VOL. XII MARCH, 1925 No. 3

# THE BROWN BOVERI REVIEW

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

THE OPENING OF ELECTRIC TRACTION ON THE ZURICH-BADEN-OLTEN SECTION OF THE SWISS FEDERAL RAILWAYS ON JANUARY, 21, 1925.
Train with 2 C 1 electric locomotive with individual axle drive in the railway station at Baden.

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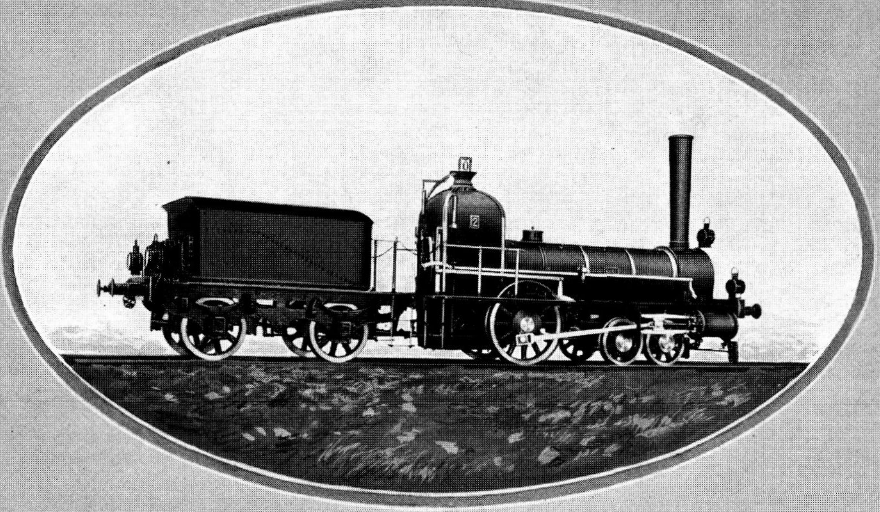
## The Opening of

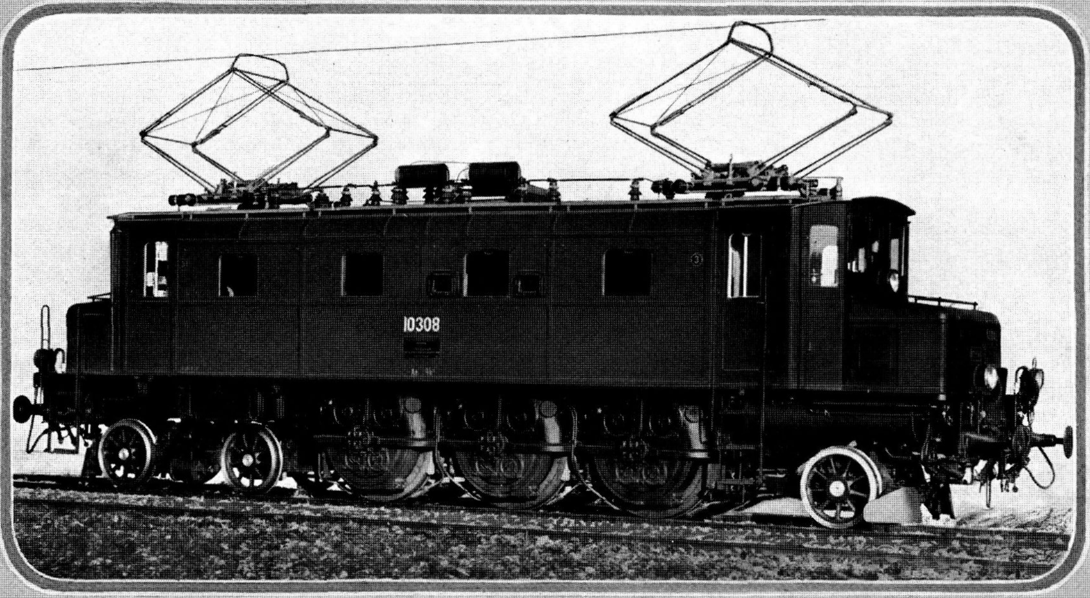
# Electric Traction

## on the Zurich-Baden-Olten Section of the Swiss Federal Railways

## January 21, 1925



**One of the first steam locomotives which ran in the year 1847 on the Zurich-Baden line, the first railway in Switzerland.**
(From a scale model in the Swiss Railway Museum at Zurich).
Steam pressure 6 kg/cm², power about 160 H. P., tractive effort 1400 kg, weight about 17 tons.



**One of the new electric locomotives fitted with the Brown Boveri individual axle drive, now running on the Zurich-Baden line of the Swiss Federal Railways.**
Supplied with single-phase current at 15,000 V, 16⅔ cycles; 2100 H. P., tractive effort 8300 kg, weight about 92 tons.

THE BROWN BOVERI REVIEW

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

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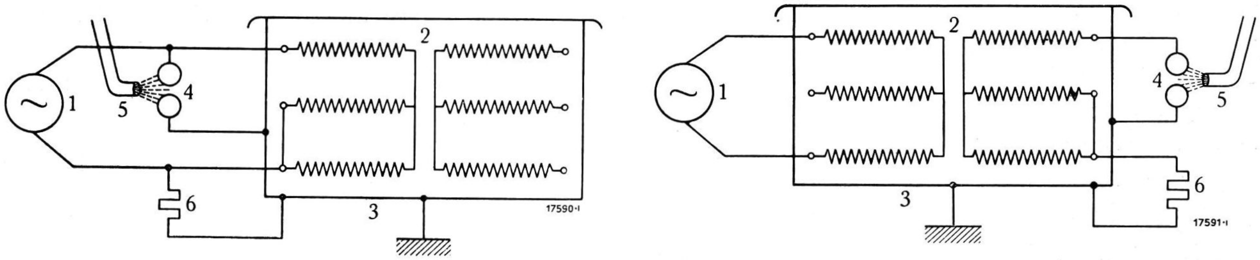
# SURGE TESTS IN THE BROWN BOVERI TRANSFORMER DEPARTMENT.

Decimal index 621. 314. 3.

UNDER actual working conditions, all transformers are subjected to surges which stress the insulation of neighbouring parts, such as coils, layers, and turns. Surge tests are carried out to examine the effect of stresses occurring in operation, and also to ensure that no manufacturing defects are present.

All transformers, to work with pressures greater than 3 kV (whether power or potential transformers), constructed by Brown, Boveri & Co. are submitted to surge tests before leaving the workshops. The connections of the circuit used for this purpose are the same as those published in the "Bulletin de l'Association Suisse des Electriciens" for August 1923 and are shown in Figs. 1 a and 1 b. Since January 1, 1924 this circuit has been recognised in Switzerland as the standard circuit for tests of this kind.

The surges occurring in practice are caused, almost exclusively, by flashovers to earth in the neighbourhood of the transformer. In the surge test, the actual conditions of a flashover should be reproduced as nearly as possible, if the test is to have any practical value. The surges are generated by charging the winding to be tested and suddenly discharging it to earth, which work is accomplished by a sphere spark gap connected between the terminal of the winding and earth. This terminal is charged by the induced voltage of the transformer until the spark gap breaks down. The spark which passes discharges the terminal suddenly, and a surge therefore results, the amplitude of which is that of the tension necessary to spark across the gap.



**Figs. 1a and b. — Diagrams of connections for surge-testing apparatus.**

1. Supply at frequency equal to or higher than that of the apparatus tested. The sources of supply can be protected from the influence of surges in various ways, e.g., condensers or choke coils.
2. Transformer to be tested.
3. Transformer tank.
4. Spark gap with compressed-air blast.
5. Compressed-air pipe.
6. Resistance.

The surge produced in this manner has very nearly the same effect on the internal insulation of the windings tested as a flashover when in service. By changing over the connections between the transformer terminals, the spark gap and the resistance 6 it is possible to test the insulation of each phase of the transformer successively.

To avoid the introduction of unknown quantities, as, for example, the earthing resistance, the spark gap is connected to earth and to the terminal of the transformer used, by connections as short as possible. The fulfilment of the preceeding conditions ensures that the flashover produced is such as would occur

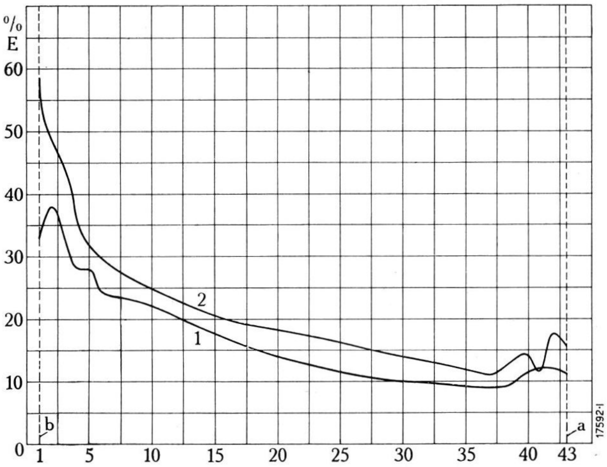
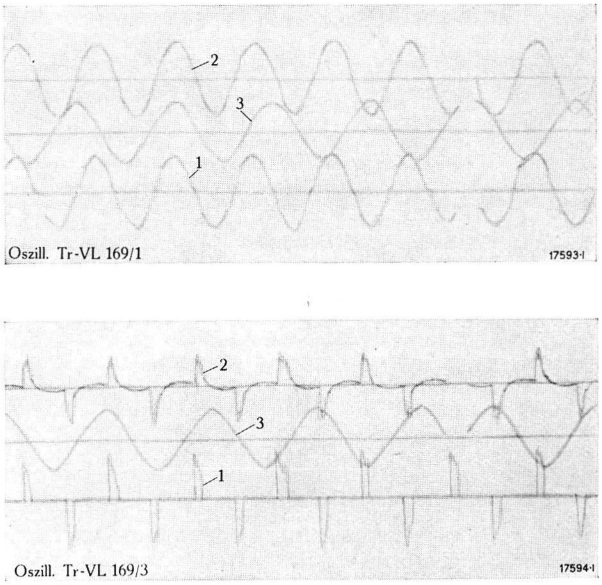


**Fig. 2.** — **Distribution of stress in the coils of a transformer winding** for 57 kV and 6000 kVA at 50 cycles. Influence of surge as a percentage of the amplitude of the surge E.

Curve 1. Terminal flashover of transformer.
Curve 2. Surge test.
a. Zero point of transformer.
b. Terminal.



**Figs. 3 a and b.** — **Oscillograms of a surge test.**

Curve 1. Current in spark gap.
Curve 2. Pressure in resistance (6 in Fig. 1).
Curve 3. Time scale = 40 cycles.

in service and that all transformers are tested in a uniform manner. Fig. 2 shows the stress set up in a 6000-kVA transformer coil compared with that of a terminal flashover in actual work.

The spark taking place between the spheres is at once extinguished by means of a blower and occurs again in the succeeding half period, as shown in the oscillograms Figs. 3 a and 3 b proving the correctness of this statement. The current across the spark gap when a blower is not in use is shown in Fig. 3 a, while in Fig. 3 b the effect of a blower on the current crossing the gap is shown. In the first case the current passes continuously in a similar manner to an alternating-current arc, while in the latter the initial values of both current and voltage are a maximum but immediately fall to zero.

The resistance 6 in Figs. 1 a and 1 b permits the potential of the terminal under test to be raised to that of the full voltage of the transformer to earth. This resistance must be at least 0·5 ohms per volt to prevent the current across the gap from becoming too large, and the greatest value shall be approximately 2 ohms per volt so that the excess

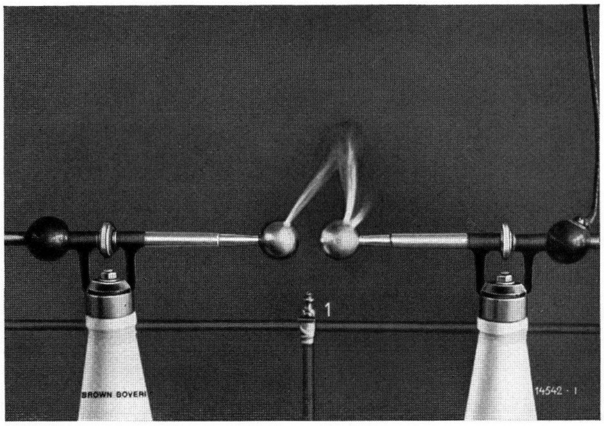


**Fig. 4 a.** — **Flashover of the spark gap at 50 kV, without compressed-air blast.**
1. Pipe for compressed air.

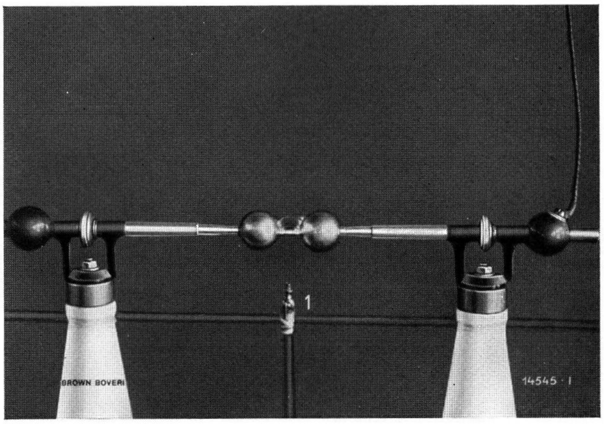


**Fig. 4 b.** — **Flashover of the spark gap at 50 kV with compressed-air blast.**
1. Pipe for compressed air.

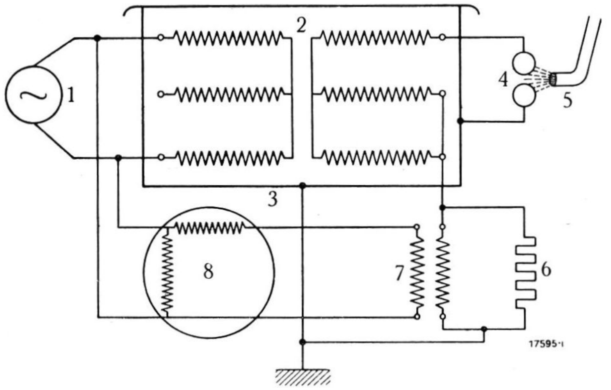


**Fig. 5. — Diagram of connections for surge test.**

1. Supply at frequency equal to or higher than that of the apparatus tested. The sources of supply can be protected from the influence of surges in various ways, e. g., condensers or choke coils.
2. Transformer to be tested.
3. Transformer tank.
4. Spark gap with compressed-air blast.
5. Compressed-air pipe.
6. Resistance.
7. Testing transformer.
8. Induction regulator.

voltage at the terminals not under test does not become inadmissibly high. If the two untested terminals of a three-phase transformer are connected, a single resistance may be used. This connection does not influence the surge stress set up.

The most favourable values for the ohmic resistance and the velocity of the blast may easily be determined by the appearance of the spark. With the correct choice of these conditions the spark will be violet or blue, while the formation of an arc of yellow colour indicates too low a resistance value or too weak an air blast. Fig. 4 a shows the arc set up when the blast is not in use, and Fig. 4 b that when the correct blast is applied. The difference between the two pictures is easily seen.

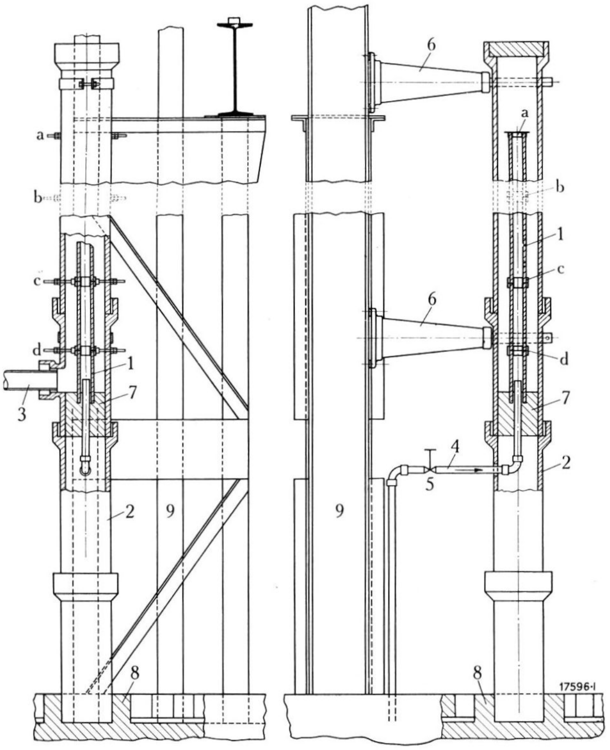


**Fig. 6. — Water resistance for surge tests.**

1. Earthenware pipe for ascending water.
2. Earthenware pipe for descending water.
3. Water outlet.
4. Water inlet.
5. Water stop-cock.
6. Supporting insulators.
7. Stop.
8. Foundation.
9. Steel column.

a, b, c, d. Tappings.

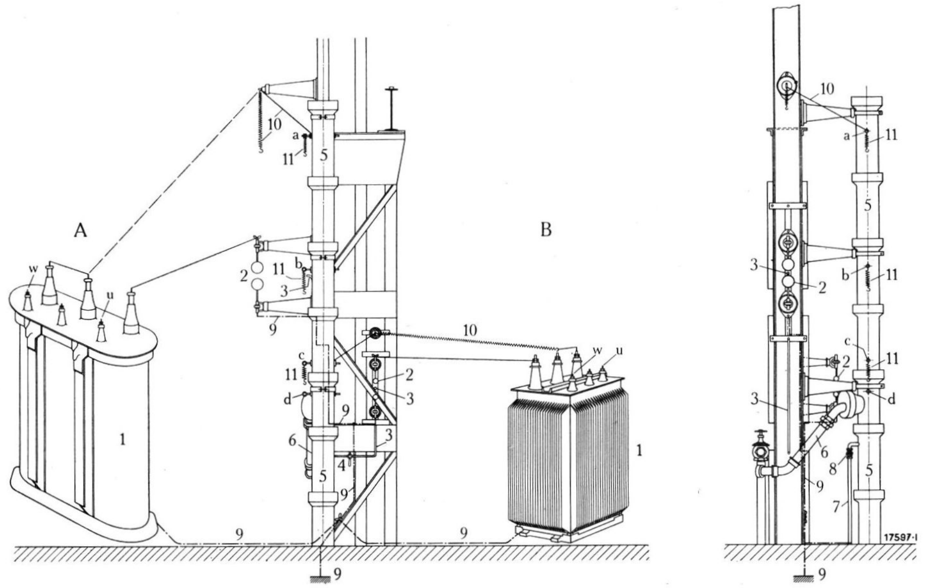


**Fig. 7. — Bays for surge tests.**

A. Bay for testing large transformers.
B. Bay for testing small transformers.

1. Transformer under test.
2. Spark gap.
3. Compressed-air supply.
4. Compressed-air cock.
5. Water resistance.
6. Water outlet.
7. Water inlet.
8. Water supply cock.
9. Earth.
10. Connection between transformer and water resistance.
11. Spiral spring to short-circuit the different resistance terminals.

a, b, c, and d. Resistance tappings for pressures smaller than 135,000, 60,000, 24,000, and 8000 V.

The object of this method of testing is not only to submit the winding to a surge but also to indicate any defect which could not be discovered by the ordinary examination. To obtain the latter result a pressure approximately equal to the normal value is applied to the terminals of the apparatus tested. Any defective places would be burnt through and the defect immediately localised.

Transformers can be tested at their normal frequency by this method, and be subjected to surges the amplitude of which approaches the applied maximum pressure, i. e. 1·3 $E_v$ in normal circumstances, $E_v$ being the working pressure. An increase of the amplitude of the surge is obtained by increasing the frequency of the source of supply. If the frequency can be doubled without the induction becoming excessive it is possible to increase the amplitude up to 2·6 $E_v$.

When it is desired to raise the amplitude of the surge above this value (e. g. for experimental purposes), suitable apparatus may be connected to the transformer as shown in Fig. 5. The transformer for the production of the auxiliary pressure is supplied from the same source, and therefore with current at the same frequency as the transformer to be tested.

The phase of this auxiliary voltage must be such that it is added to the excitation voltage of the coil tested; hence at the terminal of the latter a higher potential to earth is produced. With this arrangement it is possible to stress the transformer with a surge having an amplitude equal to that of its test pressure.

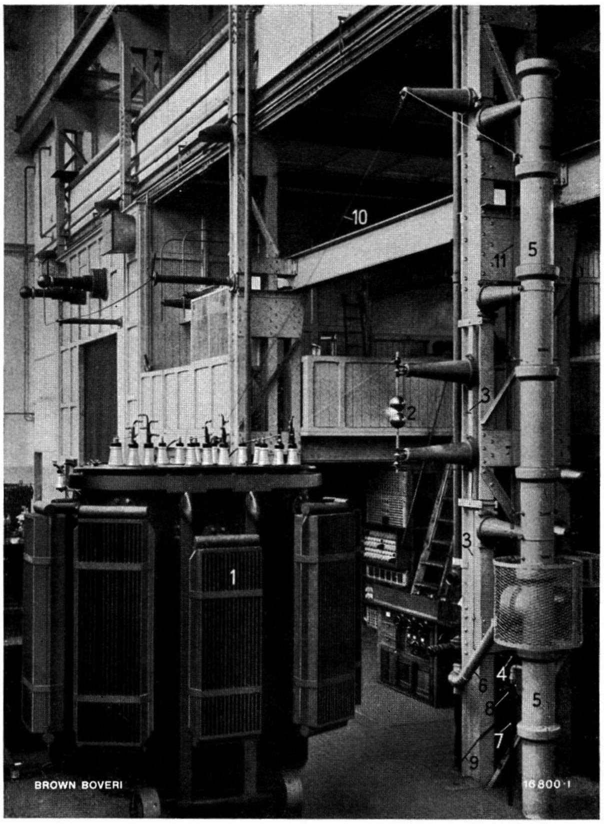


**Fig. 8. — Surge test on transformer for 660 kVA and 12 kV.**

1. Transformer under test.
2. Spark gap.
3. Compressed-air pipe.
4. Compressed-air cock.
5. Water resistance.
6. Water outlet.
7. Water inlet.
8. Water supply cock.
9. Earth.
10. Connection between transformer and water resistance.
11. Spiral spring to short-circuit the different resistance terminals.

The increase of the amplitude of the surge is possible by this method, a great advantage since the method is the same for ordinary and laboratory testing.

The design of the water resistance used in the transformer testing department of Brown, Boveri & Co., Baden is shown in Fig. 6. The resistance is formed by spring water kept in circulation to avoid undue heating. The water rises in the inner tube and flows down the outer tube, which also serves as a protective covering. Since the water in the outer tube is not under pressure, no special precautions need be taken respecting the outlet.

Fig. 7 shows the arrangement of the surge-testing bays. On the right is shown that for testing small transformers, and the spark gap for small surge tests, while on the left the bay for testing large transformers can be seen. Each spark gap is provided with a tube supplying compressed air, the flow of which can be controlled by a cock.

Fig. 8 shows the testing of a transformer for 660 kVA and a pressure of 12 kV. The method of testing described above has proved very suitable for research purposes, and also any manufacturing defect would be discovered before the apparatus left the workshops.

A surge test of similar underlying principles has been introduced in Germany since 1923. Whereas the method of surge testing laid down by the German regulations imitates the effect of making and breaking the circuits on all three phases, however, that standardised in Switzerland resembles a flashover to earth on one phase. Both methods are equally effective.

*(MS 317)* *S. Rump. (J. R. L.)*

# THE STARTING OF ROTARY CONVERTERS.

Decimal index 621. 317. 4 : 621. 313. 53.

IN common with all synchronous machines, rotary converters require special means of starting. The various methods usually employed for this purpose are described together with their advantages and disadvantages in this article; they are as follows:—

## I. ASYNCHRONOUS STARTING.

1. By means of a starting transformer, or tappings on the main transformer, either with or without the use of a choke coil when switching over.

2. By applying the full supply voltage to the converter, a choke coil being connected in series.

## II. USING A STARTING MOTOR.

1. A synchronous induction motor having the same number of poles as the converter.

2. An ordinary induction motor.

(a) The converter being run up to speed and synchronised. (The starting motor must have fewer poles than the converter).

(b) The converter being run up to a certain speed below synchronism and then connected to the mains through a synchronising choke coil. (The number of poles of the starting motor may be equal to, or less than that of the converter).

(c) Simultaneous starting of the starting motor and application of the supply voltage to the converter through a synchronising choke coil.

3. Connecting the stator of the starting motor in series as a synchronising choke coil. (The number of poles of the starting motor may be equal to, or less than that of the converter).

## III. STARTING FROM THE DIRECT-CURRENT SIDE.

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## I. ASYNCHRONOUS STARTING.

### *1. Asynchronous starting by means of tappings or a special starting transformer.*

The simplest method of putting a rotary converter into operation is to apply a reduced voltage and start it as an induction motor, the poles together with a suitable amortisseur winding acting as a squirrel-cage armature. The rotor is energised by alternating current at supply frequency, which is applied to the slip rings; this gives rise to a rotating field which revolves relatively to the rotor at a constant speed depending upon the frequency. Thus at the beginning of the starting period, the rotor being stationary, this field rotates relative to the stator at synchronous speed; as the rotor speeds up, the absolute speed of field rotation decreases, until the machine reaches synchronism, when it is zero with regard to the stator. Throughout the starting period, this field cuts all the rotor conductors at every revolution, including those which happen to lie under the commutator brushes. Heavy short-circuit currents consequently flow through the brushes, and can give rise to excessive sparking. Further, the field cuts the pole windings also, and can give rise to very dangerous voltages on account of the large number of windings on the main poles. Endeavours have been made, particularly in American practice, to eliminate this harmful sparking by raising all the brushes from the commutator during starting, with the exception of two excitation brushes. This method was previously employed by Brown, Boveri & Co. but was abandoned, as, in addition to giving rise to complicated component parts, it has the further disadvantage that it tends to prevent the brushes bedding down well on the commutator, so that the high standard of commutation now demanded is difficult to attain. To guard against the induction of dangerous voltages in the windings of the main poles, these were either divided into a number of small open circuits, or completely short-circuited during the starting period. The former measure results in complicated connections and can also involve a risk that the converter will run away; with the latter, on the other hand, there is a danger that the machine will reach half speed and refuse to run any faster.

Brown, Boveri & Co. directed their attention to making asynchronous starting as simple as possible, all avoidable auxiliary apparatus and switching operations being obviated. Entirely by suitably dimensioning such parts as the amortisseur winding, the commutation poles, the number of commutator segments covered by the brushes, the voltage between the commutator segments, etc., they have succeeded in building all their listed rotary converters capable of reliable asynchronous starting. Brown Boveri converters for 1600 V on the direct-current side up to outputs of about 1500 kW can also be started in this simple manner. By applying a pressure of about 25 % to their slip rings, these machines can be run up to speed and pulled into synchronism with certainty. When separate excitation is provided, the full excitation current flows from the beginning, i.e., the excitation corresponding to unity power factor under normal running conditions. With self excitation, the field regulator is set in the correct position for normal running on unity power factor when starting is begun. Raising or displacement of the brushes during the starting period is unnecessary, and sparking at the brushes is thus kept to limits within which it is quite harmless for the commutators and brushes. Thus the only switching operations necessary are setting the field regulator, the application of the reduced voltage to the slip rings of the machine, upon which it starts and synchronises itself, and finally switching over to the full voltage. With this method of starting, if the converter is self exciting, the polarity on the direct-current side depends solely upon chance and can be indicated by a voltmeter with central zero. If necessary, the polarity can be corrected before switching over to full pressure, by opening the switch on the alternating-current side and closing it again when the rotor has had time to slip one pole. After a certain amount of practice it is easy to judge the interval correctly so that the machine slips exactly one pole space, thus changing the polarity. If it be desired to determine the polarity from the first, the simplest method is to provide the converter with separate excitation, under certain circumstances by a directly built-on machine. In many cases (e.g. when the conditions of operation sometimes make it necessary for direct current to be converted into alternating current), this method may have additional advantages or even be the only one possible. Another method of reversing the polarity consists in a momentary reversal of the excitation. For this purpose, a reversing switch and an ammeter are provided in the field circuit; upon reversal of the field, the converter as a rule falls out of synchronism, and the pointer of the ammeter swings with the slip frequency between positive and negative maximum values. When the deflection is positive, the reversing switch is returned to its original position, whereupon the converter again returns to synchronism without any great fluctuation of current, the polarity of the excitation now being correct. If the starting voltage is not too high, a short interruption of the field circuit is sufficient to cause the converter to slip, so that, if the period during which the switch is kept open is correct, the polarity will have reversed when it is closed again. If the first attempt does not meet with success, the operation should be performed again. This method is employed for the completely automatic rotary converter substation installed by Brown, Boveri & Co. at Riehen near Basle,[1] where it has proved most satisfactory. Since it was first put into operation in November, 1919, this plant has been started and shut down considerably more than a thousand times, and on no occasion has any operation been incor-

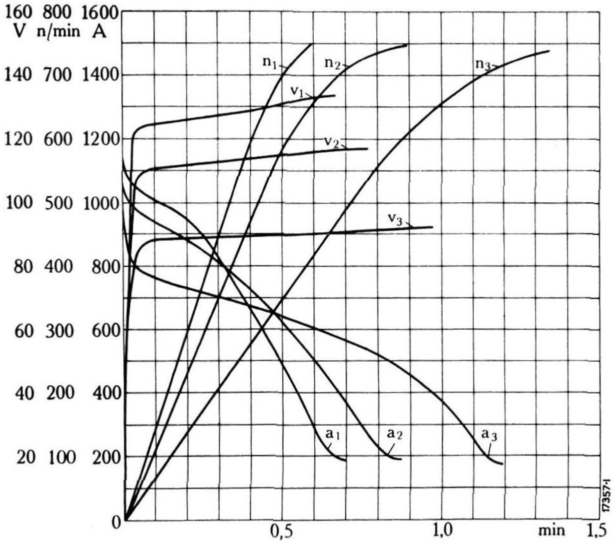

**Fig. 1. — Current and starting time corresponding to various voltages for asynchronous starting on a transformer tapping.**
Index 1 corresponds to a starting pressure of 132 V.
„ 2 „ „ „ „ „ „ 117 V.
„ 3 „ „ „ „ „ „ 92 V.
a. Starting current. n. Revolutions per minute. v. Applied voltage.

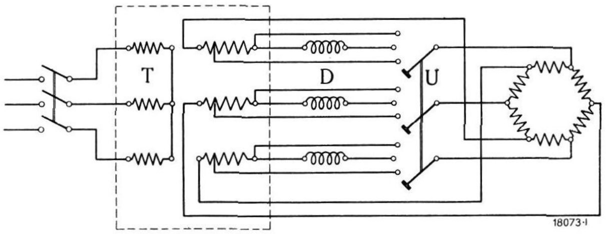

**Fig. 2. — Diagram of connections for inserting a damping choke coil between converter and transformer.**
D. Damping choke coil. V. Change-over switch. T. Transformer.

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[1] See brochure 707 E.

rectly performed. There is still the further possibility, when dealing with small powers only, of correcting the polarity by means of a reversing switch between the machine and the line.

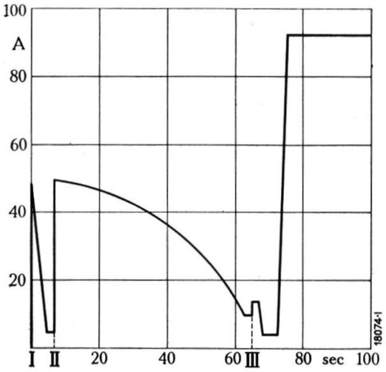


**Fig. 3. — Influence of a damping choke coil on the starting current of a 1000-kW rotary converter.**

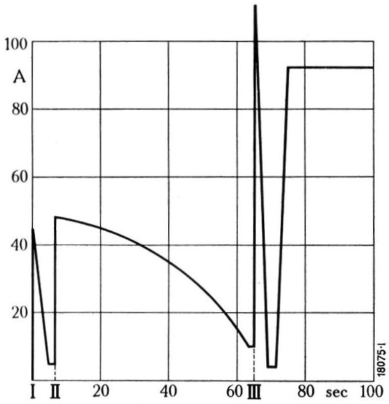


**Fig. 4. — Starting current without damping choke coil; pressure 6600 V.**

I. Main switch closed. II. Change-over switch brought into the starting position.
III. First the choke coil is connected in circuit and then the full transformer voltage is applied.

Fig. 1 shows the current and time taken for asynchronous starting with various starting voltages. The tests were made on a 1000-kW six-phase rotary converter for a pressure of 800 V on the direct-current side, 50-cycles alternating-current supply, and 750 r. p. m. As indicated by numerous tests made with favourable starting voltages, switching over to full working voltage always gives rise to a greater rush of current than when the starting voltage is applied. When the converter is connected to a sensitive supply network, this rush of current can be prevented by connecting in series a relatively small choke coil, known as a damping choke coil, when switching over to the full voltage. The manner in which a choke coil of this kind is connected is shown in Fig. 2, and its influence on the current at starting, in Figs. 3 and 4, which were taken on a 1000-kW, 750-r. p. m. rotary converter. It can be seen that switching over from the starting voltage to the full working voltage takes place almost without any rush of current whatever. The choke-coil voltage was chosen so as to be approximately equal to the secondary voltage of the transformer, the choke coil taking momentarily a current equal to about 15 % of that at the slip rings of the converter. The duration of the load may be taken as 60 seconds for large converters, and about 40 seconds for those of less than 500 kW.

The starting voltage is generally obtained from a tapping on the main transformer, a special starting transformer being only provided in very rare cases in which either the converter is not supplied with current by its own separate transformer, or it is not possible to provide tappings on the main transformer. Brown, Boveri & Co. employ *one* starting voltage only, as experience has shown that the use of a number of starting steps only results in a considerable increase in the cost of the switchgear, without any appreciable advantage as regards the rushes of current, or in any other respect.

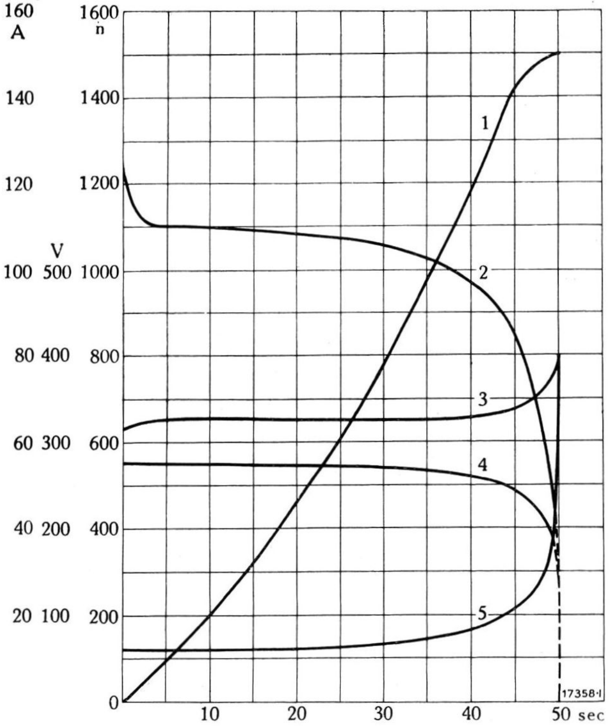


**Fig. 5. — Starting conditions of a 180-kW rotary converter when the full supply pressure is applied directly through a choke coil with an impedance per phase of about 2 $\Omega$.**

1. Speed. 2. Starting current. 3. Voltage of supply.
4. Choke-coil voltage. 5. Slip-ring voltage.

The field regulator was set for unity power factor on full load.

### *2. Asynchronous starting by application of the full supply voltage, a choke coil being connected in series.*

A detailed account of this method of starting is unnecessary as it is so similar to that just described. Over the latter, however, it has the advantage of cheapness, the starting change-over switch being dispensed with, and, in addition, the whole switching operation is simplified so that this method is particularly suitable for six-phase rotary converters. The following test results obtained on a small six-phase converter show clearly the starting conditions. The particulars of the machine were as follows :— output 180 kW, D.C. pressure 550 V, frequency of A. C. supply 50 cycles, speed 1500 r.p.m.

As shown in Fig. 5, with a choke coil having an impedance of about 2 $\Omega$ per phase, the maximum starting current was about 90 % of the full-load current of the converter, and the starting time 50 seconds. At the commencement of the starting period, the slip-ring voltage amounted to 14 % of the full value, this proving prefectly adequate to start the machine. The voltage was then gradually increased to a value sufficient to ensure synchronisation without excessive sparking. When the machine has reached synchronous speed, the choke coil is short-circuited, the rush of current occasioned being negligible. As the direct-current polarity depends on chance with this method also, separate excitation was tested. It was found that the converter would only start if the excitation was quite weak (it should not exceed 10 to 15 % of the excitation when working with normal voltage and unity power factor), and this was insufficient to ensure correct polarity. It is therefore necessary in this case to increase the excitation just before the machine reaches synchronism in order that the polarity may be correct.

## II. USING A STARTING MOTOR.

### *1. Starting by means of a synchronous induction motor.*

The rotary converter can be brought exactly to synchronous speed by a starting motor with an equal number of poles, providing it is a synchronous induction motor. Assuming both machines to be connected to the same alternating-current supply, the relation of their phases depends solely upon the position in which the armatures are keyed. Once this is correctly adjusted, the two machines will necessarily be in phase every time starting is carried out. The excitation has a slight influence upon the relative position of the phases, and it is thus possible to compensate small unavoidable errors in assembly by adjustment of the excitation current. The range of such compensation is an angle of about 20° (electrical). The starting process is the same as that for synchronous condensers, described in The Brown Boveri Review, 1923, p. 144. On the same page, a diagram of connections is given in which the exciter of the synchronous condenser is used to supply the field current of the starting motor also. If the rotary converter has a built-on exciter, as is very common practice particularly with high-tension machines, or when conversion from direct to alternating current is required, the exciter can also be employed to supply the field winding of the starting motor; otherwise a special excitation machine is required for this purpose. When the converter has been brought up to synchronous speed and the polarity is the same as that of the mains, the slip-ring voltage can be adjusted by means of the converter excitation so that it is equal to the

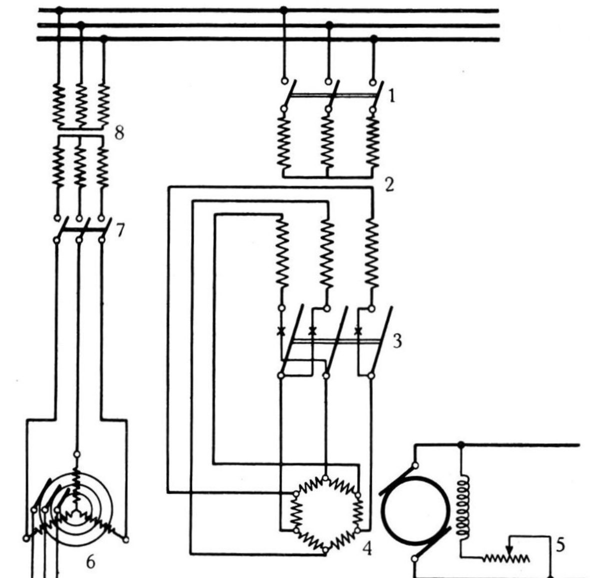


**Fig. 6. — Diagram of connections of a rotary converter for starting by an ordinary induction motor and connecting to the supply by means of a synchronising device.**

1. Transformer switch.
2. Transformer.
3. Switch with synchronising device.
4. Rotary converter.
5. Shunt regulator for 4.
6. Starting motor.
7. Starting switch for 6.
8. Transformer for 6.

secondary voltage of the transformer, and the converter can be connected to the alternating-current supply by simply closing a switch, without any rush of current.

In practice, this method of starting, frequently employed for synchronous condensers, is hardly ever considered for rotary converters. In any case it is out of the question for small converters, while, with those for greater outputs and a higher number of poles, the four-pole synchronous induction motor necessary would be both costly and unusual in design.

### 2 (a). *Starting by means of an ordinary induction motor and a synchronising device.*

The converter is run up to synchronous speed by a direct-coupled slip-ring motor of the ordinary type with a smaller number of poles and therefore a higher speed of synchronism than the converter (usually it has one pair of poles less). The speed of this machine is adjusted to the value required by means of a finely graduated slip resistance in its rotor circuit. When the number of poles is small, this method gives rise to difficulties, partly because it is not possible to regulate the speed exactly to synchronism, and also on account of the risk that a negligent attendant may allow the speed of the converter to increase so far beyond synchronism that the centrifugal stresses on its rotor and commutator become excessive. With machines having a greater number of poles, the difference in the synchronous speeds of the converter and starting motor is not so great, and this danger no longer exists. In this case, the adjustment of the speed can easily be effected and also, by suitable excitation, the slip-ring voltage necessary for the converter can be accurately regulated. The converter can then be connected to the mains with the help of a synchronising device, such as synchronising lamps, without any rush of current. Fig. 6 is the diagram of connections for a rotary converter started on this system. The transformer for the starting motor can be dispensed with as can be seen from the diagram in Fig. 7.

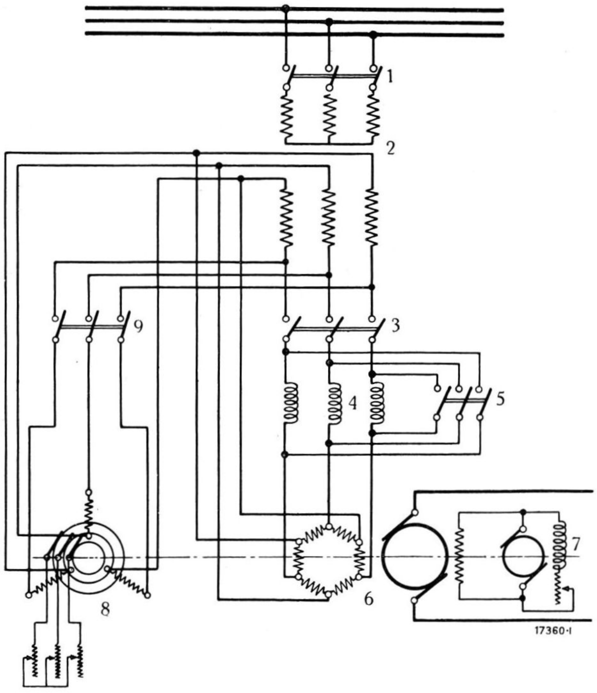


**Fig. 7. — Diagram of connections of a rotary converter for starting by an ordinary induction motor and connecting to the supply through a synchronising choke coil.**

1. Transformer switch.
2. Transformer.
3. Main switch.
4. Synchronising choke coil.
5. Short-circuiting switch for 4.
6. Rotary converter.
7. Exciter for 6.
8. Starting motor.
9. Starting switch for 8.

Chiefly owing to the complicated nature of the attendance necessary, this method is almost invariably replaced by that described in the following section.

### 2 (b). *Starting by means of an ordinary induction motor and synchronising choke coil.*

In order to obviate the need for a synchronising device, the rotary converter, having been run up to synchronous speed by the starting induction motor, can be connected to the alternating-current mains through a synchronising choke coil, entirely irrespective of the relation of the phases. With this method, current peaks cannot be completely avoided, but it has the advantage that the adjustment of the speed need not be absolutely accurate as the machine will pull into synchronism even if its speed varies slightly from that value. Consequently, a starting motor having as many poles as the converter can be employed and it may be of the squirrel-cage type. Naturally, the greater the slip when the converter is switched on to the mains, the greater will be the current peak, but it can always be kept within reasonable limits. It is advantageous to connect the starting motor to the secondary of the transformer of the rotary converter, in which case it must have open connections (i.e., six terminals with three-phase supply). This method of connection is shown diagrammatically in Fig. 7.

Tests carried out upon a 750-kW rotary converter for 600-V direct current, a slip-ring pressure of 460 V at 50 cycles, and a speed of 1000 r.p.m., and for which this method of starting was employed, gave the results tabulated below. With 1% slip, a minimum slip-ring pressure of 150 V (= about 30% of the normal voltage) was necessary to pull the rotary converter into synchronism; this gave a maximum current peak of 200 A (= about 35% of the full-load current). If the converter was excited for unity power factor after being synchronised, it was possible to short-circuit the choke coil with practically no rush of current. No excessive sparking at the brushes occurred at any time during starting.

Those results given as percentages are calculated on a basis of the full-load slip-ring current.

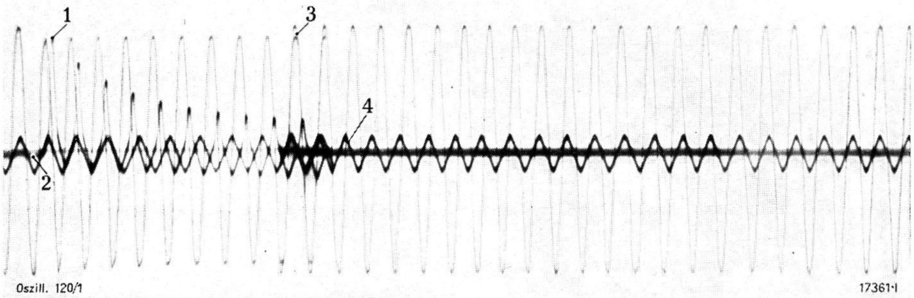


**Fig. 8. — Oscillogram of the current peak at switching over a 750-kW rotary converter to the supply through a synchronising choke coil, when running with 1% slip.**

1. Maximum current peak. 2. Commencement of switching in. 3. Supply voltage. 4. Calibration current = 52 A.

| Supply pressure | Slip-ring pressure | Maximum current peak at switching in | | Time required for synchronising from rest | Pressure drop across choke coil | | Current peak on short-circuiting the choke coil | |
|---|---|---|---|---|---|---|---|---|
| | | Amperes | % | | Maximum voltage during synchronising period | After synchronising | Amperes | % |
| Volts | Volts | | | Seconds | | | | |
| 460 | 150 | 200 | 35 | 31 | 410 | 230 | 305 | 53 |
| 460 | 200 | 250 | 44 | 29 | 450 | 200 | 260 | 46 |
| 460 | 250 | 340 | 60 | 31 | 450 | 165 | 245 | 43 |
| 460 | 350 | 410 | 72 | 16 | 480 | 95 | 100 | 18 |
| 460 | 375 | 500 | 88 | 18 | 490 | 75 | 100 | 18 |
| 460 | 400 | 510 | 90 | 20 | 500 | 65 | — | — |
| 460 | 425 | 600 | 105 | 20 | 450 | 60 | — | — |

In the table are given a number of values of the slip-ring voltage corresponding to various values of the excitation, together with the maximum peak currents occurring with these slip-ring voltages upon switching over to the mains. The current peaks which occur when the choke coil is short-circuited after synchronising has been effected are also given, the excitation remaining constant.

The currents were measured by high-precision instruments, but, owing to the still greater sensitivity of the oscillograph, the oscillogram (Fig. 8) shows somewhat higher current peaks. Among the methods referred to for obtaining correct polarity, separate excitation and the use of a polarised relay in the excitation circuit of the converter are the most important in this connection. Allowing the rotor to slip by momentary disconnection on the alternating-current side was not possible during this test, as the current peak upon switching in again was excessive owing to the small impedance of the choke coil. The maximum value measured was 1100 A.

### 2 (c). *Starting by means of an ordinary induction motor and simultaneous application of the supply voltage through a synchronising choke coil.*

In order to simplify the switching operations, it is possible to connect the stationary converter to the alternating-current mains through a synchronising choke coil and start it simultaneously by means of an induction motor. This has the advantage that the starting motor required is considerably smaller. The connections remain the same as indicated in Fig. 7.

Tests were carried out upon this method of starting with a 750-kW six-phase rotary converter for 600 V direct current, 50-cycle alternating current, and 1000 r. p. m. This was started by an induction motor with an equal number of poles, and simultaneously connected to the mains through choke coils of various impedances. The converter was of the self-exciting type, and from the beginning the field regulator was set for an excitation corresponding to unity power factor on full working voltage. The short-circuiting of the choke coil took place without any great rush of current.

With choke coil No. II, the converter was just able to synchronise itself; with all the other coils it synchronised itself easily and without any excessive sparking at the brushes. In Fig. 9, the impedance and magnetisation curves of the choke coils employed are given. The excitation current of 7·0 A corresponds to normal full load and unity power factor.

Further tests showed that when the slip was as great as 4% the converter synchronised itself in every case, the current peak being naturally greater, as shown in the second of the following tables:—

| Supply pressure | Starting | | | | Synchronous running | | Short-circuiting of choke coil | | | | Choke coil |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Maximum pressure drop across choke coil | | Maximum current peak | | No-load current | Pressure drop across choke coil | Maximum current peak | | No-load current | Excitation current | |
| Volts | Volts | % approx. | Amperes | % approx. | Amperes | Volts | Amperes | % approx. | Amperes | Amperes | No. |
| 400 | 380 | 95 | 225 | 40 | 25·0 | 78 | 190 | 33 | 33 | 7·00 | I |
| 400 | 360 | 90 | 200 | 35 | 26·5 | 85 | 185 | 32 | 29 | 7·30 | II |
| 400 | 350 | 87 | 400 | 70 | 28·0 | 65 | 150 | 26 | 34 | 6·85 | III |
| 400 | 355 | 89 | 260 | 45 | 26·5 | 75 | 160 | 28 | 32 | 7·10 | IV |

The results given as percentages are calculated on a basis of the normal working voltage or full-load current.

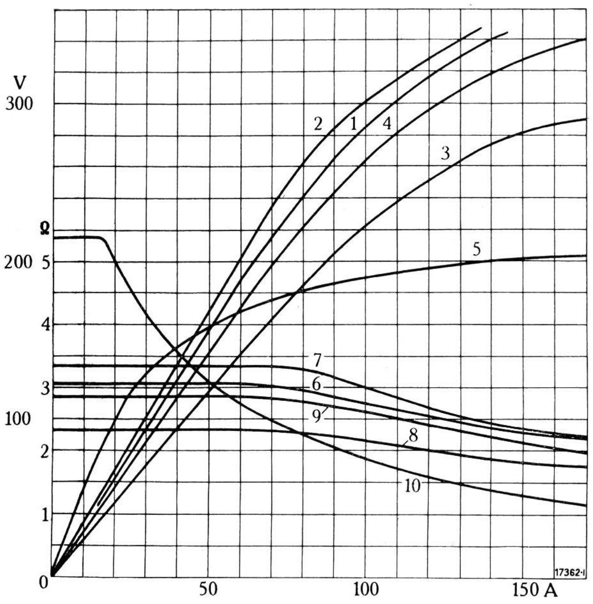


**Fig. 9.** — **Magnetisation and impedance curves of the choke coils referred to in the tables on this page.**

1. Magnetisation curve of choke coil I
2. " " " " " II
3. " " " " " III
4. " " " " " IV
5. " " " " " V
6. Impedance " " " " I
7. " " " " " II
8. " " " " " III
9. " " " " " IV
10. " " " " " V

| Slip-ring pressure | | Choke coil V | | Choke coil II | |
|---|---|---|---|---|---|
| | | Current at synchronising | | Current at synchronising | |
| Volts | % approx. | Amperes | % approx. | Amperes | % approx. |
| 80 | 20 | 500 | 85 | 300 | 50 |
| 160 | 40 | 570 | 100 | 360 | 60 |
| 240 | 60 | 670 | 115 | — | — |

(For practical reasons, these tests as well as those previously mentioned were only carried out at a supply pressure of 400 V, although the converter was designed for 460 V).

The direct-current polarity depends upon chance with this method also, and, if incorrect, must be corrected by one of the methods already mentioned.

With separate excitation at constant voltage, it is not advisable to apply the full excitation voltage corresponding to unity power factor right from the commencement of the starting process, because to speed up a converter with such a strong field would require a much larger starting motor. For this reason, the

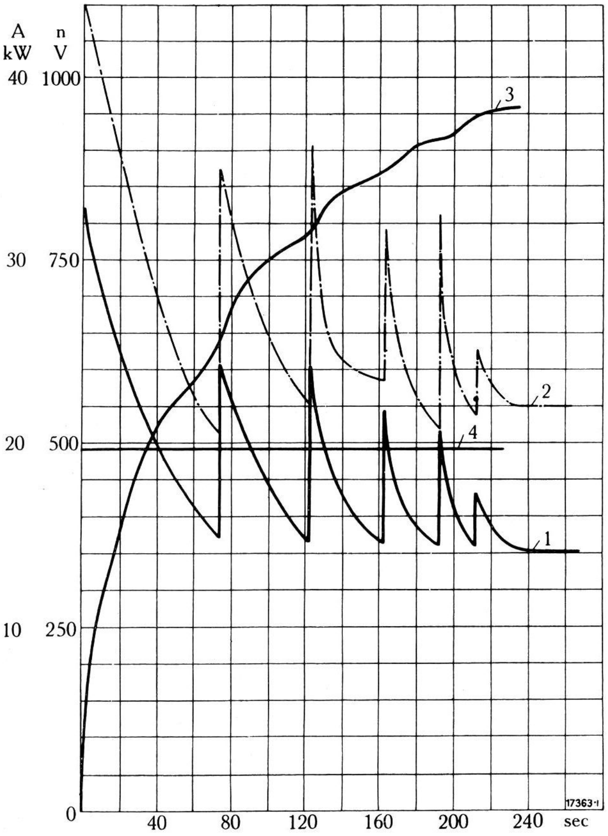


**Fig. 10.** — **Behaviour of an induction motor starting a 750-kW rotary converter, which is simultaneously connected to the supply through a synchronising choke coil.**

1. Power consumption in kW.
2. Stator current.
3. Speed.
4. Starter voltage.

field current is kept as small as possible to begin with, and the converter only excited for unity power factor after it has been run up to synchronous speed; this is done in order to minimise the rush of current before short-circuiting the choke coil.

On account of the high efficiency and particularly of the small constant losses of Brown Boveri rotary converters, the starting motor can always be a relatively small machine. With the method of starting at present under discussion, the converter provides a certain torque right from the beginning, thus assisting the starting motor. In the case under consideration, a motor with a continuous rating of 25 kW was sufficient for starting, i.e., about 3·5 % of the output of the converter. The stator current, power, etc. taken by the motor at starting can be seen in Fig. 10.

Owing to its simplicity, this method of starting is always preferred by Brown, Boveri & Co. when purely asynchronous starting is not adopted, and the starting motor always has the same number of poles as the converter, so that no slip resistance is necessary. As further simplicity and saving of first cost are achieved in this way, this manner of starting possess the greatest advantages, particularly for completely automatic installations.

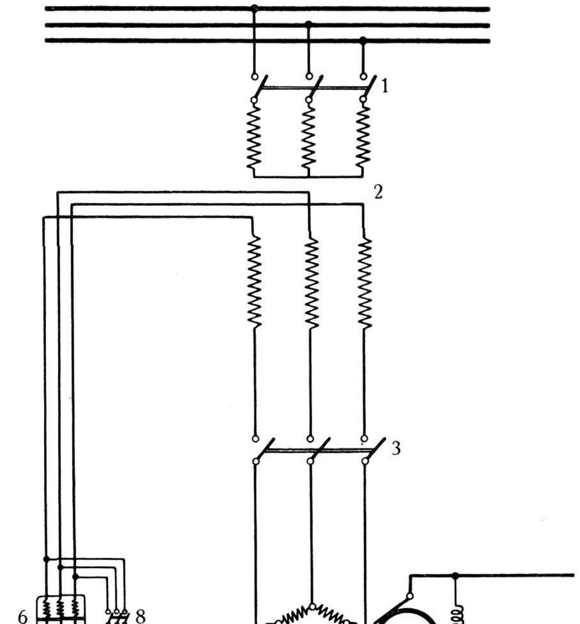


**Fig. 11. — Diagram of connections of a rotary converter started by an induction motor, the stator of which serves also as a synchronising choke coil.**

1. Transformor switch.
2. Transformer.
3. Main switch.
4. Rotary converter.
5. Shunt regulator for 4.
6. Starting motor.
7. Starting switch for 6.
8. Short-circuiting switch for 6.

### 3. *Connecting the stator of the starting motor in series as a synchronising choke coil.*

In the place of a special synchronising choke coil such as described in the foregoing sections, the stator of the starting motor itself can be used as a choke coil, as shown in Fig. 11. In principle, this method of connection is not different from the foregoing in any respect. The starting induction motor can either have a smaller number of poles than the converter and be provided with a finely graduated slip resistance, or have an equal number of poles should the higher current peaks involved be allowable. As already mentioned, the impedance of a synchronising choke coil is confined within narrow limits; its effect, however, varies with increasing current to different extents depending upon the saturation (Fig. 10). To determine the most favourable conditions, i.e., the dimensions for the choke coil which ensure synchronising with minimum rushes of current, these variations should be taken into consideration. The use of the stator of an induction motor also as a choke coil to fulfill such exacting requirements results in a compromise which makes it difficult to chose favourable starting conditions, so that the advantage of the simplification effected becomes questionable.

## III. DIRECT-CURRENT STARTING.

The rotary converter can be started from the direct-current side in exactly the same way as a D. C. motor and run up to synchronous speed. For this purpose, direct current at an absolutely definite voltage must be available, as the slip-ring voltage of the converter started up in this way must agree exactly with the secondary voltage of the transformer to which it is to be connected. When the speed and voltage agree, the converter can be paralleled with the alternating-current supply without any rush of current, with the help of a suitable synchronising device. Should the D. C. voltage be subject to sudden fluctuations, and no induction regulator be provided by means of which the transformer voltage could be suitably adjusted, synchronising may prove exceedingly difficult, and it may be necessary to disconnect the converter from the direct-current mains for a moment just before connecting it to the alternating-current supply. When the conditions are not too unfavourable, it is sufficient to leave enough of the starting resistance in circuit to damp out the voltage fluctuations. In any case, trained attendants are essential when this method of starting is employed.

The condition that a direct-current supply at an absolutely definite voltage shall always be available is so rarely satisfied that starting from the direct-current side does not often come into consideration. When a number of rotary converters are installed together in the same substation, however, the advisability of providing a special starting set (direct-current generator coupled to an induction motor) should be taken into account. A set of this kind can be used to start all the converters in the station, whereas none of the other starting devices described can be applied to more than one converter only. It should have a short-time rating (1—2 minutes) equal to about 10 % of the output of the largest converter to be started. In order that D. C. starters may be dispensed with, the converters are started by varying the voltage applied, a kind of Ward Leonard connection being employed for this purpose. High-tension rotary converters always have a separate exciter, which is usually direct coupled. If a source of low-tension direct current is available, this machine can very well be slightly larger and serve also as a direct-current starting motor.

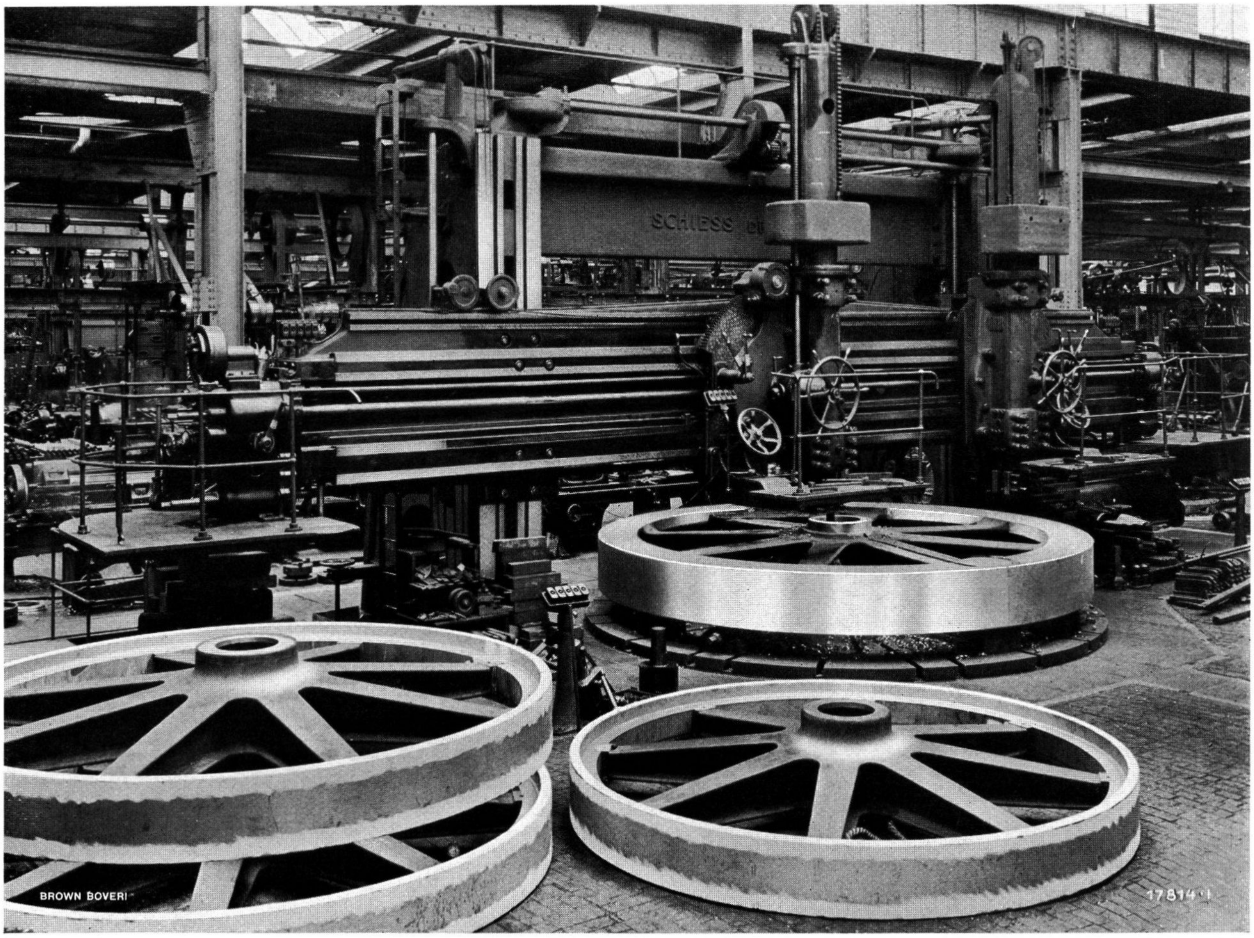
## IV. CONCLUSION.

A consideration of the advantages and disadvantages of the various methods usually employed for starting rotary converters, supported by test results obtained, leads to the following conclusions:—

Asynchronous starting, either by means of a tapping on the main transformer or by applying the full supply voltage through a coke coil, is the simplest and cheapest solution, but imposes somewhat exacting conditions as to the correct dimensioning of the converter. The listed Brown Boveri converters all fulfill these conditions, and also their converters for 1600 V direct current. The rush of current upon switching over from the tapping to the mains can be minimised by connecting a damping choke coil in circuit during the switching operation. If the damped current peaks are still excessive, or the converter is not suitable for asynchronous starting, a starting motor must be provided. In this manner the converter can be put into operation without the slightest rush of current, a synchronising device being employed. This method of starting, makes greater demands upon the attendants, however, and is therefore avoided by Brown, Boveri & Co. as far as possible. A synchronous induction motor with a number of poles equal to that of the converter also enables starting to be effected without current peaks, as, once the two machines are correctly coupled, they must always run perfectly in phase. Synchronous condensers are often started with advantage by this system, but it is rarely applied to rotary converters on account of the high cost of four-pole synchronous induction motors. When an ordinary induction motor is employed for starting, the rotary converter being connected to the mains through a synchronising choke coil, current peaks cannot be entirely avoided. They are, however, somewhat smaller when the converter is run up exactly to synchronous speed before switching over to the mains (only possible if the starting motor has a smaller number of poles than the converter) than when the speed differs from synchronism by about 1—2 %, as with the natural slip of a starting motor with an equal number of poles. Even in the latter case, in which the cost of a slip resistance for the starting motor is avoided and attendance is simplified, the rushes of current occurring are negligible if the choke coil is correctly dimensioned. A further saving can be made in the cost of both the choke coil and the starting motor if the converter is connected to the mains at the same time that the motor is started; this combines most of the avantages of the other methods, the necessary attendance being very simple, and it is consequently adopted by Brown, Boveri & Co. in all cases where asynchronous starting cannot be considered; it is the ideal method of starting particularly for entirely automatic installations. Further, it is possible to employ the stator of the starting motor also as a choke coil, but this combination rarely results in a saving in cost. When starting is effected from the direct-current side, a synchronising device is also necessary; this method usually comes into consideration only in substations where direct current at a suitable voltage is available.

In conclusion, one further possible solution of this problem may be referred to: the starting of rotary converters as alternating-current commutator motors, either as a series motor by means of a series winding on the magnet poles (a compound winding already provided may be used for this purpose), or with short-circuited brushes as a repulsion motor. Both these methods, however, give rise to complicated interchanging of connections, without affording any particular advantages, and are hardly ever employed.

*(MS 302)* *F. Emmerich. (G. T. S.)*



**The machining of heavy pole wheels on the large turning and boring mill at the Baden works of Brown, Boveri & Co.**

## NOTES.

### Fuel economy in steam power stations particularly with regard to boiler plant.

Decimal index 621.312.132.0064 — 621.184.

It is repeatedly found that purchasers of steam turbines insist on the turbine builders guaranteeing an exceedingly low steam consumption under the misapprehension that this is the only important factor influencing the fuel consumption of the installation. In most cases, however, a much greater fuel economy would result if the boiler plant were constructed according to modern methods, and its management conducted in a scientific manner, and if care were taken for the turbine to work under the conditions for which it was designed, thus enabling the guaranteed conditions to be fully realised.

A very effective means of decreasing the steam consumption per kWh is to increase the boiler pressure and superheat the steam above the values usually employed at present. Normally built turbines, supplied with steam at a gauge pressure of 34 kg/cm$^2$ and an inlet temperature of 400° C give quite favourable figures for the steam consumption. Boilers working at a pressure of 35 kg/cm$^2$ and with superheaters for steam to 425° C come within the range of normal, reliable and not too costly types.

With a high initial temperature and pressure the necessary volume of steam for obtaining the required output of the turbine is reduced, as a result of which the heating surface provided in the boiler may be smaller, but the cost of the boiler is not necessarily less. Much more favourable steam consumption can be obtained if the initial pressure and temperature are increased to 100 kg/cm$^2$ and 450° C respectively.

Fuel economy and the economic working of the boiler plant is primarily dependent upon the boiler-house staff.

Soot and ashes must be blown from the outside of the water tubes as often as possible, even while working, and no scale should be allowed to form on the inside of the drum or of the tubes. Reserve boiler plant, having a heating surface of at least 20% that of the total installation should always be provided, and should be cleaned and overhauled when not in use.

The firing of boilers with crude oil, tar oil, pulverised coal, or gas results in great economy in heating surface and attendance, practically smokeless operation, the possibility of cutting off the fuel supply immediately the demand for steam ceases, rapid steam rasing and easy regulation of the boilers, ability to stand overloads, and great cleanliness. The fuel control is very simple and almost automatic. Oil firing is largely used in countries naturally provided with oil wells, where the cost of transit does not greatly affect the price. Tar oil is obtained by the carbonisation of coal and is equal in all respects to crude oil, but the supply available is not sufficient for commercial purposes, even in the vicinity of coal mines. Similar advantages can be obtained by means of pulverised-fuel firing and to-day it is possible to utilise cheap low-grade small coal, with a high percentage of ash in this way.

Low-temperature carbonisation of coal, with the recovery of valuable by-products will become increasingly important with the construction of large new power stations. The gas obtained by this process would be most suitable for firing boilers.

A record of the working of each boiler should be kept. For this purpose suitable instruments must be fitted, preferably of the automatically recording type, and should include a draught gauge, a steam pressure gauge, thermometers for temperatures of flue gas, superheat, and of feed water, and also a meter to record the volume of steam generated. To enable the combustion process and draught to be suitably controlled, CO and $CO_2$ recorders should be fitted, and also a means of determining the weight of fuel consumed. The recording instruments should be mounted in a room, near the boiler house but protected from dust. In order to inform the boiler-house staff of the total output of the station, telephonic communication between the boiler house and switchboard attendants should be installed, so that preparation may be made for expected overloads.

Instead of using an economiser to heat the feed water, it can be heated advantageously by steam extracted from one or two tappings in the main turbine. By this method the feed water can be heated to a temperature of 90°—140° C, and thus a considerable part of the latent heat of the steam is recovered. Fuel economy may be improved by 6·5% by preheating the feed water in this way. The waste heat of the flue gases must be utilised to preheat the combustion air in this case[1].

A distillation plant, to make up losses to the feed water can be combined with the feed-water heating plant. Distillation is the most suitable means of softening the water. All air must be taken from the make-up water in order to avoid corrosion, a source of danger, particularly with boilers working at a high pressure.

The removal of air from the make up water is effected in the surface condenser of the main turbine, by a special device adopted by Brown, Boveri & Co. Care must also be taken to prevent the condensate coming into contact with the air between the surface condenser and the boiler.

The boiler pressure should be so chosen that the difference of pressure between the boiler and the turbine stop-valve is approximately 1 kg/cm$^2$. In very large power stations the pressure drop in the pipe-line should never exceed this value. It is often advisable, however, to allow for an additional increase in boiler pressure of 1 kg/cm$^2$ to prevent blowing off at the safety valve upon a sudden decrease in the load on the power station. A considerable quantity of steam is lost through an escape at the safety valve.

For reliability, a half of the centrifugal pumps supplying the boiler-feed should be driven by auxiliary turbines, the exhaust steam of which can be used to heat the feed water. The other half of the pumps should be driven electrically and should be employed when the feed water is heated by extraction steam from the main turbine.

As regards the choice between the use of forced draught or a chimney stack, the latter is always to be preferred wherever possible. A chimney stack enables the superfluous heat of the flue gases to be used to create a draught, while, owing to the power used, forced draught always gives rise to a considerable increase in fuel consumption. The reduction of boiler-house staff is assisted by coal-conveying and ash-handling plant which are necessary parts of the equipment for economical working. The coal conveyer should be provided with automatic scales, recording the weight of coal used. The coal supplied to the fires should be tested daily for calorific value, percentage moisture, and ash. Unburnt coal can be recovered from the ash and clinker by washing or by magnetic attraction.

To ensure economical working of the boilers, care must be taken to see that the gate in the flue at the back of each boiler is firmly closed when that boiler is not in use, to prevent cold air entering the main flue. Small rotating dampers do not close the flues completely and therefore must not be used for this purpose. Frequent interruptions in the working of a boiler should be avoided, since by lighting and drawing the fires a considerable quantitiy of fuel is lost.

Each stoker must regulate the draught and excess air so that a good efficiency is obtained from the boiler. Careful trials must be made to determine the draught required for each kind of coal, and only when dealing with a heavy intermittent demand may a greater draught be used. $CO_2$ recorders enable the required draught to be determined.

The blow-off cocks must not leak and discharge pipes connected to them should be cold to the touch. There must be no cracks in the boiler brickwork through which cold air may enter the flues and so affect the efficiency. The gradual starting and drawing of fires is necessary if the formation of cracks in the brickwork is to be avoided. Turbines and boilers should be in continuous operation for as long a period as possible, as they rapidly deteriorate through rust and temperature changes if working is frequently interrupted.

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[1] See the article in The Brown Boveri Review 1924, No. 10, p. 230: "Feed water heating by extraction steam, preheating of the combustion air, and pulverised fuel firing."

The design of the steam pipes in the boiler house should be such that the calculated velocity of the steam in the pipes is not greater than 55 m/sec; the maximum allowable velocity is 70 m/sec, which value must never be exceeded.

An effective lagging must be provided for all live steam pipes, to prevent considerable heat losses. All flanges should be carefully lagged and kept perfectly steam tight; leaky flanges are a prevalent source of large steam losses.

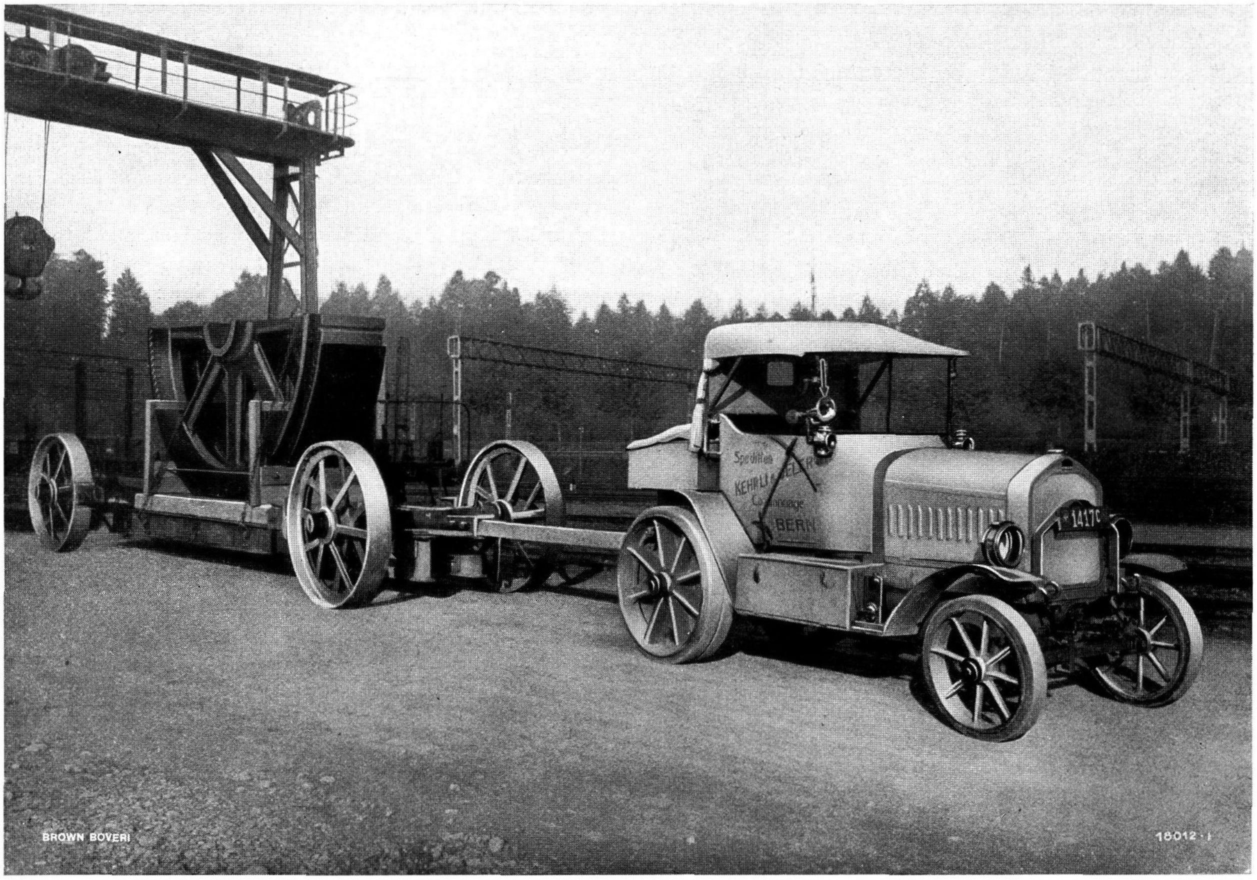
All stop valves should be of the gate-valve type with nickel-alloy seatings on account of the fact that, as regards losses, this type is equivalent to only four metres of straight pipe line, whereas with valves of other types the losses are about ten times as great.

By means of a daily record, the station engineer can see where the plant is not in order and so remedy the defect. To avoid losses, special care must be taken to ensure that:— the waste heat in the flue gases is as small as possible, no unconsumed combustible gas escapes, the correct draught and excess air are used, no unburnt coal is lost in the ashes, and also that no excessive losses occur.

### *Conclusion.*

From the point of view of fuel economy it is not sufficient to have only good turbines with a guaranteed steam consumption per kWh; a modern boiler plant scientifically worked is equally important. A continuous and systematic supervision of all plant must be arranged. Particular attention must be paid to the boiler plant, the improvement of the efficiency of which must be the chief aim of every engineer in charge of a steam power station. With bad attendance the boiler plant can be the source of large losses for which one tenth of a kilogram per kWh more favourable steam consumption will not compensate.

*(MS 328)* *G. Leidig. (J. R. L.)*



**Berne Municipal Electricity Supply.**
**Transport of half of a rotor weighing 18 tonnes for one of the two three-phase alternators each, 1760 kVA, 5800—6600 V, 0·8 power factor, 40 or 50 cycles, 109—136 r. p. m., to be driven by a Diesel engine.**

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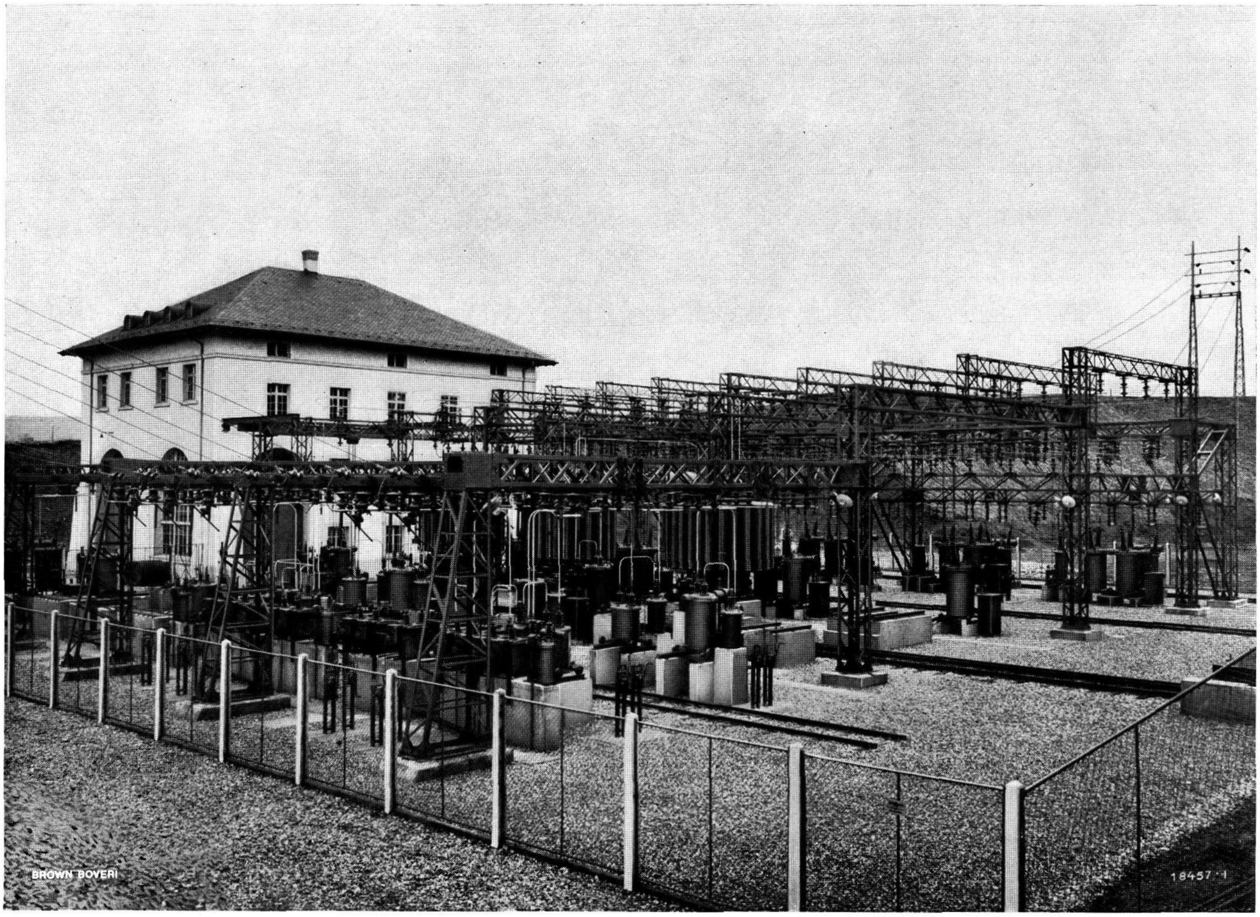
# EQUIPMENT OF RAILWAYS

## FOR ALL CURRENT SYSTEMS, PRESSURES AND FREQUENCIES



GENERAL VIEW OF THE BRUGG SUBSTATION OF THE SWISS FEDERAL RAILWAYS.
This outdoor station supplies the recently electrified Zurich - Baden - Olten section.

# LOCAL AND INTERURBAN RAILWAYS
# TRAMWAYS - MOUNTAIN RAILWAYS
# AERIAL ROPEWAYS AND FUNICULARS