly brought out by the final values of the pressure.

An automatic synchronising device<sup>1</sup> is placed in the 15 000 V circuit. Tests showed that alternators could be connected in parallel very quickly and without jerks. This device is especially suitable for power stations feeding railways where it meets a long-felt want, as connecting in parallel with manually-operated devices is very laborious and difficult on account of

the fluctuating load. Besides the tests undertaken to determine the characteristics of the machines, the alternators were also tested in order to ascertain that all abnormal conditions occurring in service could be safely withstood. Each alternator was submitted to *over-speed tests* at 500 r. p. m., which is considerably above the normal speed of  $333 \frac{1}{3}$  r. p. m. These tests were undertaken with and without excitation of magnetic field of the poles, and were successfully carried out in every case.

The operation of the electric and mechanical safety devices of the turbines and alternators was most satisfactory.

**The temperature tests.** The temperature rise was measured at a great number of points with different loads. Thermo-couples embedded in the windings and thermometers were used to record the temperatures. It was found that embedded thermo-couples were easily damaged; consequently, only a limited amount of confidence was placed in the figures thus obtained. The maximum temperature rises measured in degrees centigrade are tabulated on the next page. It will be observed that the measured figures are considerably lower than those guaranteed.

The alternators were thoroughly tested by rigorous *short-circuit tests*, which consisted of suddenly connecting them to the line, and a short circuit was produced artificially at Piotta Station by placing a copper rod between the contact wire and the rails. The tests were carried out first of all at reduced pressures, and afterwards with the full pressure of 7500 V<sup>1</sup>. The maximum-current relays were adjusted for releasing at the end of different time intervals. A recording

<sup>1</sup> Some months later, similar short-circuit tests were undertaken, but with the normal pressure of 15 000 V, and with instruments belonging to the firm.

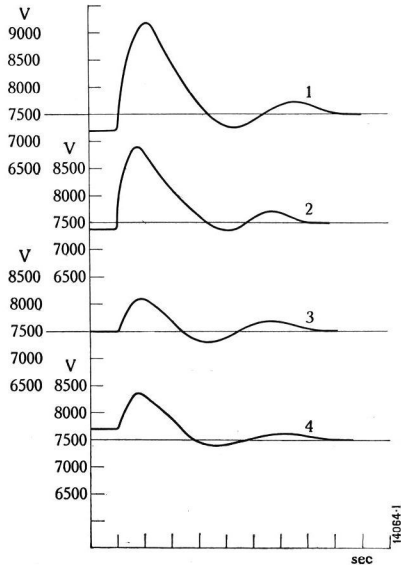


Fig. 14.— Automatic regulation of the pressure when the load is switched off.  
1. 11 500 kVA at 0.75 power factor are switched off.  
2. 9000 kVA at 0.75 power factor are switched off.  
3. 4700 kVA " 0.75 " " " " "  
4. 8600 kVA " 1.00 " " " " "

<sup>1</sup> This device has already been described in the Revue BBC or BBC Mitteilungen, 1921, No. 9.

Maximum temperature rises in degrees C					
Output	Cooling air	Stator copper	Rotor copper	Stator iron	Notes
9000 kVA, 7500 V, 1200 A, 0.75 power factor, during 7 hours	19.8	37.3	43.0	50.2	Measured figures
	—	75	60	70	Guaranteed figures
11500 kVA, 7500 V, 1535 A, 0.75 power factor, during 1½ hours following on a 7000-kVA load	15.2	58.2	55.0	57.5	Measured figures
	—	75	60	70	Guaranteed figures

device was fitted to the stator coils in order to reveal any deformations which might occur. Moreover, strips of paper were glued over the windings of the stator — these strips being more or less tightly stretched — so as to ascertain the mechanical effects of severe short circuits on this part of the machines. Oscillograms were taken during these tests by instruments belonging to the Federal Railways. Notwithstanding the severity of the tests, no deformations were found to occur, thanks to the excellent bracing of the stator

coils and the mechanically sound design of the machines.

The *insulation tests* of the stator and rotor were satisfactory in all respects, despite their severity. The required pressures were obtained by a testing transformer supplied by the Federal Railways.

On summing up the results of these tests, it will be noticed that the guaranteed figures were kept in every case, and very often considerably improved upon, as with the efficiencies, for instance.

Finally, mention may be made to the following power stations equipped with Brown Boveri single-phase alternators:—

Barberine Power Station, Swiss Federal Railways.

Three single-phase alternators of 10000 kVA each, 15000 V,  $16\frac{2}{3}$  cycles, 0.75 power factor,  $333\frac{1}{3}$  r. p. m.

Walchensee Power Station, Munich.

Two single-phase alternators of 10650 kVA continuous rating each, 16000 kVA one hour rating, 6600 V,  $16\frac{2}{3}$  cycles, 0.75 power factor, 250 r. p. m.

Hakavik Power Station of the Vassdragsvesenet, Christiania.

Two single-phase alternators of 2700 kVA each, 5600 V, 15 cycles, 0.8 power factor, 300 r. p. m.

Muhleberg Power Station, Bernese Power Works, Berne.

Two single-phase alternators of 5000 kVA each, 15000 V,  $16\frac{2}{3}$  cycles, 0.7 power factor, 500 r. p. m.

*F. Wuthrich (D. M.)*

## TYPE E SWITCHBOXES.

Decimal index 621. 317. 3.

ONE of the first points to be considered in electrical installations is the prevention of accidental contacts with the live parts of the switchgear; at the same time, the working parts must be enclosed, and protected against mechanical damage. For currents up to 60 A, Type F switchboxes are suitable.<sup>1</sup> For higher ratings (200 to 600 A) and for working pressures up to 750 V, a new line of switchboxes has been evolved, which possesses many advantages over all existing types. Particulars and a description of the new Type E  $8\frac{3}{4}$  switchboxes, which are suitable for a nominal current of 200 A, are given in the present article.

A switchbox always contains two essential parts: a circuit breaker which serves to cut off the current at all the poles, and a suitable current-limiting device.

<sup>1</sup> These switchboxes were already described in the Revue BBC, No. 5, or BBC Mitteilungen, No. 3, 1919.

Although fuses are still used to limit the intensity of the current for small values of the latter, their place is being taken more and more for heavier ratings by switches with an automatic release, as the higher initial outlay is soon compensated by the fact that the expense involved in the replacement of blown fuses is avoided. Moreover, a switch, which has been released automatically, can be immediately switched in again once the cause of disturbance has been removed.

Current-limiting switches, intended primarily for switching in and out and for protecting three-phase motors, have to fulfil certain requirements, the most important of which will now be briefly reviewed: If a short circuit occurs in any phase, all phases must be immediately switched out. However, unnecessary interruptions must not be incurred by tripping on short overloads — such as occur when starting or

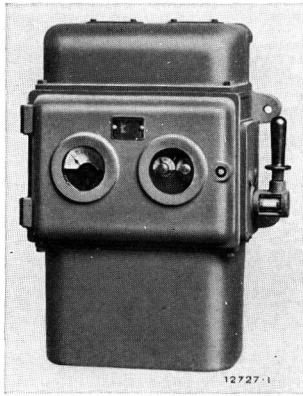


Fig. 1. — Type E 8/3 switchbox closed.

in service — which do not endanger the plant. With overloads lasting a long time — as, for instance, if the current of one of the incoming lines is interrupted — all phases must be switched off before the temperature rise in the motor windings reaches a dangerous value. (Fuses do not enable this requirement to be fulfilled, as they must be liberally dimensioned in order to carry the starting current of the motor.) On switching in with a short circuit on the system, the switch must release instantaneously, even if the handle is held in the “on” position. The switch must also trip when a motor stops owing to the pressure failing or dropping considerably, so as to avoid the danger of the motor starting up with its rotor short circuited, should the pressure be restored unexpectedly. All these conditions are met by the Type E 8/3 switchboxes. Moreover, as can be seen from the illustrations, a simple external form as well as an extreme accessibility of the working mechanism is obtained.

Figs. 1—3 show that the switchbox comprises three parts, viz:—

(a) An oil-switch in a cast iron tank which is easily removable.

(b) A cast iron casing with a hinged door containing the operating spindle of the oil-switch, together with a free-return clutch, and a no-volt coil. An overload time-limit relay, a current transformer and an ammeter are also housed within the casing.

(c) A terminal board which forms the upper part of the casing. It is provided with a cast iron cover to protect the ends of the incoming and outgoing wires against accidental contact.

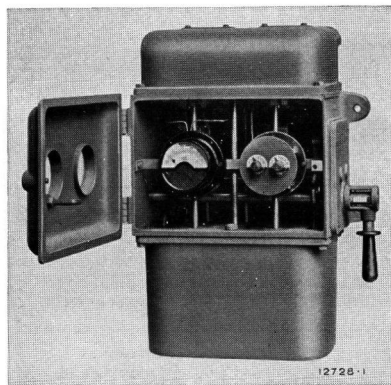


Fig. 2. — Type E 8/3 switchbox opened.

The three-pole oil-switch is of similar design to the Brown Boveri high-tension

oil-switches.

Two movable contacts of massive copper are fitted per pole, one of them being displaced with respect to the other (Fig. 4), so as to act as a sparking contact. These contacts require neither adjusting nor

cleaning, and need only be changed after several thousand switching operations. Care has been taken to ensure that no part of the switch can break or get out of order. The stationary contacts are mounted on insulated bolts, which pass through the casing directly to the terminal board, as can be seen in Fig. 3. Insulating partitions prevent flashovers between phases and to the oil tank. This arrangement enables the switches to have a very high breaking capacity, which amounts to about 3000 kVA with the usual pressures. For instance, a short-circuit current of 3500 A with a working pressure of 500 V can be broken safely.

The valuable properties of fuses — such as opening the circuit only after a certain lapse of time with moderate overloads, but blowing immediately a short circuit occurs — have been imitated as far as possible. A relay (Fig. 5) was chosen for this purpose, which, besides the direct-acting electromagnetic relay proper, comprises an iron resistance connected in parallel with the winding of the relay coil in order to secure the necessary time lag with moderate overloads. The relay is connected to a current transformer, designed for a secondary current of 10 A, the nominal values of the primary current being 120, 150, 180 and 200 A. Thus, the release always occurs with the same secondary current, and relays can be kept

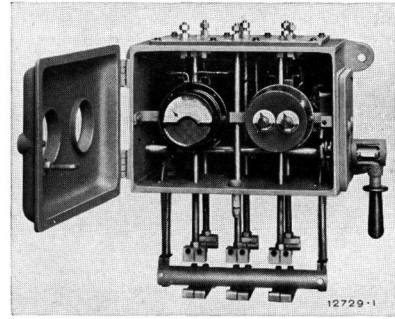


Fig. 3. — Type E 8/3 switchbox opened with oil tank and cover of terminal board removed.

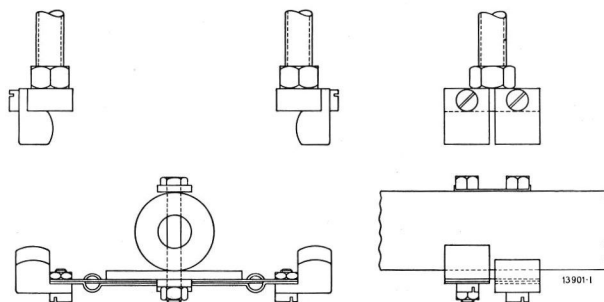


Fig. 4. — Arrangement of contacts of the oil-switch.

in stock which are already correctly wound and calibrated. The nominal current of the transformer is shown on the dial of the relay. The adjustment of the releasing current is made according to nine graduations showing the values of the same as mul-

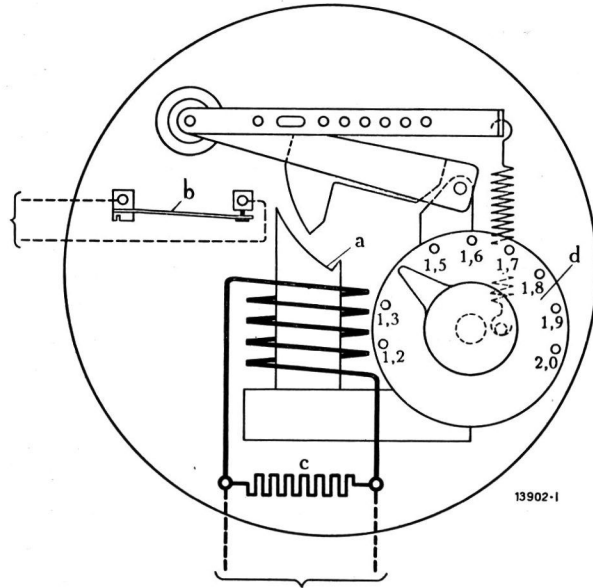


Fig. 5. — Type D overload time-limit relay.

- a. Magnet.
- b. Opening contact.
- c. Iron resistance.
- d. Adjustment of the releasing current.

tiples (1.2—2.0) of the nominal current of the transformer secondary winding. For instance, if a motor for a normal working current of 160 A is to be switched off when the overload exceeds 40%, the pointer of the relay is set to

$$\frac{160 \times 1.4}{150} = 1.5$$

if a current transformer for 150 A nominal current is employed.

Use is made of the well-known property of iron, namely, of its increased resistance when heated, to alter the distribution of the current between the relay coil and the iron resistance. For instance, if a current of 18 A goes through the relay, it will be evenly divided between the two circuits when first switched in. Assuming the iron resistance to be dimensioned in such a way that the temperature difference between the iron and relay coil amounts to 250° C when a state of thermal equilibrium is reached, the current in the coil will increase slowly until 12.5 A is attained, only 5.5 A going through the iron. As soon as the

current in the coil is sufficient to attract the armature, the relay will operate by interrupting the circuit of the no-volt trip coil. If a normal working current of 160 A is again assumed, the time taken to attract the armature will depend on the setting of the relay, i. e., on the tension of the spring holding back the armature. The release just takes place when the pointer is set to 1.8 times the nominal current, the time lag amounting to about 180 seconds. If the pointer is advanced to 2 times the nominal current, no release occurs; whereas, if it is put back to 1.4, the release takes place at the end of about 25 seconds.

The connections inside the switchbox are shown in Fig. 6. The current transformer and no-volt coil are placed on the motor-side of the switch, and are consequently not energised when the switch is open. A choke coil in the circuit of the no-volt coil is only necessary for pressures greater than 500 V.

Fig. 7 gives the secondary current as a function of the time lag for different settings, namely: 1.4, 1.7 and 2 times the nominal current, the load being directly switched on. Naturally, the time lag is somewhat less for the same values of the secondary current if the overload follows on the normal load. The time lag is inversely proportional to the current to a power greater than unity, and is therefore considerable for small overloads. This property is much sought after when the load is liable to frequent fluctuations. The time lag of 180 seconds with the

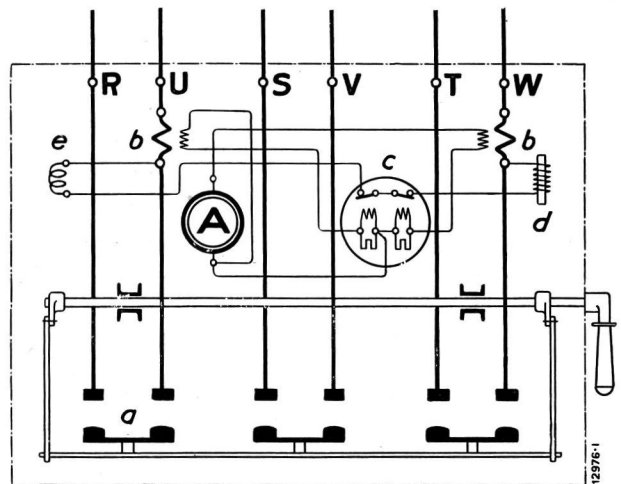


Fig. 6. — Diagram of connections in switchbox.

- a. Oil-switch.
- b. Current transformer.
- c. Overload time-limit relay.
- d. No-volt magnet.
- e. Choke coil (only for pressures greater than 500 V at 50 cycles).

adjustment 1.4 times the nominal current, corresponds pretty nearly to the overload capacity of 40 per cent. during 3 minutes which is often called for in practice. Moreover, for larger overloads — such as occur when a motor is started up — the time lag is sufficiently

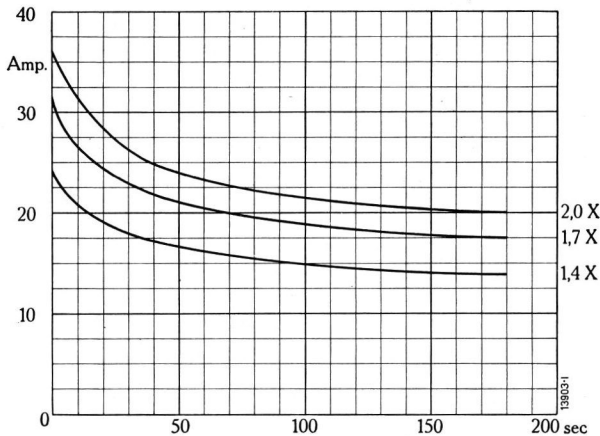


Fig. 7. — Variations of the secondary current with the time lag for different settings of the relay.

long with the setting for 1.4 times the nominal current to meet ordinary requirements.

It is evident that a certain time must elapse after the switch has been tripped on an overload before it can be closed again, in order to allow the iron resistance to cool down. In the present instance, the dimensions are chosen so that this interval amounts only to a few seconds. If a resistance with a high thermal inertia<sup>1</sup> is used, the action of the relay is rendered more sluggish, and the time lag with overloads increased. A disadvantage of this arrangement is that the interval before a tripped switch can be closed again is increased. If the starting conditions are exceptionally severe, they can be met by using a resistance with a high thermal inertia, since by this means the current necessary for releasing the relay can be kept low. Another solution consists in temporarily diverting part of the motor current from the relay by inserting resistances in parallel to it, which are cut out in normal service by a two-pole contact on the starter or on the brush-lifting device. Fig. 8 shows the connections with this arrangement.

<sup>1</sup> The thermal inertia of a body may be defined as a quantity depending on the rapidity with which it cools down or can be heated.

An automatic circuit breaker must always be provided with a free-return clutch in order to obtain a non-rigid connection between the handle of the switch and its spindle, so that the switch can be tripped, even when the handle is held in the "on" position. A free-return clutch has been designed for switches requiring a torque not exceeding 500 kgcm, which, on account of its small overall dimensions, is very suitable for switchboxes. The design of this clutch differs somewhat from those for large oil-switches; an idea of its mechanism can be gathered from Figs. 9 and 10. The driving disc (b), which is fixed to the handle, turns loose on the spindle of the switch (a). Another disc (c), keyed on to the shaft (a), carries a pin (d), on which is mounted a pawl (e). The latter engages with the disc (b), through the action of a spring. For switching in, the handle with the disc (b) is turned in a clockwise direction, the disc (c) being also compelled to rotate on account of the pawl (e), until a notch in (c) engages with the fixed pawl (g). This pawl must be tripped in order to release the switch. For this purpose, it is necessary to cause the pawl (e) to rotate through a small angle around (d); this movement is produced

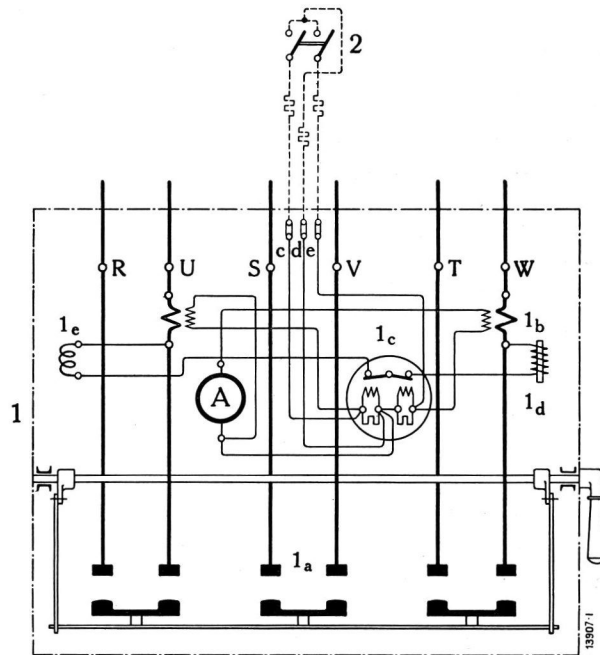


Fig. 8. — Diagram of connections in switchbox with arrangement for increasing the time lag.

- 1. Switchbox.
- 1a. Oil-switch.
- 1b. Current transformer.
- 1c. Overload time-limit relay.
- 1d. No-volt magnet.
- 1e. Choke coil (only for pressures greater than 500 V at 50 cycles).
- 2. Auxiliary switch on motor.

by the inclined surface (f) of the disc (b) when releasing by hand, or by the armature lever (h) when the no-volt release operates.

The equipment of the switchbox is completed by an ammeter. The dial of the latter, as well as

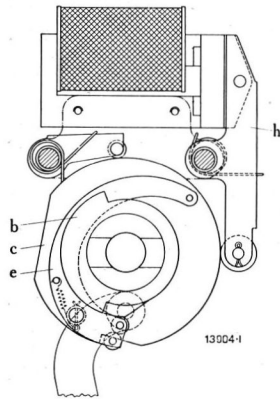


Fig. 9. — Free return clutch (switch released).

- a. Spindle of switch.
- b. Driving disc.
- c. Disc.
- d. Pin for pawl.
- e. Pawl.

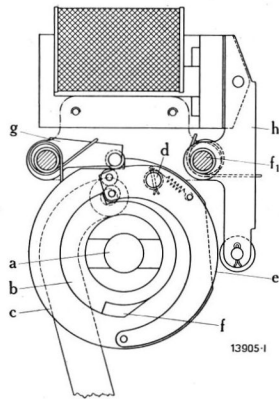


Fig. 10. — Free return clutch (switch closed).

- f. Disc with inclined surface for tripping switch by hand, forming part of b.
- f<sub>1</sub>. Pin for magnet.
- g. Fixed pawl.
- h. Lever with armature of no-volt magnet.

that of the two-pole relay, can be seen through glass windows in the hinged door (Figs. 1 and 2). A double mechanical interlocking device not only prevents the door of being opened when the oil-switch is switched in, but also makes it impossible to switch

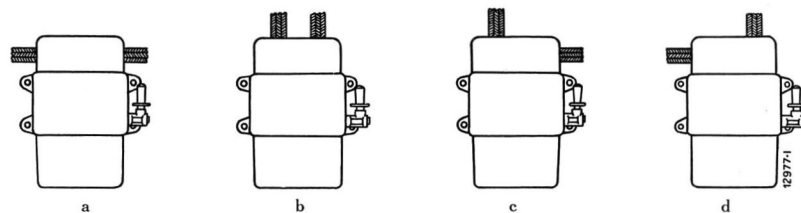


Fig. 11. — Different connections possible with incoming and outgoing wires.

in when the door is opened. The position of the switch is shown by the words "on" and "off" cast on the handle.

The terminal board is liberally dimensioned so that the connections to the line and the motor can be made as convenient as possible. Four openings are provided in the cover which permit of the

connections being carried out in a number of different ways, as shown in Fig. 11.

In order to be certain that the motor will not be switched in with the rotor short circuited, it is advisable — especially with unskilled operators —

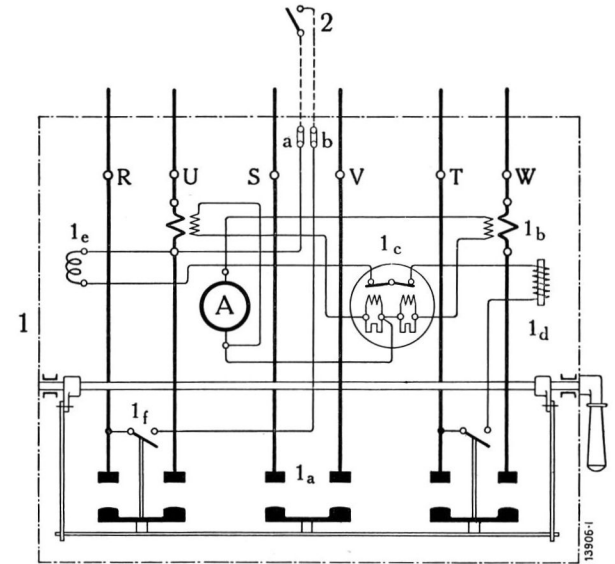


Fig. 12. — Diagram of connections in switchbox with auxiliary interlocking switch.

- 1. Switchbox.
- 1<sub>a</sub>. Oil-switch.
- 1<sub>b</sub>. Current transformer.
- 1<sub>c</sub>. Overload time-limit relay.
- 1<sub>d</sub>. No-volt magnet.
- 1<sub>e</sub>. Choke coil (only for pressures greater than 500 V at 50 cycles).
- 1<sub>f</sub>. Auxiliary switch.
- 2. Auxiliary switch for interlocking the starter.

to interlock the switchbox and starter in such a way that the latter must be brought to the starting

position before the switch can be closed. This is ensured by fitting supplementary contacts in the circuit of the no-volt coil (Fig. 12), which close the circuit of the latter through the interlocking contact of the starter after the switch handle has been turned slightly in the "on" direction. When the switch is completely closed, the switch is bridged over by a connection within the switchbox.

*G. Gut. (D. M.)*

## NOTES ON THE CHOICE OF MOTORS FOR CENTRIFUGALS.

Decimal index 621.313: 670.

### Summary.

THE requirements which have to be met by motors driving centrifugals are examined and gone into. It is shown that the continuous rating of such motors can be determined with sufficient accuracy by considering the root-mean-square output of the duty cycle. This method of calculating is discussed, and illustrated by an example.

### General.

UNDER the heading of centrifugals may be classed machines making use of the centrifugal force for technical purposes or processes.

The most elementary form of centrifugals consists of a basket rotating around a vertical axis which holds the material to be treated. The functions of such machines differ according to the work they have to perform. Amongst the industrial processes for which centrifugals are suitable may be mentioned: separating unrefined sugar, as well as forming sugar discs which are cut up later on into lump sugar in sugar refineries; phosphating silk in the silk industry; separating out water from stuffs during drying processes in textile mills, etc.

The quantity of material which can be dealt with at a time is limited by the capacity of the baskets. The duty cycle of a centrifugal may be divided up as follows: a rest period, during which the basket is emptied and recharged, and a working period, which comprises the time taken to accelerate the machine, running at full speed and braking. This class of service is manifestly only suitable for individual drives, since the energy and transmission losses are very heavy with other classes of drive, such as group drives which operate through belting. The requirements are best met by vertical-shaft electric motors, which are directly coupled to the centrifugals; moreover, with this class of drive, all the working parts can be arranged to be easily accessible without detracting from the pleasing appearance of the machine, and only a small floor space is taken up.

With individual electric drives, the load is intermittent, and depends on the duty cycle of the centrifugal. Consequently, a large starting torque is required to overcome the comparatively heavy flywheel effect of the basket when the centrifugal is

being accelerated; a small torque is sufficient at full speed, as only the windage and friction losses need to be compensated, and no motor torque at all is required while braking and standing still. The size of a motor working under these conditions depends on two factors: the highest value of the starting torque required, and the probable temperature rise of the machine.

The largest torque required is, as will be shown later on, found out in a very simple manner, and the rating of the motor in this respect is given by the maximum (peak) torque — the value of which can be determined exactly — which can be developed by a motor of a given type. The question of the maximum temperature rise is less easily taken into account, as the effect of many obscure phenomena can only be surmised. Some of the factors affecting this latter question will now be examined.

The temperature rise of a motor depends on the magnitude of the motor losses and the cooling arrangements. Its determination can be carried out by graphical or analytical methods from curves giving the temperature rise and temperature drop, or else by computing a continuous load which

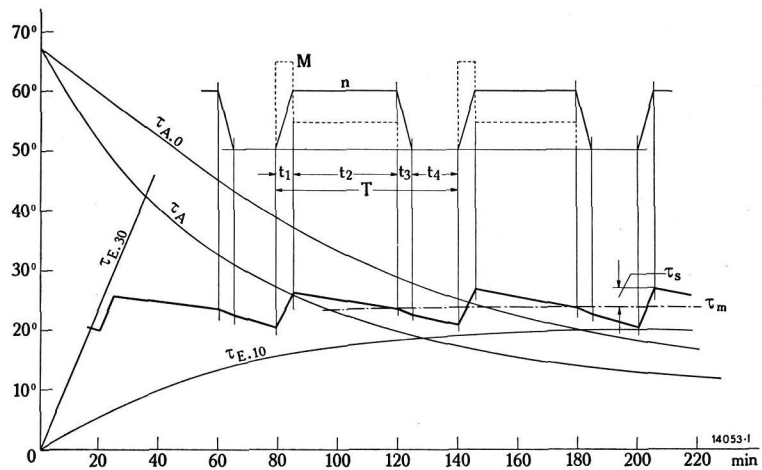


Fig. 1. — Duty cycle and corresponding temperature rise of a motor for driving a centrifugal.

Duty cycle:  
 Accelerating period,  $t_1 = 5$  min, torque M corresponding to 30 H.P.  
 Running period,  $t_2 = 35$  min, torque M corresponding to 10 H.P.  
 Braking period,  $t_3 = 5$  min.  
 Rest period,  $t_4 = 15$  min.

Temperature rise:  
 $\tau_{E.10}$ ,  $\tau_{E.30}$ . Curves giving the temperature rise for outputs of 10 and 30 H.P.  
 $\tau_{A.0}$ . Cooling curve at rest.  
 $\tau_{A.}$ . Average temperature rise.  
 $\tau_{s.}$ . Maximum temperature rise.

is equivalent, in this respect, to the known intermittent load of the motor. The first method<sup>1</sup> undoubtedly gives satisfactory results; however, it is somewhat involved, and the heating and cooling constants of the motor have to be assumed, since data of this

cycle is long, the maximum temperature rise is only slightly in excess of the average value of the same. Figs. 1 and 2, which show the temperature rises for two extreme cases, confirm these deductions.

It is only necessary, therefore, to consider the probable mean temperature rise when determining drives for centrifugals, and keep to the simpler calculating method, which consists of ascertaining the root-mean-square value of the power, that is to say, the continuous output for which the heat losses would be the same as with the given intermittent duty cycle. Account must also be taken of the effect of the comparatively long accelerating, braking and rest periods, during which the conditions for dissipating heat are less favourable than when running at full speed.

As already mentioned, the working cycle may be subdivided into four periods, namely: (a) accelerating, (b) running, (c) braking and (d) rest. The latter comprises the time taken to discharge and reload the basket. The operating conditions during these four periods will now be gone into.

(a) Accelerating period.

The work expended on accelerating is taken up by the inertia of the rotating parts and the frictional losses.

For determining the work required for accelerating the rotating masses, three factors are preponderant: the flywheel effect ( $GD^2$ ) of the masses to be accelerated, the time taken to attain full speed ( $t_1$ ) and the full speed ( $n$ ). Most usually,  $t_1$  and  $n$  are given; they depend on the centrifugal and the working process.

The flywheel effect can be divided up into three components:

1. The flywheel effect of the basket,  $GD_1^2$ .
2. The flywheel effect of the load,  $GD_2^2$ . (A distinction must be made in this case according to whether the centrifugal is completely filled while standing still, and than started up, or whether the baskets are gradually filled while they are being accelerated. In either case, the value of  $GD_2^2$  varies: firstly, because the load is thrown outwards when the speed is increased; secondly, because the weight of the load is increased with the speed. The average of the initial and final values of the flywheel effect usually gives sufficiently exact results.)

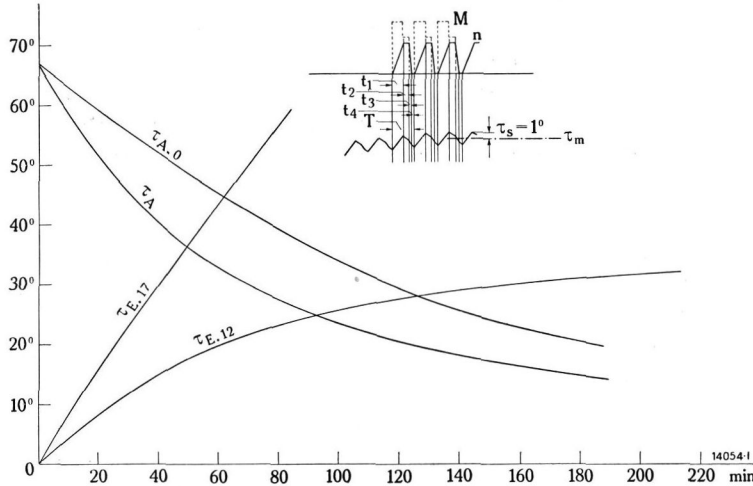


Fig. 2. — Duty cycle and corresponding temperature rise of a motor for driving a centrifugal.

Duty cycle:  
 Accelerating period,  $t_1 = 4$  min, torque  $M$  corresponding to 17 H.P.  
 Running period,  $t_2 = 2$  min, torque  $M$  corresponding to 12 H.P.  
 Braking period,  $t_3 = 1$  min.  
 Rest period,  $t_4 = 1$  min.

Temperature rise:  
 $\tau_{E.12}$ ,  $\tau_{E.17}$ , Curves giving the temperature rise for outputs of 10 and 30 H.P.  
 $\tau_{A.0}$ , Cooling curve at rest.  
 $\tau_A$ , Cooling curve while running.  
 $\tau_m$ , Average temperature rise.  
 $\tau_s$ , Maximum temperature rise.

description are usually not known to the designer. Such an exact determination of the temperature rise is superfluous in this case, as, with motors for centrifugals, the working periods are not only short, but follow on one another at close intervals, and consequently the maximum values of the temperature rise do not appreciably differ from the average temperature rise. Although in certain cases the duty cycle may be of comparatively long duration, such as one hour, for instance, the heating conditions are favourable inasmuch as the motor is solely overloaded during the accelerating period of the centrifugal, which only lasts for a few minutes, even if the operating conditions happen to be severe. The load subsequently decreases, and falls below normal during the period of running at full speed, so that the motor is able to cool down again. Hence, on account of the short time the overload lasts, even if the duty

<sup>1</sup> G. Gut: "Ein neues graphisches Verfahren zur Vorausbestimmung der Erwärmung elektrischer Maschinen und Apparate für intermittierende Betriebe, einschliesslich Bahnen," Bulletin des S. E. V., 1918, No. 2.

3. The flywheel effect of the rotor of the motor and the coupling,  $GD_3^2$ , which is usually negligible in comparison with that of the basket and load.

If:

$g$  = gravitational acceleration,

$G$  = a weight,

$D$  = diameter of gyration and

$GD^2$  = the flywheel effect of the rotating masses, the energy stored up by the latter once full speed has been reached amounts to

$$\frac{1}{2} \frac{G}{g} \left( \frac{\pi D n}{60} \right)^2 = \frac{1}{2g} GD^2 \left( \frac{\pi n}{60} \right)^2 \quad (1)$$

This energy is equal to the work of the motor during the accelerating period, exclusive of the friction and windage losses. On assuming the torque to be invariable,  $M = Pr$ , and consequently a constant resultant acceleration of the masses, the following relation can be written:

$$P \cdot 2\pi r \frac{n}{2} t_1 = \pi M n t_1 \quad (2)$$

On equating the second terms of (1) and (2), the accelerating period

$$t_1 = \frac{1}{22\,500} \frac{GD^2}{M} n \quad (3)$$

is obtained, or the torque

$$M = \frac{1}{22\,500} \frac{GD^2}{t_1} n \quad (4)$$

in kgm necessary to attain the speed  $n$  in the interval  $t_1$ . These calculations presuppose that the rotative speed of the motor ( $n_m$ ) is, the same as that of the centrifugal ( $n_c$ ), i. e., that the motor is directly coupled to the centrifugal. If this is not the case, all the quantities must be referred to the same rotative speed. In the present instance:

$GD_1^2$  and  $GD_2^2$  have a rotative speed  $n_c$

$GD_3^2$  has a rotative speed  $n_m$

In order to refer  $(GD_1^2 + GD_2^2)$  to the rotative speed  $n_m$

$$(GD_1^2 + GD_2^2) \frac{n_c}{n_m}$$

must be considered. The accelerating torque of the motor becomes

$$M_m = \frac{1}{22\,500} \frac{1}{t_1} \left[ (GD_1^2 + GD_2^2) \frac{n_c^2}{n_m} + GD_3^2 n_m \right] \quad (5)$$

The rating of the motor can be ascertained from the torque it has to furnish. Although the torque is constant, the output will not be invariable, since the rotative speed increases from zero to its maximum value. The effective motor output while accelerating must not be considered when calculating the root-mean-square value of the output, but that which corresponds to the power input during this period. When the torque is constant, the current taken by D. C. motors having an invariable field and by induction motors is practically independent of the speed and output, and is almost the same as if the motor was running at full speed. Consequently, the output  $N_1$  has to be considered, which corresponds to the torque  $M$  at full speed, that is to say

$$N_1 = \frac{n \cdot M}{716} = \frac{1}{16} \frac{GD^2}{t_1} n^2 \cdot 10^{-6} \text{ H. P.} \quad (6)$$

The effective output of the motor while accelerating increases from zero to the maximum value  $N_1$ , and its average value is equal to  $\frac{N_1}{2}$ , whereas

the power taken from the line remains practically constant, and its value corresponds to the torque  $M$  at full speed. Consequently, as the temperature rise is considered, the output  $N_1$  has to be taken into account which is required for the torque  $M$  at full speed. The energy loss in this case is dissipated as heat in the resistances.

Attention must be drawn to the fact that the expression "power input while starting" is ambiguous and therefore misleading. With plants already in commission, the power input measured with the help of an ammeter is most usually understood, as it is easily obtained; however, no account is taken of the losses in the resistances this way, so that the same power input as at full speed — that is to say, the power input corresponding to  $N_1$  — is obtained for fractional speeds when the torque is constant. The latter input must be distinguished from the total effective input of the motor while accelerating, as the two quantities are, as already shown, in the ratio of 2 to 1. When giving the power input required for accelerating, it should always be specified whether the input is obtained from ammeter readings, or the effective starting input is meant.

The friction losses are not constant, but are dependent on the momentary value of the bearing and windage losses, which vary with the speed. Moreover, the friction losses increase when the baskets are filled whilst being accelerated.

Simplified methods can be adopted when calculating the frictional work, as this quantity is small when compared to the work necessary for accelerating the masses. Hence, sufficiently accurate results are obtained by considering the power  $N_2$ , necessary to overcome the friction losses, constant at all speeds, and equal to the power required for this purpose at full speed.  $N_2$  depends on the design of the centrifugal, and should be specified by the makers.

(b) *Running period.*

The output  $N_2$  required when running at full speed, which has been given above, is principally needed to overcome the bearing and windage losses.

(c and d) *Braking and rest periods.*

If braking takes place electrically, the braking power  $N_3$  has to be calculated in a similar manner to the accelerating power. In this case, however, the frictional couple has the *same* direction as the braking couple.

With mechanical braking, the motor runs light while being slowed down, and this interval can be assimilated to the rest period. These simplified conditions will be examined in the following paragraph.

*Determination of the continuous rating of the motor.*

Let:

- $t_1$  = accelerating period in minutes.
- $t_2$  = period of running at full speed in minutes.
- $t_3$  = braking period in minutes.
- $t_4$  = rest period in minutes.
- T = duration of the duty cycle in minutes,

$$T = t_1 + t_2 + t_3 + t_4.$$

$N_1$  = motor output in H.P. required to accelerate the centrifugal.

$N_2$  = motor output in H.P. necessary to overcome the friction losses.

(When calculating these two outputs, the torque at full speed must always be considered).

The root-mean-square (r. m. s.) output is defined by the relation

$$N = \sqrt{\frac{\sum (t N^2)}{T}}$$

As already mentioned, account has to be taken of the less favourable conditions for dissipating the heat during the accelerating, braking and rest periods, hence the duration of the duty cycle T is replaced by a shorter time interval

$$\begin{aligned} T_{red} &= \frac{2}{3} t_1 + t_2 + \frac{2}{3} t_3 + \frac{1}{3} t_4 \\ &= \frac{2}{3} (t_1 + t_3) + t_2 + \frac{1}{3} t_4 \end{aligned}$$

Under these conditions, the rating of the motor in H.P. is given by

$$N = \sqrt{\frac{t_1 (N_1 + N_2)^2 + t_2 N_2^2}{\frac{2}{3} (t_1 + t_3) + t_2 + \frac{1}{3} t_4}} \quad (7)$$

The average temperature rise of a motor of this rating will be the same as that which would be found if the given duty cycle were replaced by a constant output equal to N. The machine must, however, be able to furnish a larger torque while accelerating. Whenever the latter is greater than 1.8—2 times the normal couple, it is as well to ascertain whether a motor of the above rating is suitable, as a larger size machine may be required. An inexactitude is committed by determining the motor rating from the r.m.s. output, as the losses are assumed to be proportional to the square of the output; this only applies to the copper losses, but is not true for the other losses. Moreover, the output while accelerating corresponds to a higher rating than the continuous motor rating, and the supposed losses are too great while starting and too small while running at full speed, that is, with a reduced output. However, these inexactitudes pretty nearly counter-balance themselves, as the r.m.s. output corresponds to the mean value of a large accelerating torque succeeded by a small running output, and does not result from a duty cycle where the output is occasionally considerably greater than the average output, for which the r.m.s. output would be too small. The exact ascertainment of the iron and friction losses is superfluous, as the schedule assumed will naturally not be kept to the second in practice, and the resultant discrepancies are not more important than the small inaccuracies of the calculations. Consequently, the results obtained by the determination the continuous motor rating by considering the r.m.s. output are sufficiently precise for all practical purposes.

*Numerical example.*

A sugar centrifugal for a load of 300 kg has the following particulars:—

- Average flywheel effect,  $GD^2$  . . . 500  $kgm^2$ .
- Full speed . . . . . 970 r.p.m.

Duty cycle:

- Accelerating period . . . . . 1½ min.
- Running period . . . . . 2½ min.
- Braking period . . . . . 1 min.
- Rest period . . . . . 1 min.

Friction losses at full speed, about 5 H.P.

The output of the motor necessary to accelerate the masses amounts to:

$$N_1 = \frac{1}{16} \frac{GD^2}{t_1} n^2 10^{-6}$$

$$= \frac{1}{16} \frac{500}{1.5} 970^2 \times 10^{-6} = 19.6 \text{ H.P.}$$

The output required to overcome the friction is

$$N_2 = 5 \text{ H.P. and}$$

$$N_1 + N_2 = 24.6 \text{ H.P.}$$

The continuous rating of the motor can now be calculated:

$$N = \sqrt{\frac{t_1 (N_1 + N_2)^2 + t_2 N_2^2}{\frac{2}{3}(t_1 + t_3) + t_2 + \frac{1}{3}t_4}}$$

$$= \sqrt{\frac{1.5 \times 24.6^2 + 2.5 \times 5^2}{\frac{2}{3}(1.5 + 1) + 2.5 + \frac{1}{3} \times 1}} = 14.7 \text{ H.P.}$$

The motor must be dimensioned for this output with respect to the temperature rise. Furthermore, it must also be ascertained whether the motor can furnish the necessary accelerating torque. In the example considered, the accelerating torque amounts to  $\frac{24.6}{14.7} \times 100 = 165\%$  of the normal torque, a value which is perfectly allowable.

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NOTES.

**Mercury arc rectifiers for D. C. pressures of 5000 V.**

Decimal index 621.313.73.

MOST usually, pressures of 1500—3000 V have been chosen for the electrification schemes of main-line railways with direct current. Rotary converters and rectifiers have so far been employed for converting A.C. into D.C. when the contact-wire pressure does not exceed 1500 V, whereas, for higher pressures, motor-generators have to be used. The latter are not only considerably more expensive, but have a lower efficiency than the former machines. This accounts for the preference accorded to direct current at pressures not greater than 1500 V in Europe, where only a few lines are operated with higher D.C. pressures, amongst which several railways equipped by Brown, Boveri & Co. may be mentioned, such as the Turin-Lanzo-Ceres Ry. (4000 V), the Rome-Ostia Ry. (2400 V) and the Coire-Arosa Ry. (2000 V).

Some months ago, however, Brown, Boveri & Co. have designed a new type of rectifier which is suitable for high D. C. pressures, and which has successfully undergone trials on the test bed. Direct current was supplied continuously at different pressures: first of all, the D. C. pressure was 2500 V and the output 450 A (1125 kW) per cylinder; the pressure was subsequently raised to 3500 V with an output of 350 A (1225 kW), and finally to 5400 V and 300 A

(1620 kW). The same overloads are permissible with this class of rectifier as those given in these pages in April, 1922. During each series of tests, the rectifier remained uninterruptedly on load day and night for a considerable time, without the slightest disturbance occurring while switching, overload and short-circuit tests were carried out. The output of the rectifier was dissipated by water resistances. The neutral point of the transformer was grounded, and the rectifier and vacuum pump set were insulated — an arrangement which is usually adopted by the firm for plants of this description.

These tests show for the first time that mercury arc rectifiers can not only be built for D. C. pressures of over 5000 V, but also, that they are technically suitable for such high pressures, as was shown by switching overload and short-circuit tests. Rectifiers are well adapted for completely automatic substations, and several plants of this description equipped by the firm will be placed in service this year. Since D.C. traction motors can now be built for terminal pressures greater than 2000 V — as has been proved by the motors for the Turin-Lanzo-Ceres Railway — and the construction of switches, controllers, etc. for pressures of 4000 V and over no longer offers any difficulties, all obstacles which prevented the advantages of electrification of main-line railways with high-pressure direct current from being utilised, have now been removed.

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# BROWN, BOVERI & CO.

BADEN (SWITZERLAND)

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