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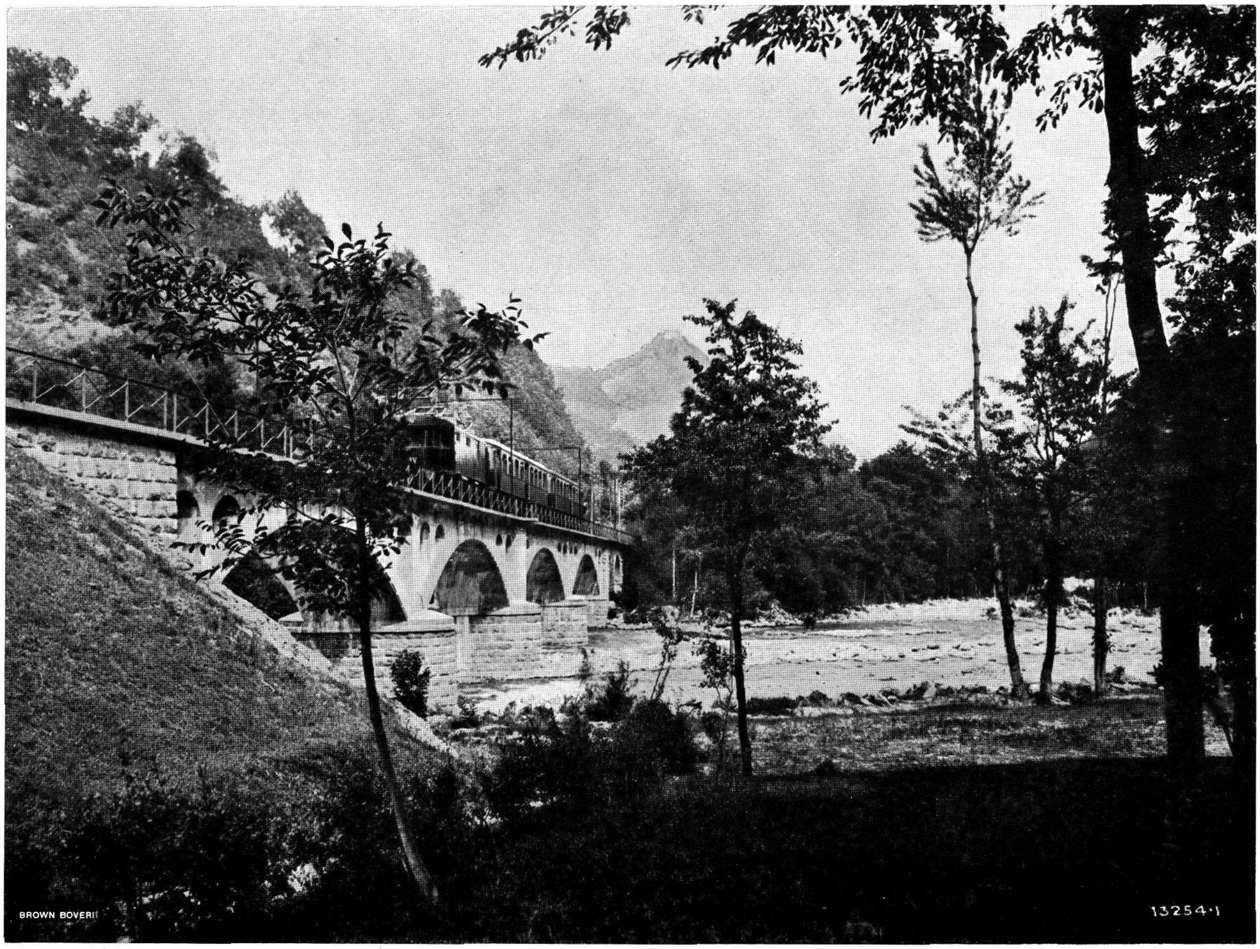

VIEW ON THE HIGH-TENSION DIRECT-CURRENT TURIN-LANZO-CERES RAILWAY.
Contact-wire pressure 4000 V.

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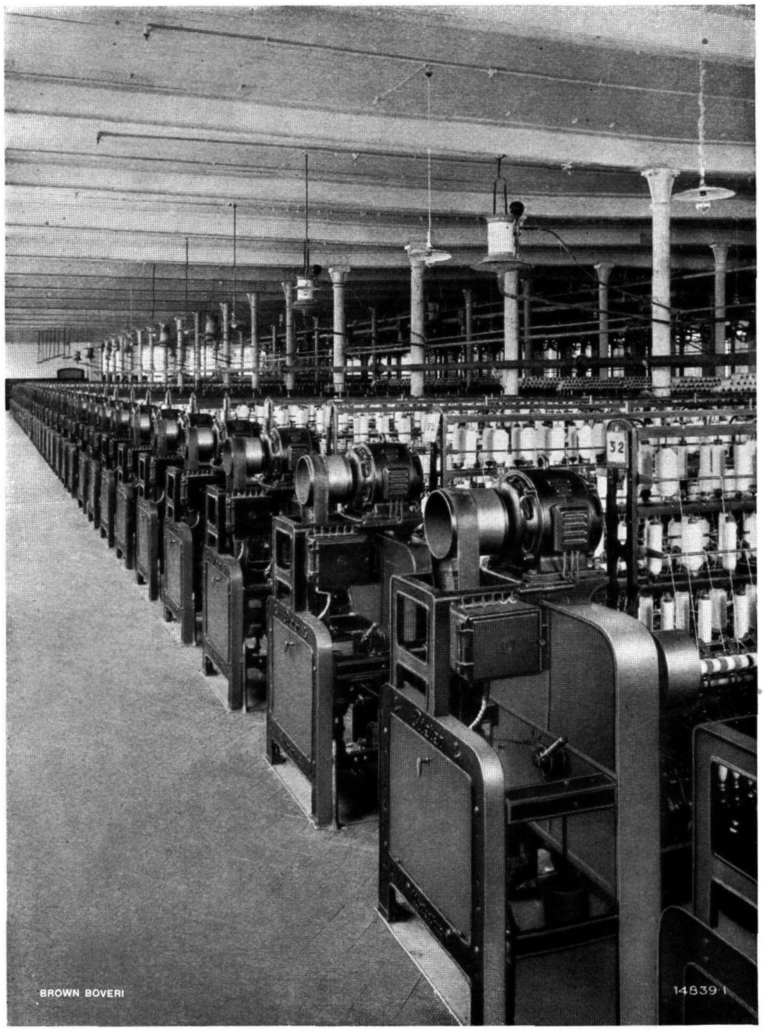
ELECTRIC DRIVES FOR
INDUSTRIAL PLANTS



MANIFATTURA FESTI RASINI, VILLA D'OGNA, ITALY.
Individual drive of 37 ring spinning frames by Brown Boveri squirrel-cage motors, fitted with a device for decreasing the speed during the formation of the cops.

SPECIAL DRIVES FOR SPINNING AND DOUBLING MACHINES
FLYER FRAMES - LOOMS - EMBROIDERING MACHINES
CALENDERS - FINISHING AND DYEING MACHINES

THE BROWN BOVERI REVIEW

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VOL. X FEBRUARY, 1923 No. 2

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TURBO-COMPRESSORS AND TURBO-BLOWERS AND THEIR FIELDS OF APPLICATION.

Decimal index 621. 63.

2. Blast furnace blowers[1].

§ 21. *Economic advantages.* Very high efficiencies can be reached by turbo-blowers; this is especially the case of those for blast furnaces, which generally have to be constructed for dealing with large quantities of air. Due to the relatively moderate pressures and to the correspondingly small decrease of volume at the delivery end, blowers of this description can have all impellers of the same diameter without the efficiency of the high-pressure stages falling off, so that efficiencies ranging from 78 to 85 % are attainable. The turbo-blower is therefore equivalent to the reciprocating blower in this respect. However, contrarily to the latter class of machines, the efficiency of a turbo-blower remains unchanged even after many years' service, as there are no interior parts liable to wear.

With uncooled turbo-blowers—such as blast furnace blowers, for instance—the ideal compression will be assumed adiabatic, and under these conditions the theoretical work of compression becomes:

$$L = P_a \, Q_o \, \frac{k}{k-1} \left[\left(\frac{P_e}{P_a} \right)^{\frac{k-1}{k}} - 1 \right]$$

where L = work input.
P_a = absolute intake pressure.
P_e = absolute delivery pressure.
Q_o = volume of free air drawn in.
k = adiabatic exponent, $k = \frac{c_p}{c_v} = 1 \cdot 4$.

Blast furnace blowers should not only have a high efficiency at the so-called normal point, i. e. point of the highest efficiency on a pressure-volume curve, but should also be able to meet all conditions occurring in practice in an economical manner. Turbo-blowers can fulfil these requirements, provided that appropriate means are chosen for adapting the machinery to the varying service conditions. A description of these different solutions is given in the following article. Moreover, it is shown that the opinion occasionally held by metallurgists as to the inability of turbo-blowers to free a hanging furnace is utterly unfounded. In this connection, Brown, Boveri & Co. have evolved a procedure which enables the highest pressures called for in practice to be reached in a simple manner.

§ 22. *Regulation of blast furnace turbo-blowers.* Throttling at the delivery end has already been described when dealing with turbo-compressors[1], and it was shown that this mode of regulation is uneconomical. As the same conclusions apply also here, it is not necessary to enter into further details.

Hence, the following means can be employed to adjust the machine to service requirements:—

1. Throttling at the intake.
2. Speed regulation.
3. Diffuser regulation.
4. Parallel-series connection.
5. Combinations of 2—4.

1. Throttling at the intake has likewise been gone into when the regulation of turbo-compressors was discussed. A considerable difference exists, however, in that the working domain without pumping or blowing off can be enlarged by this method of regulation to a much greater extent with turbo-blowers than with turbo-compressors—quite a small amount of throttling being sufficient to cause a considerable displacement of the pumping limit towards the ordinates axis. The locus of the pumping limits need not coincide with the straight line G passing through the origin of the absolute pressure axis, but can be much higher up, as shown in Fig. 23 by the line JP. This locus of the pumping limits will herinafter be called the ideal pumping-limit locus[2].

Throttling at the intake is also accompanied by losses with turbo-blowers. These are small in the neighbourhood of the characteristic without throttling, and it follows that economical working is possible along the pumping-limit locus—in fact, much more so than

[1] Concluded from April, 1922.

[1] See Revue BBC, 1921, Nos. 7 and 8.
[2] See Revue BBC, 1920, No. 2.

if blowing off to the atmosphere is resorted to for precluding pumping. As can be seen in Fig. 23, the losses increase rapidly as soon as relatively moderate pressures combined with large delivery volumes are required.

Furthermore, if in special circumstances, a regulation ensuring constant volume, as given by a vertical

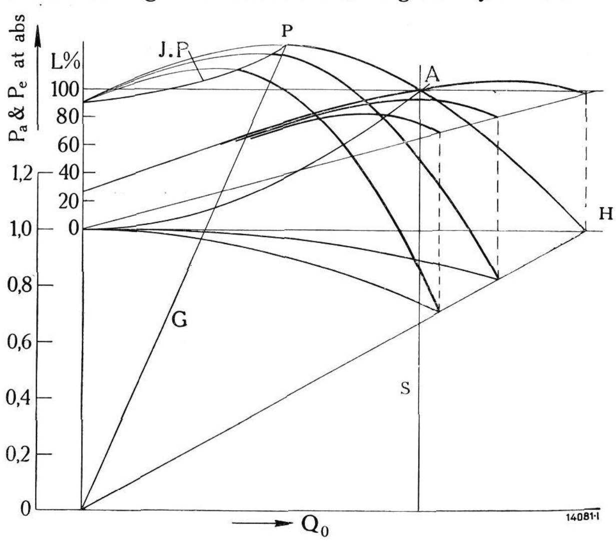

Fig. 23. — Influence of throttling at the intake on the pressure-volume and power-input characteristics.

Ordinates:

P_a, P_e. Intake and delivery pressure in kg per cm² absolute pressure.
L. Power input as a percentage of that at the normal point A.

Abscissæ:

Q_0. Volume of free air drawn in (15° C, 1 kg per cm² absolute pressure).
G. Lower pumping-limit locus.
J. P. Upper or ideal pumping-limit locus.
A. Normal point.
J. Regulation with constant volume of free air drawn in.
P. Critical point.
S. Regulation with constant delivery pressure.

straight line J, or constant pressure, as given by a horizontal straight line S, has to be obtained by throttling at the intake, throttling losses occur, especially in the first case. A glance at Fig. 23 will show that the regulation curve for either of these conditions differs widely from the characteristic without throttling.

These remarks also apply if it is assumed that the ideal pumping-limit locus JP can actually be attained. This is possible whenever turbo-blowers working either isolated or in parallel are exclusively employed for one or several blast furnaces, that is to say, whenever no reciprocating blowers work on to the system. If blowers of both types work together, this locus cannot be reached, because reciprocating blowers give rise to a pulsating flow in the pipelines, the effect of which is to render the working of the turbo-blower unstable at low outputs, thereby causing the pumping-limit locus to become much steeper. Under these conditions, only the straight line G passing through the origin of the pressure axis can usually be reached, and it follows that the stable working domain is reduced. Consequently, the blow-off valve has to be kept open at small fractional loads. The modified conditions just mentioned merely affect the pumping domain, and the efficiency is not modified in the slightest, provided that at partial loads the corresponding points are not to the left of the critical point P. The latter contingency is exceptional, however, and arises, for instance, during disturbances of the blast furnace, which are, as a rule, only of short duration, and are therefore not of any great economic importance.

The ideal pumping-limit locus is defined by the following considerations:—

It still happens that turbo-blowers are intended as machines for forming the standby or helping over peak loads. In order to have the necessary capacity to draw on, they have large dimensions, although peak-load machines are only called upon to deal with comparatively small quantities of air. Economical operation under such conditions can only be realised by these machines if they run with other turbo-blowers, and can therefore be regulated to the ideal pumping-limit locus.

If, on the other hand, the turbo-blowers have to work in parallel with reciprocating blowers, they should take over the ground load, so that the reciprocating machines form the standby or peak-load plant. Should this not be feasible, other methods of regulation must be employed for the turbo-blowers.

2. Speed regulation. Altering the speed entails modifications of the output, delivery pressure and power input. The laws giving the dependence of these quantities on the speed of the blower are given by the following well-known expressions:—

$$Q_o = K' n$$

$$\frac{P_e - P_a}{P_a} = K'' n^2$$

$$L = K''' n^3$$

where Q_o = volume of indrawn air.
P_a = absolute intake pressure.
P_e = absolute delivery pressure.
L = power input.
n = speed in r. p. m.
K, K'', K''' = constants.

The exponents of the speed (n, n^2, n^3) are only strictly accurate for ventilators and single-stage blowers. Whenever several impellers work in series, these exponents are greater, as has been found when discussing high-pressure turbo-compressors, and as is shown in the following example.

Example. The behaviour of a blower having two impellers is considered. The compression ratio in the first stage is supposed to be the same as that of the second stage at normal speed. Hence, the curve n_1, Fig. 24, is valid for both impellers under these conditions if the abscissæ give the volume of free air

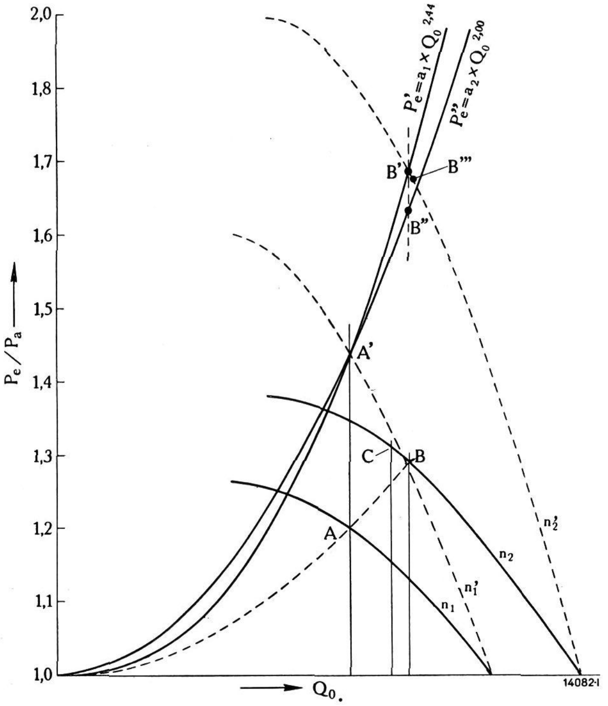

Fig. 24. — Compression ratio as a function of the volume of free air drawn in, showing the effect of speed regulation on impellers connected in series.

Ordinates:

$\frac{P_e}{P_a}$. Compression ratio.

Abscissæ:

Q_0. Volume of free air drawn in.

n_1. Pressure-volume characteristic of the first impeller.
n'_1. Pressure-volume characteristic with two impellers in series.
n_2. Same as n_1, but with speed raised by 20 %.
n'_2. Same as n'_1, but with speed raised by 20 %.
P'_e. Locus of normal points with two impellers in series and variable speed (exponent 2·44).
P''_e. Parabola (exponent 2·00) giving the same locus as P'_e with one impeller only.
A. Normal point of the first or second impeller considered separately.
B. Normal point of the first impeller with the speed raised by 20 %.
C. Normal point of the second impeller when connected in series with the first one, but with the speed raised by 20 %.
A'. Normal point of the two impellers when connected in series.
B'. Normal point of the two impellers when connected in series with the speed raised by 20 %.
B''. Normal point of the two impellers when connected in series with the speed raised by 20 %, and if the parabola with the exponent 2·00 were valid.
B'''. Corrected normal point with the speed raised by 20 %, and with the exponent about 2·30.

drawn in by the first impeller. The resultant characteristic of the two impellers is then the curve n'_1. At the normal point A, the compression ratio per impeller is 1·2, so that the total compression ratio of the two impellers amounts to $1{\cdot}2 \times 1{\cdot}2 = 1{\cdot}44$.

Should the speed be raised by 20 %, for instance, the characteristic of the first impeller is given by a parabola, similar to those obtained with ventilators. As a linear law between the volume and speed has been assumed, the volume of air dealt with by this impeller increases in this way by 20 %, and the delivery pressure becomes $1 + \left(\frac{120}{100}\right)^2 \times 0{\cdot}2 = 1{\cdot}288$ kg per cm² absolute. The volume of air drawn into the second impeller, however, does not augment 20 %, because the pressure of the air at its intake is higher than previously, with the result that the temperature of the air is also greater. If an intake temperature of 15° C for the first impeller and an efficiency of 80 % for the first stage are assumed, the temperature before the second impeller amounts to about 308° C absolute; on raising the speed by 20 %, it becomes equal to about 316° C absolute. Consequently, the intake volume of the second impeller is altered in the following manner by this change of speed:—

$$120 \times \frac{1{\cdot}2}{1{\cdot}288} \times \frac{316}{308} = 114\,\%$$

that is, the increase is less than 20 %. This means that the working of the second impeller is not given by the point B, but by the point C, where the pressure ratio is 1·31 instead of 1·288. On this account, the new delivery pressure of the blower is $1{\cdot}288 \times 1{\cdot}31 = 1{\cdot}69$. Hence, the pressure rise due to the increase of speed depends on the 2·44 power of the speed—and not on the square of the speed—if the intake volume is assumed to augment with the first power of the speed. This shows that even with two stages an appreciable discrepancy with the general law admitted exists. It can easily be seen that this difference instead of growing proportionately with the number of stages increases faster. It follows that the pressure does not depend on the work expended according to a linear law, but to a curve which rises more rapidly. This fact is particularly noticeable with high-pressure turbo-compressors.

The supposition that a linear law exists between the volume of air dealt with and the speed does not give the exact normal point for reasons which have not been gone into here. This point is somewhat lower than B′ (Fig. 24) at B‴. Consequently, the volume of air drawn in depends on the speed to a power greater than unity, which, moreover, increases with the number of stages. This is due to the fact that the exponent characterising the locus of the normal points (points of highest efficiency) is somewhat smaller than that found between pressure and speed (2·44), but nevertheless greater than two, and increases with the number of stages. Hence, the law which is valid for ventilators is, with blowers, not even true for the normal point for which the impellers have been adjusted. The discrepancy is still more marked if the results are compared with points other than the normal.

When dealing with a numerical example[1] for a high-pressure turbo-compressor, the following relations were found:—

$$Q_o = K' n^2; \quad \frac{P_e - P_a}{P_a} = K'' n^4; \quad L = K''' n^5$$

The same reasoning as applied to turbo-compressors can be repeated here: it follows that the efficiency is approximately constant for points which are situated on the same parabola passing through the origin of the coordinate system.

Special regulating conditions, e. g., a constant volume of indrawn air or a constant delivery pressure, can be met more efficiently by adjusting the speed than by throttling at the intake.

The effect of altering the speed is less satisfactory, however, with respect to the stable working domain, as the pumping limits of the different pressure-volume curves lie on a parabola passing through the origin, as shown in Fig. 25.

3. Diffuser regulation is carried out by adjusting the diffuser vanes; from the economical point of view, it is intermediate between throttling at the intake and speed regulation. In this case, the throttling losses of the preceding method no longer occur, but a fundamental difference with speed regulation exists, inasmuch as the losses due to the friction of the impeller do not fall off at fractional loads, but remain constant, that is, they augment with respect to the other losses. Nevertheless, when expressed as a percentage of the total losses, this increment is inconsiderable, so that efficient working is possible at small fractional loads (Fig. 26). Furthermore, it will be seen from Fig. 26 that diffuser regulation is still more satisfactory than throttling at the intake as regards the stable working domain. The former mode of regulation is particularly economical if the pressure of the system has to be maintained constant. On the other hand, if the indrawn volume of air has to be kept constant, the same shortcomings arise as with throttling at the intake.

[1] See Revue BBC, 1921, No. 7.

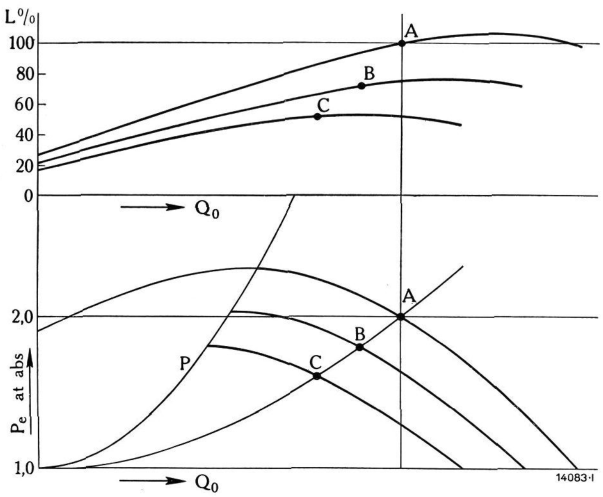

Fig. 25. — Pressure-volume characteristics and power input with speed regulation.

Ordinates:
P_e. Delivery pressure in kg per cm² absolute.
L. Power input in per cent.

Abscissæ:
Q_0. Volume of free air drawn in.
A. Normal point at normal speed.
B, C. Normal points at reduced speeds.
P. Pumping-limit locus.

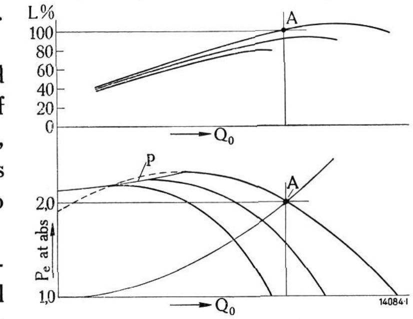

Fig. 26. — Pressure-volume characteristics and power input with diffuser regulation.

Ordinates:
P_e. Delivery pressure in kg per cm² absolute.
L. Power input in per cent.

Abscissæ:
Q_0. Volume of free air drawn in.
A. Normal point with diffusers fully opened.
p. Pumping-limit locus attainable.

§ 23. *Comparison of the different modes of regulation from the economical standpoint.* The conditions depicted in Fig. 27 have been chosen for this purpose, which are namely the following:—

(a) A falling delivery pressure given by the parabola A B C.

(b) A constant delivery pressure given by the horizontal straight linie A B′ C′.

(c) A constant indrawn volume given by the vertical straight line A B″ C″.

TABLE 1. THROTTLING AT THE INTAKE.

Regulation curve	**Parabola**			**Horizontal**			**Vertical**		
Points . . .	A	B	C	A	B′	C′	A	B″	C″
Power input, L % (100 % = normal input)	100	91	82	100	92	84	100	96	91

TABLE 2. SPEED REGULATION.

Regulation curve	Parabola			Horizontal			Vertical		
Points . . .	A	B	C	A	B′	C′	A	B″	C″
Power input, L %	100	72	53	100	83	68	100	80	60

TABLE 3. DIFFUSER REGULATION.

Regulation curve	Parabola			Horizontal			Vertical		
Points . . .	A	B	C	A	B′	C′	A	B″	C″
Power input, L %	100	87	76	100	89	78	100	93	86

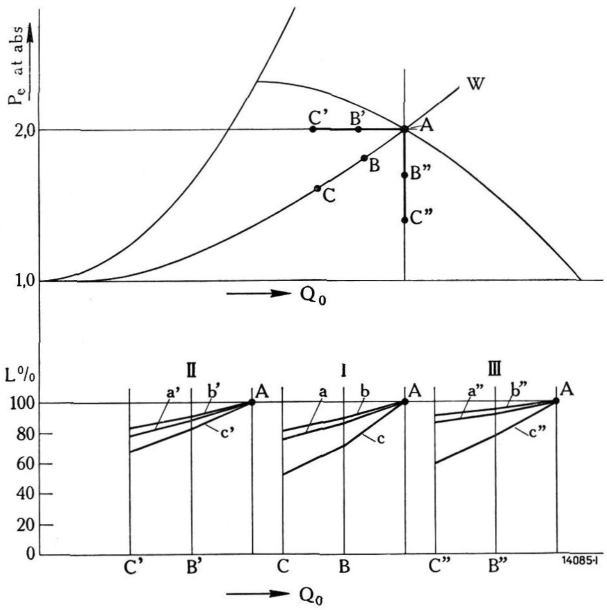

Fig. 27. — Power input with different modes of regulation and different loads.

I. Parabolic regulation curve. II. Regulation with constant pressure. III. Regulation with constant volume.

Ordinates:

P_e. Delivery pressure in kg per cm² absolute.
L. Power input in per cent.

Abscissæ:

Q_0. Volume of free air drawn in.

A, B, C, B′, C′, B″, C″ } Normal point and points corresponding to fractional loads.
a, a′, a″. Power input with diffuser regulation.
b, b′, b″. Power input with regulation by throttling at the intake.
c, c′, c″. Power input with speed regulation.

The foregoing tables show, as might have been expected, that speed regulation is by far and away the most satisfactory inside the stable working domain. Diffuser regulation, although not so economical as speed regulation, is, all the same, superior to throttling at the intake. These considerations only apply to the blowers, without any account having been taken of the drive.

§ 24. *Conditions affecting the drive.* It has already been seen that blast furnace blowers have to be able to satisfy the widely-differing conditions met with when operating furnaces of this description, with the result that extensive regulation has to be carried out.

If considerable variations of speed are possible without adversely affecting the efficiency of the prime mover, speed regulation is manifestly the most suitable, and, in such cases, this mode of regulation should be employed as far as practicable. Amongst the drives possessing this characteristic, the steam turbine and the direct-current motor must be specially mentioned.

Because of the reduction of the stable working domain, however, throttling at the intake or diffuser regulation have to be resorted to once the pumping limit is gone under.

Amongst alternating-current motors, a distinction must be made between induction and synchronous motors. With the former, the speed can be altered very simply by the provision of resistances in the rotor circuit. The additional losses (slip losses) thereby entailed are given by:

$$\Delta L = K L_m \frac{n_{max} - n_{eff}}{n_{syn}}$$

or in per cent.

$$\Delta L\,\% = K \frac{n_{max} - n_{eff}}{n_{syn}} \frac{1}{\eta_{mot}} \times 100$$

where:

ΔL = slip losses in kW.
L_m = power input of the motor in kW.
n_{syn} = synchronous speed.
n_{max} = maximum speed with the load L_m.
n_{eff} = effective speed.
K = factor taking account of the increased rotor losses.
η_{mot} = efficiency of motor with the load L_m.

It is now proposed to ascertain whether, despite these losses, speed regulation by adding resistances is superior to throttling at the intake or diffuser regulation.

If account is taken of the slip losses, the figures given in Table 2 are modified; the new values are given in Table 2a, and plotted out in Fig. 28.

TABLE 2a. SPEED REGULATION,
account having been taken of the slip losses.

Regulation curve	Parabola			Horizontal			Vertical		
Points . . .	A	B	C	A	B′	C′	A	B″	C″
Power input, L %	100	80	66	100	87·5	75	100	88	72

On comparing Figs. 27 and 28, the undeniable superiority of meeting differing requirements by adjusting the speed even with induction motors having slip-ring regulation will be readily recognised. As with

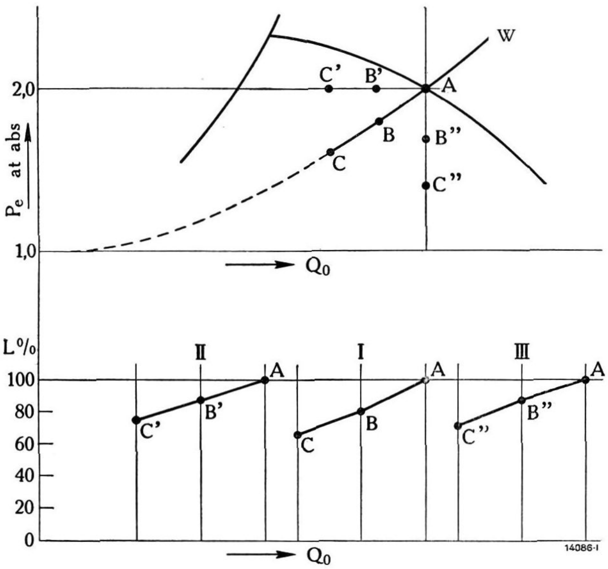

Fig. 28. — Power input, inclusive of slip losses of the induction-motor drive.

I. Parabolic regulation curve. II. Regulation with constant pressure. III. Regulation with constant volume.

Ordinates:

P_e. Delivery pressure in kg per cm² absolute.

L. Power input in per cent.

Abscissæ:

Q_0. Volume of free air drawn in.

A, B, C, B′, C′, B″, C″ Normal point and points corresponding to fractional loads.

turbine drives, diffuser regulation should be employed in conjunction with speed regulation so as to obviate pumping or blowing off to the atmosphere at small fractional loads.

Fig. 27 also shows how regulation should be carried out with synchronous-motor drives, with which the speed necessarily remains invariable; it will be noticed that under these conditions, diffuser-vane regulation is the most preferable.

Thanks to the comparative flatness of the pressure-volume characteristics, the regulation of turbo-blowers can ordinarily be effected by the drive itself. Should modified conditions of the blast furnace operation call for adjustment of the blower, this can be carried out by hand—if the speed can be altered, by choosing a suitable speed, otherwise by changing the opening of the diffuser vanes, or by operating the throttle. These means enable all special regulation conditions to be met.

Whenever the requirements are such that the blast needs either a constant volume of air or a constant pressure, the regulation should be automatic as far as possible. A description of devices for this purpose with steam-turbine drives has been given in the Revue BBC, 1920, No. 4.

With electrical drives, the conditions are not as simple, but Brown, Boveri & Co. have successfully tackled the problem, notwithstanding the difficulties. For example, Fig. 29 shows the arrangement adopted with an induction-motor drive when the volume of air has to be kept constant. The component parts of this regulating device are very simple, and comprise essentially a liquid starter (g) with movable electrodes displaced by a servo-motor (i). The latter is operated by a pressure oil relay (m), whose spindle is controlled by the delivery volume. The servo-motor is provided with a special starting valve (k) and an interlocking contact (h). After the valve (k) has been shut, the main switch (e) is closed, and the stator is energised. The piston (q) of the servo-motor is then in its lowest position, and the electrodes are only slightly immersed, so that the motor starts up. The oil pump (o) now begins to operate, and pressure oil is supplied to the piston of the servo-motor, with the result that the electrodes sink and the motor gathers speed. Once normal working conditions have been attained, a falling off of the volume causes the spindle of the relay to descend. This augments the pressure under the piston of the servo-motor which rises, thereby lowering the electrodes and increasing the speed of the motor. The same sequence of operations, only in the opposite sense, takes place if the volume increases.

§ 25. *Means of overcoming disturbances in blast furnace operation.* All the demands which blowers may be called upon to satisfy in blast furnace operation cannot be met by the methods of regulation described. As a matter of fact, the speed can be easily raised above the normal in cases where the prime mover is a turbine, a direct-current or an induction motor, and appreciable increases of pressure can be obtained either with the volume of air remaining constant or diminishing. If, for instance, the speed can be raised 25 %, an increase of pressure of about 100 % is possible when the blast falls off slightly,

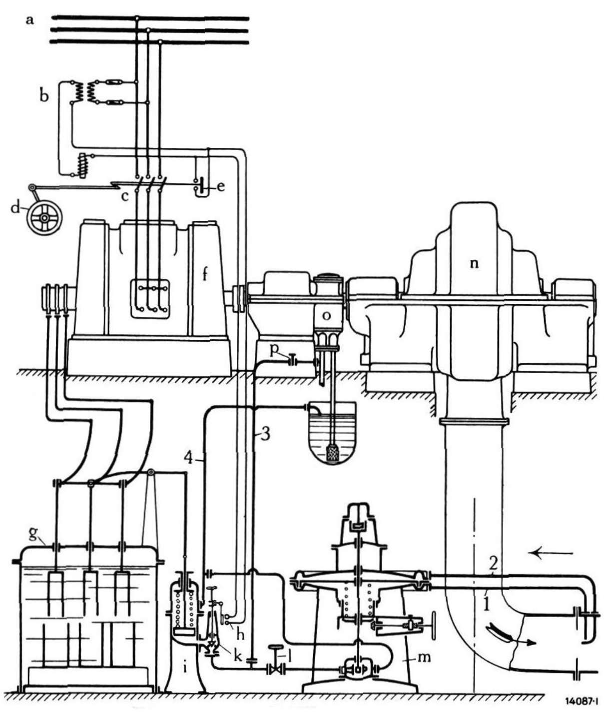

Fig. 29. — Arrangement for keeping constant the volume of air delivered by a blower driven by an induction motor.

a. Current supply.
b. Potential transformer.
c. Oil switch.
d. Hand drive for c.
e. Auxiliary contact.
f. Induction motor.
g. Liquid starter.
h. Interlocking contact.
i. Servo-motor.
k. Starting valve.
l. Shut-off valve.
m. Pressure oil relay.
n. Blower.
o. Oil pump.
p. Oil-regulating valve.
1. Straight pipe leading to diaphragm.
2. Pitot tube leading to diaphragm.
3. Pressure oil pipe.
4. Oil return pipe.

or of about 80 % when the blast remains constant. Brown Boveri turbines intended for driving blast furnace blowers on this account are provided with special regulation which enables the speed to be altered by ± 25 %. The features just mentioned are depicted in Fig. 30.

This procedure has in both cases a drawback, inasmuch as the prime mover under normal conditions is not utilised to its full capacity. Consequently, the machines are larger than absolutely necessary, so that the plant is more expensive. Furthermore, with electric-motor drives, the extra losses due to the speed regulation must not be lost sight of when choosing the plant—in the example above, the slip losses alone amount to about 25 %. With synchronous motors, where the speed cannot be altered, the losses are still greater, because only throttling at the intake or diffuser regulation can be employed.

The correct solution was furnished by the observation that with a hanging furnace only a comparatively small volume of air is required, despite the much greater back pressure. For instance, if the back pressure increases by 100 %, the volume rarely exceeds 50—60 % of the normal volume. Hence, these conditions cannot be fulfilled economically by

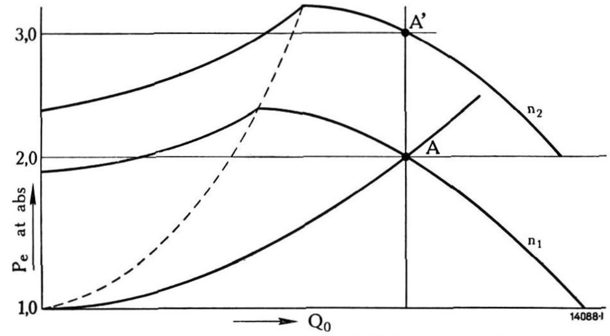

Fig. 30. — Increase of pressure possible by raising the speed.

Ordinates:

P_e. Delivery pressure in kg per cm² absolute.

Abscissæ:

Q_0. Volume of free air drawn in.

n_1. Pressure-volume characteristic at normal speed.

n_2. Pressure-volume characteristic with speed raised by 25 %.

A. Normal point.

A'. Working point with the normal delivery pressure and volume increased by 100 %.

speed regulation, since they correspond to a very small fractional load on the new characteristic, whose normal point corresponds to a volume of about 130 % (curve n_2, Fig. 30).

Such abnormal working conditions can be met in a more economical manner by connecting the two halves of a double-flow blast furnace blower, which normally run in parallel, so that air is only drawn in at one end, and the two parts work in series; in this case, the delivery volume is reduced approximately by half, whereas the pressure is about doubled. It follows that no appreciable difference in the power input occurs, and the prime mover need not be chosen unduly large so as to be able to cope with abnormal conditions. The characteristics of a turbo-blower with this arrangement are shown in Fig. 31. In order that the change over can be carried out at the correct instant, the steep characteristic is displaced with advantage to the right, as shown in Fig. 31. This is possible if the blower is provided with movable diffusers, which allow the volume of air to be increased when they are opened wider. An augmentation of the power input is thereby entailed, which must not be forgotten when dimensioning the prime mover — the increase, however, is nothing like as considerable as with the aforementioned method.

§ 26. *Particularities of the different classes of drive.* If a blower has to be able to meet all requirements occurring in blast furnace operation, and, at the same time, work as economically as possible, account must be taken of the following details:—

(a) Turbine or direct-current-motor drives. Speed regulation should be employed for ordinary working conditions and for fractional loads when the pressure does not greatly exceed the normal up to the point where the volume cannot be further diminished by this method. For very small quantities of air, the diffuser area should be reduced in order to regulate.

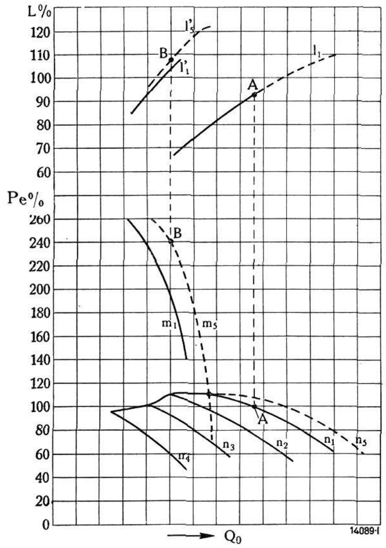

Fig. 31. — Characteristics of a turbo-blower with parallel and series connections and movable diffusers.

Ordinates:
- L. Power input in per cent.
- P_e. Gauge pressure at delivery end in per cent.

Abscissæ:
- Q_0. Volume of free air drawn in.
- n_1. Pressure-volume characteristic with normal diffuser opening and impellers connected in parallel.
- n_2, n_3, n_4. As n_1, but with diffusers more closed.
- n_5. As n_1, but with diffusers opened wider on account of an overload.
- m_1. Pressure-volume characteristic with normal diffuser opening and impellers connected in series.
- m_5. As m_1, but with diffusers over opened.
- l_1. Power input when connected in parallel.
- l'_1, l'_5. Power input when connected in series.
- A. Normal point under normal conditions.
- B. Delivery pressure attainable with the volume reduced to 50% (the pressure is 140% greater than normally).

If there is a considerable rise in the back pressure due to disturbances, the working should be changed from parallel to series, and the diffusers suitably adjusted.

(b) Three-phase induction-motor drives. For normal working conditions, as well as for fractional loads with reduced pressures, use should be made of speed regulation exclusively. For fractional loads or overloads with pressures slightly above normal, diffuser regulation should be employed. A change from parallel to series working should be made whenever there is an abnormal increase of the back pressure.

(c) Synchronous motor drives. For normal working conditions and for fractional loads, diffuser regulation alone need be considered, and for increased pressures, series connection combined with diffuser regulation.

The same results as with a blower having series-parallel connections can be attained equally well by arranging two blowers in series which are normally independent of one another. This solution is particularly suitable for large plants where the blowers are centralised in one power house, so that several blowers are close together and either work on to a common main, or supply air independently to different blast furnaces. The layout of the plant should be planned so as to enable the stand-by blowers to be used not only to replace other machines, but also to be connected in series either before or after them. By this means, without entailing an excessive overload or an unduly large prime mover, it is possible to raise the pressure to twice its normal value with the volume of free air drawn in remaining invariable, or to still higher values if the volume of air is reduced.

One particular way of realising the above conditions consists of arranging each two adjacent machines so that they can be connected in any series arrangement. The drawback of having long pipelines is more than compensated for by the practical advantages of this arrangement.

§ 27. *Gas-engine-driven reciprocating blowers and turbo-blowers.* Blast furnace gas can be utilised either by converting it directly into mechanical energy in gas engines or by burning it under boilers which supply steam to turbines. No hard and fast rules can be laid down as to the advantages of either method, since so much depends on local conditions. Moreover, personal ideas have a considerable influence. On this account, only the advantages and shortcomings of both these methods will be gone into for as far as they effect the blast furnace blower sets. Three principal solutions are forthcoming, viz.:

(a) Reciprocating blowers driven directly by gas engines.

(b) Electrically-driven turbo-blowers.

(c) Steam-turbine-driven turbo-blowers.

Since reciprocating blowers driven by steam engines or by electric motors are hardly ever employed nowadays, it is not worth while to enter into further details on this matter.

(a) Gas-engine drives are extensively employed because they enable very efficient use to be made of the heat at normal loads. Comprehensive research

has shown that large gas engines — as is the case here — when in good working order require 3500 calories per kWh, which is equivalent to a thermal efficiency of about 24·6 %.

At fractional loads, the consumption increases very rapidly, however, so that the energy consumption at no load attains as much as 40 % of the full-load consumption. Furthermore, gas engines have only a small overload capacity. This feature is a weak point of these machines, because they have to be chosen larger than necessary for everyday operation, so as to be able to meet irregular working conditions in the furnace, such as those which call for an increase of pressure with the quantity of air remaining unchanged, for instance. It follows that *gas-engine-driven blowers do not usually work under the most favourable conditions, and, because of this, the maximum efficiency cannot be maintained.*

Attention must also be called to the considerable space taken up by slow-running gas engines and blowers, to the difficulties of obtaining gas of the right composition, and to the necessity of careful supervision which entails high maintenance costs. On this account, the intial outlay and upkeep are considerable, not only for the machines, but also for the buildings. Moreover, the reliability is not so great as with turbo-sets, unless a large standby plant is available.

(b) Electrically-driven turbo-blowers are employed in ironworks whenever the power supply is centralised. The overall efficiency, which is greatly influenced by that of the power station, is ordinarily good, since the latter usually comprises a number of large, well-loaded machines, but does not come up to that of the first solution, on account of the losses caused by the conversion and transmission of power in the generator, cables and motor. These losses, which on the average probably amount to about 12 % of the energy transmitted, are partly compensated for by the more favourable conditions for utilising the energy at the central power stations. This is especially marked when the energy required for the blast furnace blowers forms only a small portion of the total output, as in combined works, e. g., those producing steel and pig iron. Fractional loads can be carried more advantageously than in the first case, because, as it has already been pointed out, the efficiency of turbo-blowers does not vary to any great amount for an extended regulation domain, and, at the same time, the no-load losses are small — about 25 % of the power input at full load.

Rotary blowers also possess other advantages, amongst which may be mentioned: less space required, small capital expenditure, smaller buildings and lighter foundations, less attention and upkeep, reduced wear, and efficiency not falling off with time. Nevertheless, the cost of the switchgear, cables and electrical apparatus must not be forgotten.

It almost goes without saying that electrically-driven turbo-blowers should only be employed in plants which are some distance away from the central power station whence they are fed.

Blowers for the main plant should be installed preferably in the central power station, since they should be in close proximity to the blast furnaces, which requirement is certainly fulfilled by the gas power plant for which the furnaces serve as gas producers. Energy conversion under these conditions is a superfluous complication, which can be avoided by having gas-engine drives.

(c) The overall efficiency of turbo-blower sets driven by steam turbines reaches about 20 % at the normal point, and is consequently inferior to that of gas-engine drives. The flexibility and efficient working at fractional loads, however, are weighty considerations in favour of turbines for driving turbo-blowers, to which must be added the advantages of rotary blowers just enumerated.

Whenever blast furnace gas is burnt under boilers, steam-turbine-driven turbo-blowers are unrivalled.

A striking feature, which cannot escape comment when making a comparison between gas-engine-driven blowers and steam-turbine-driven turbo-blowers, is that of the expenditure involved — the gas-engine plant costing at least $1\frac{1}{2}$—2 times as much as that for steam turbine, inclusive of the entire boiler and condenser plant. This fact, together with the remarkable flexibility of steam-turbine-driven turbo-blowers, renders their installation advantageous, even in plants where gas engines already exist.

R. Gilly, A. Fischer. (D. M.)

NOTES.

Paralleling device for exhibition purposes.

Decimal index 621.317.4 : 606.

AN automatic paralleling device has recently been added to the permanent exhibition of Brown Boveri manufactures[1] for the purpose of showing its operation in a convenient and convincing manner. On this account, care had to be taken to reproduce as exactly as possible the conditions existing in a power station or substation.

The most obvious solution would have been to provide two small alternators and drive these by direct-current motors fed by 220-volt current from an existing supply. In order to render the installation as simple as possible, however, it was decided to employ two small rotary converters for 160 volts, 50 cycles. Since the paralleling device is designed for a total pressure of 2×110 volts, the difference between 160 and 110 volts has to be taken up by a series resistance (8, Fig. 1). By adjusting the excitation of one of the rotary converters, its speed, and consequently the frequency, can be altered as desired.

[1] See Revue BBC, 1921, No. 1.

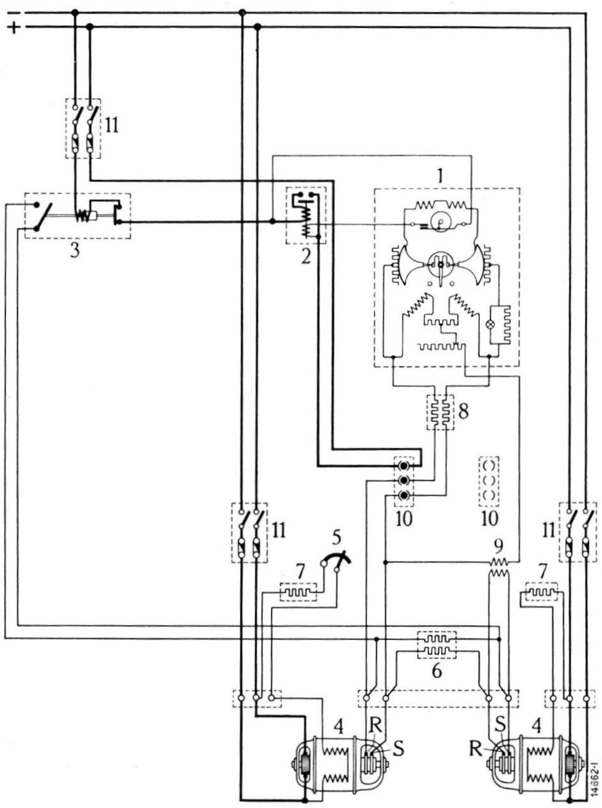

Fig. 1. — Diagram of connections of the paralleling device.

1. Paralleling device.
2. Contact relay with retaining coil.
3. Oil switch with solenoid remote control.
4. Rotary converter.
5. Field regulator.
6. Resistance equalising the load of the converter.
7. Constant shunt resistance.
8. Auxiliary resistance.
9. Reversing transformer.
10. Plugs.
11. Fuse-switch.

It follows that by means of the field regulator (5, Fig. 1), the rotary converters, which are running at different speeds to begin with, can be brought closer to synchronism. As soon as the difference of frequency becomes small enough and the phases coincide, the paralleling device closes the oil switch, which connects the two converters in parallel.[1]

While working out the arrangement just described, which appears perfectly simple at first glance, several interesting problems were encountered. The paralleling device has to be operated by phase addition, that is to say, its terminal pressure must amount to 220 volts (2×110 volts phase pressure) when the currents of the two converters are in phase. In order to do this, the opposite terminals of the converter would have to be connected, i. e., R with S, and S with R; such an arrangement however, would give rise to a short circuit across the commutator because of the connection between the direct and alternating-current circuits in the rotary converters. On account of this, a reversing transformer has to be provided, which ensures the phase addition necessary for the paralleling device.

Moreover, by reason of the continuous phase displacement, the current taken by the paralleling device produces an intermittent load, and consequently an intermittent braking torque, the effect of which is considerable on these very small converters. This effort reaches a maximum when the two converters are about to be brought into phase. In fact, if the field regulator is adjusted for a very small difference of speed, the braking effect is so marked that it synchronises the machines, but prevents phase coincidence. Under such conditions, paralleling is manifestly impossible.

This difficulty was easily surmounted once its cause had been recognised. For this purpose, the converters are connected in parallel over a resistance 6, which is dimensioned in such a way that the load due to the exchange current is the same as that due to the paralleling device. This load likewise depends on the difference of the displacement between the two machines, and is therefore of an intermittent nature. The maximum value of the exchange current is reached, however, when its phase is advanced by 180^0 with respect to that corresponding to the maximum load due to the paralleling device. The combined braking effort of the two loads consequently remains practically constant, independently of the phase displacement. It thus becomes possible to give the converters any phase displacement required, no matter what the difference of speed may be, and thus exactly reproduce the conditions met with in power-station operation.

The installation works most satisfactorily and can be handled by anybody without mistakes in switching or damage to the apparatus being possible. Another valuable feature worth mentioning is that only trifling alterations are necessary to adapt the paralleling device for operating in places where no direct current, but only alternating current is available. Under such conditions, one of the converters is used to generate direct current, whereas the other delivers alternating current whose frequency with respect of the existing supply can be altered at will.

H. C. Kloninger. (D. M.).

[1] A description of the paralleling device appeared in the Revue BBC, 1920, No. 2.

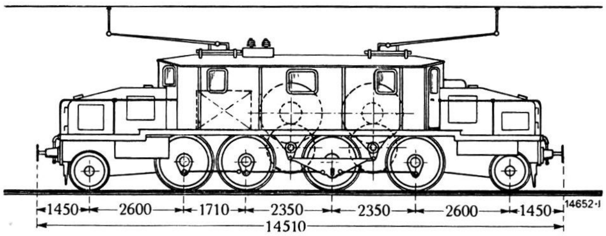

Fig. 1. — 1D1 three-phase express passenger locomotive, Italian State Railways.

Contact-wire pressure 10'000 V, 45 cycles, one-hour rating of motors 2700 H. P., speed 100 km per hour.

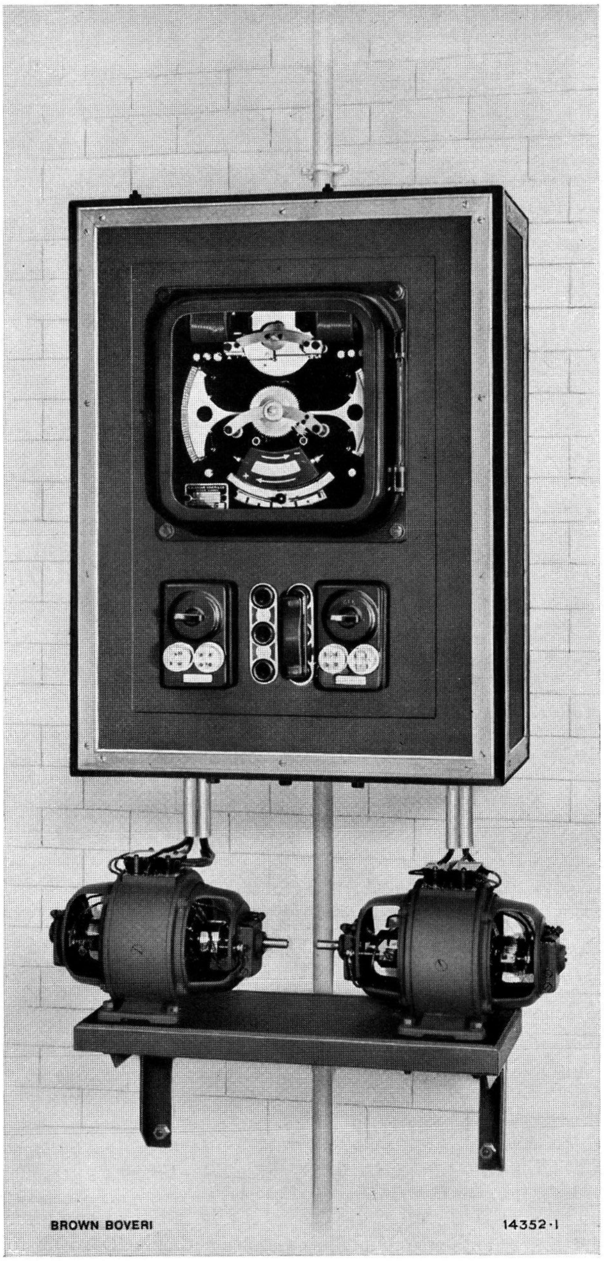

Fig. 2. — Paralleling device with two small rotary converters.

Electrification tests on the Italian State Railways with three-phase current of normal frequency.

Decimal index 621. 331. 433 (45).

WITH the exception of a few sections of minor importance, electrical energy is supplied to main-line railways either as three-phase current of normal frequency, which is converted by rotary machines, or by special power stations which generate suitable current directly. Both alternatives involve comparatively high expenditure for the plant and energy. A notable reduction of these costs can be achieved by feeding the contact wires with high-tension three-phase current of normal frequency. Moreover, it becomes possible to interconnect power-supply systems for railway and for industrial purposes, and thereby ensure important economic advantages.

The suitability of three-phase current for main-line railways was recognised by Brown, Boveri & Co. in the pioneering days of electric traction, and the successful electrification of the Burgdorf-Thun Railway affords an ample proof of their foresight.

Present-day developments have enabled trials on a large scale to be undertaken on the Italian State Railways with three-phase current, 10'000 V, 45 cycles. The use of such a high pressure—which had not been considered feasible hitherto for three-phase contact wires—is rendered possible by taking account of the high inductive pressure drop occurring. The reason why the frequency of 50 cycles, which is standard in many countries, is departed from in Italy, is due to the fact that the two frequencies of 42 and 50 cycles are about equally common, and the average value of 45 cycles permits the standardisation of frequencies to be carried out as rapidly as possible.

These trials will be begun in the summer of 1923 on Rome-Tivoli section, which has a total length of 40 km. Curves abound on this line, and there are seven intermediate stations. The first twenty kilometres are about level, only a few gradients of 1·5 % have to be climbed, whereas there is a practically uninterrupted gradient of 1·5 % for the remainder of the journey. If this electrification comes up to expectations, the conversion of the level section between Rome and Anzio (60 km), as well as of other lines in Central Italy will be proceeded with.

The existing three-phase supply, 3300 V, 16·7 cycles, is to be retained for extensions of the electrification of the upper Italian system. It follows that interchange stations will have to be able to accommodate locomotives belonging to both systems. The induction motors employed can use low-pressure current, inasmuch as they are able to develop their full torque when the normal pressure and frequency are lowered by two-thirds, their speed, however, in such cases is only one-third of the normal. Consequently, when the necessity of having interchange stations arises, these will be supplied with low-frequency three-phase current.

For working the traffic on the first-mentioned section, four express passenger locomotives and four freight locomotives are to be supplied to the Italian State Railways by the Tecnomasio Italiano Brown Boveri, Milan. The leading particulars of these machines are the following:

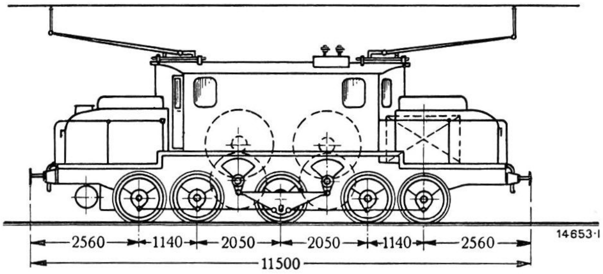

Fig. 2. — E-type three-phase freight locomotive, Italian State Railways. Contact-wire pressure 10'000 V, 45 cycles, one-hour rating of motors 2300 H.P., speed 50 km per hour.

2700 H. P., 1 D 1 express passenger locomotives (Fig. 1). The four pairs of coupled wheels have a diameter of 1630 mm. Each of the guiding axles and the adjacent coupled axle are mounted on a Krauss-Helmholz truck. The drive is transmitted by pinions on both sides of the motors to twin gear wheels on the jackshaft, and thence by a Scotch yoke to the second coupled axle. The gear ratio is 1 : 2·7.

The two 1000-kW motors are placed in a high position and have forced ventilation. Their number of poles can be changed from six to eight, and four speeds are obtainable by series or cascade connection. According to the number of poles, the rotor winding is either three or four phase, and is connected by seven slip-rings to the liquid starter.

The pinions are placed on either side of the motors between the rotor and slip-rings.

An oil-immersed transformer, having a one-and-a-half-hour rating of 1730 kVA, lowers the contact-wire pressure down to about 1000 V for the motors, and is provided with a third winding for 110 V, which supplies current for auxiliary purposes. Efficient cooling is ensured by circulating the transformer oil in a system of coiled pipes located outside the locomotive body — an arrangement similar to that adopted for the 1 B-B 1 locomotives of the Swiss Federal Railways.

Disconnecting switches are placed in the high-tension and low-tension circuits, all apparatus necessary for controlling the motors being mounted directly on the low-tension switch. Liquid resistances — of a type which has given excellent results in service — with automatic adjustment are used for starting up.

The capacity of one of these locomotives is given in the following table :—

Motors	number of poles . .	2×8	2×6	8	6
	speed in r. p. m. . .	337	450	675	900
Speed in km per hour . . .		37·5	50	75	100
One-hour tractive effort at the tread of the wheels in kg .		6600	6600	8500	7000

On going downhill, regenerative braking sufficient to hold the entire train comes into action automatically. The weight of one of these locomotives in working order amounts to about 91 tons, with a maximum axle load of 16 tons.

2300 H. P., E freight locomotives (Fig. 2). The mechanical details of these machines resemble those of the well-known Italian ten-coupled freight locomotives. The transmission from the motors to the coupled wheels is similar to that just described for the passenger locomotives — a twin drive and a Scotch yoke being also provided. The gear ratio is 1 : 3·625.

The transformer does not differ from that of the passenger locomotives. The number of poles of the motor cannot be changed, but series and cascade connections are possible.

The capacity of one of these locomotives amounts to:

Motors	number of poles	2×6	6
	speed in r. p. m.	450	900
Speed in km per hour		25	50
One-hour tractive effort at the tread of the wheels in kg		10'000	12'000

These locomotives are also capable of holding the weight of the entire train when going downhill with regenerative braking. The weight of one of these locomotives in working order is about 76 tons.

Electric traction will be inaugurated on the trial section in the summer of 1923. If the results are satisfactory, a notable development in electric traction will have been realised.

C. Cohen. (D.M.)

The automatic substation at Diegten (near Basle).

Decimal index 621. 312. 6 (49. 4).

ACCORDING to the hour of the day, the electricity supply company for the country around Basle obtains the necessary power for the districts of Ober- and Unter-Diegten either from Augst power station on the Rhine or from Olten-Gœsgen power station on the Aare. The necessity for this dual supply is due to the fact that during the night the cost of the superfluous energy available at Augst is much smaller than that obtained from Olten-Gœsgen.

On this account, the power supply company decided to instal an automatic switching station, which would connect at any time required the consumers of the aforementioned districts either on to the supply from Gœsgen or that from Augst. Automatic operation was essential, because this substation is at a considerable distance from any power station with attendants, and the working costs with continuous supervision would be much too great.

In order to meet the foregoing requirements, the following conditions had to be fulfilled:—

The incoming line from Augst, which has an average pressure of 9200 V, is directly connected through an oil switch to the outgoing distribution lines for the district; that from Gœsgen, on the other hand, has an average pressure of 7500 V, which is raised to 9200 V by an auto-transformer. Switches are connected both before and after the latter, and are coupled together mechanically so as to disconnect the transformer from the line during periods when no current is taken from Gœsgen power station, thereby eliminating the no-load losses.

The "Augst" and the "Gœsgen" switches have motor remote control, and are interlocked so that the two incoming lines cannot feed the substation together. Switching is carried out by remote control from a time switch, which enables the supply to be changed at whatever time and as often as required. The auxiliary current for driving the motor control is supplied by a small 5-kVA transformer, which is permanently connected to the line from Gœsgen through fuses.

Overload protection is ensured by providing each of the three switches with two series time-limit relays (one on each of the outer phases) with electrical release. By means of a contact device, these relays interrupt the current of the tripping coils in the remote-control circuit, thus causing the switch to be opened.

Further, it was desired that whenever a momentary short circuit or an arcing ground occurs—as produced by branches of trees that are close to the lines in windy weather, for instance—the switches should close again after having been tripped, and only remain open should there be a lasting defect on the line. In the latter case, an alarm device placed wherever convenient should give notice of the de-energised state of the line.

These conditions are met by the substation described below, the operation of which is shown by the diagram, Fig. 1.

In the first place, attention must be called to the fact that the material is of standard Brown Boveri design throughout, with the exception of one alteration which consists of removing a cam from the free-return clutch of the motor remote control that lifts the releasing pawl and trips the switch when the motor runs backwards with the ordinary designs.

To render automatic operation of the substation possible, the three change-over switches A, B and C, which can be seen near to the time switch V in Fig. 1, must be closed, and turned upwards.

With the positions depicted in the diagram, the "Augst" switch is closed, the "Gœsgen" switch open, and the finger of the time switch on contact (y). In the case under consideration, two switching operations have to be carried out every day — one being in the morning and the other in the evening.

When the finger of the time switch leaves the contact segment (y), no modification of the working conditions takes place until it meets the segment (x). The circuit of the tripping coil of the "Augst" switch is then closed. In this circuit is a contact disc (g_1), which is mounted on the spindle of the switch, and rotates with it. The electric interlocking of the two drives I and II is thereby ensured in such a way that it is impossible for one of the switches to be closed before the other has been tripped.

In the present instance, the "Augst" switch is opened by the drive I, and this movement causes the contact disc (g_1) to be rotated. As soon as the switch is opened, this disc closes a circuit starting from the busbar (Q) and comprising the contact segment (x) of the time switch, the switch (C), the contact disc (g_1), the point (G_2), the contact disc (f_2) of the drive II, the pressure coil (i_2) of the relay (IV_2), and finally the busbar (P). On being thus energised, the relay (IV_2) closes the motor circuit over the retaining coil (k_2), which forms part of the relay (IV_2), and the change-over switch (e_2) of the remote control. The closing of the oil switch causes the disc (f_2) to rotate, with the result that the pressure coil of the relay (IV_2) is de-energised. The core of this relay, however, is still held down by the retaining coil (k_2) until the switching operations are finished, that is, until the change-over switch (e_2) is brought to its other position — which can be seen on referring to the diagram — by a pin on the geared disc of the drive. This constitutes the final operation when switching in, and since the current in the relay is interrupted by the change-over switch, the core of the relay is no longer held down.

The circuit of the motor is connected through the relay (IV_2) to ensure its being opened as soon as the switching-in operations are accomplished. Just at the last moment, the switch (e_2) is thrown over. This movement also causes the circuit to be broken at the relay (IV_2), which is absolutely

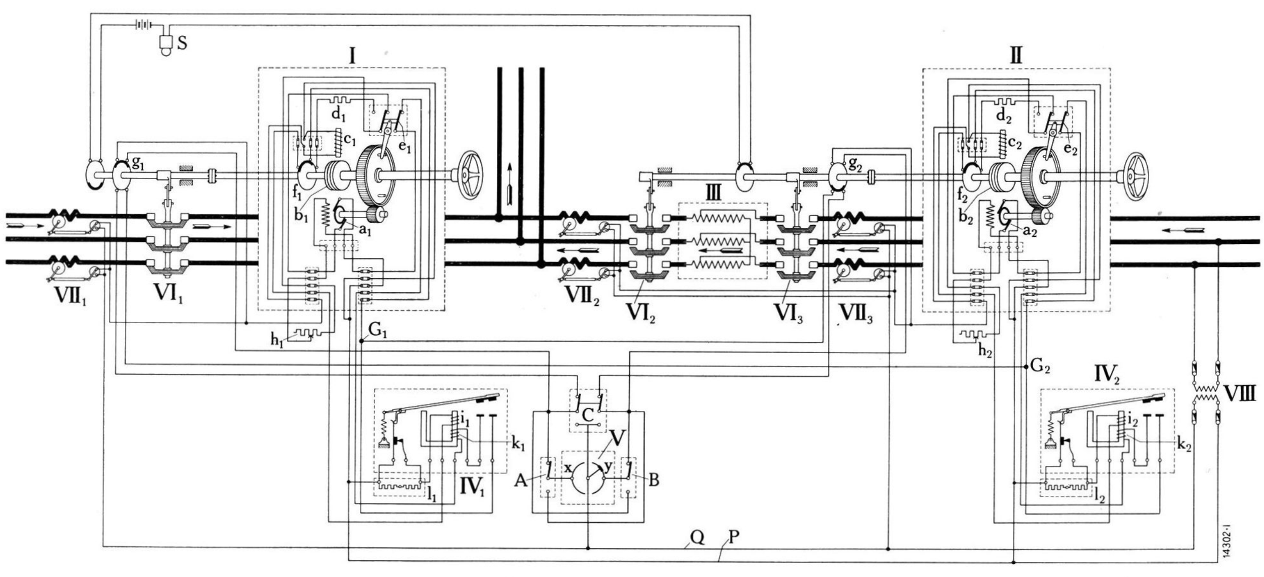

Fig. 1. — Diagram of connections showing operation of switches in Diegten automatic substation.
Left: Incoming line from Augst. Centre: Outgoing line to Diegten. Right: Incoming line from Gœsgen.

I, II. Automatic drives.
III. Auto-transformer.
IV_1, IV_2. Relays.
V. Time switch.
VI_1. "Augst" oil switch.
VI_2, VI_3. "Gœsgen" oil switch.
VII_1, VII_2, VII_3. Series time-limit relays.
VIII. Transformer for auxiliary circuit.

A, B, C. Change-over switches.
G_1, G_2. Junction points.
P, Q. Auxiliary busbars.
a_1, a_2. Motors driving the switches.
b_1, b_2. Free-return clutches.
c_1, c_2. Tripping coils.
d_1, d_2. Resistances for reverse operation.
e_1, e_2. Change-over switches.

f_1, f_2. g_1, g_2. Contact discs.
h_1, h_2. Rheostats.
i_1, i_2. Pressure coils.
k_1, k_2. Retaining coils.
l_1, l_2. Resistances.
x, y. Switching contacts.

necessary since the motor after having closed the switch, runs in the opposite direction without tripping the latter, as will be explained further on.

If the switching-in current only went through the two contacts to the left of the disc (f_2), there would be a danger of overrunning the outmost of these before the switch was completely closed and before the pawl which acts as a catch engaged with the free-return clutch. If this comes to pass, the motor is pulled backwards by the spring of the switch until the contact, i. e., the switching-in circuit, is re-established. It is evident that under these conditions the motor oscillates to and fro indefinitely. On the other hand, if the contact segments are made longer, so as to maintain contact to the left after switching in, the switch would be properly closed, but the motor after running backwards would go forwards again; the motor would continue running backwards and forwards indefinitely, and the successive reversals would be accomplished in exactly the same manner as explained when the switching-in process was described. In order to obviate both of these objectionable features, a relay is provided; it would not be necessary, however, with the normal type of remote control, which is operated by push-buttons.

Immediately after the switch is closed, the motor is reversed, as a connection exists between the two contacts to the right of the disc (f_2), and the current flows through the circuit for reverse operation. This circuit starts from the point G_2, comprises the disc (f_2, right-hand contacts), the change-over switch (e_2, in the position not drawn in the diagram), the field coils and rotor, and finishes at the auxiliary busbar (Q). The alteration of the position of the change-over switch causes the current to flow in the field winding in the direction opposite to that when switching in, but entails no change in the direction of the current flowing through the rotor. It follows that the motor is reversed. The switch is not tripped, however, because the tripping cam has been removed from the free-return clutch, as already mentioned. The position of the contact disc (f_2) also remains unaltered, as it is situated beyond the free-return clutch, that is, on the same side of the latter as the switch.

As the switching operations only occupy a fraction of a second, the small interval during which the distribution system is de-energised is not sufficient to affect any motors that may happen to be connected to it, so that there is no interruption to their running.

The same sequence of operations is repeated when the finger of the switching clock meets the segment (y): the "Gœsgen" switch is first of all tripped, and the "Augst" switch is then closed. The different phases of closing the "Augst" switch can be immediately deduced from the description already given simply by permutating the indices 1 and 2 of the symbols used for the auxiliary circuit for operating the switch.

Supposing the "Augst" switch closed — as shown in the diagram — then should a short circuit occur under these conditions, the series time-limit relay (VII_1) trips this switch. The disc (f_1), which is mounted on the switch spindle, rotates, and connects the two contacts to the left of the former, thereby reclosing the switching-in circuit through the relay (IV_1). The switch is then closed again in the normal manner as has already been shown. If there is a short circuit in the system, the series time-limit relay trips the switch as soon as contact is established before it can be closed again. Since the retaining coil still holds down the core of the relay (IV_1), the motor will continue to run forwards, as usual, until it throws over the switch (e_2). It is then, however, unable to run backwards, since the circuit cannot be closed because it is broken at the two contacts to the right of the disc (f_1) by the tripping of the switch. The latter therefore remains open, and the alarm circuit is closed through the contact discs which are mounted on the spindles of each of the two switches. Notice of the de-energised condition of the outgoing distribution lines is given at a suitable place. Once the short circuit or fault has been removed, the switch in question can be closed by hand.

The change-over switches A, B and C also serve as contact-makers, and enable switching operations to be carried out independently of the time switch. This may come in very useful should it be necessary to control the operation of the switchgear.

Since the two incoming lines belong to two distinct systems with dissimilar electric conditions, they must on no account be connected in parallel, that is, it must be impossible for the two switches to be closed simultaneously. For this reason, the interlocking devices are arranged so that one of the switches cannot be closed by hand unless the other is open, as otherwise the contact discs (*g*) complete the releasing circuit of the switch which is about to be erroneously closed, so that it is tripped before being able to complete the circuit.

This automatic substation has now been in operation for some time back, and has given entire satisfaction.

F. Grieb. (D. M.)

Temperature measurements in electric machines and apparatus.

Decimal index 621. 313. 1 + 621. 317. 1.

THE determination of the temperature rise that will occur in different parts of machines and apparatus in service is of very great importance, so that a considerable portion of the measurements made on test-beds are carried out for this purpose.

Different methods have been devised for measuring the temperature, which, according to the circumstances, can be employed either separately or together.

The simplest way to measure the temperature is with mercury thermometers, which are specially made in suitable shapes. Very satisfactory results can be obtained, provided that good heat transmission to the mercury in the bulb can be ensured. They are not applicable, however, when the point where the temperature is to be determined is hard to get at or inaccessible. In such cases,

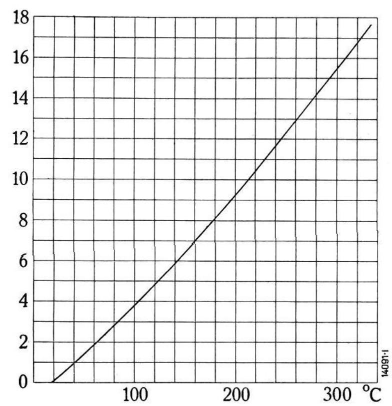

Fig. 1. — Chart giving the temperature at the soldered point in degrees centigrade once the thermo-emf in millivolts is known.

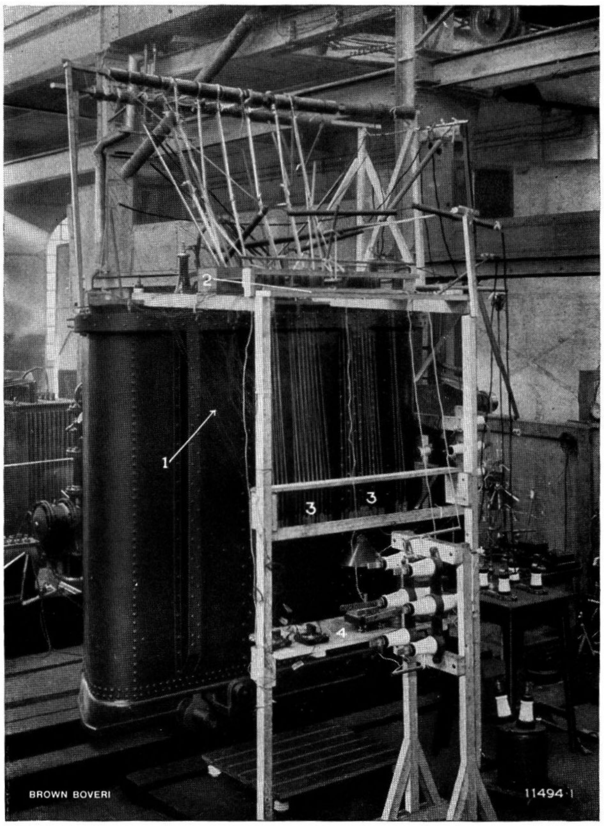

Fig. 2. — Arrangement for measuring temperatures of a large transformer.

1. Wires of a thermo-element.
2. Vessels containing mercury into which the free extremities of the thermo-elements are plunged so as to enable the connections to be easily changed.
3. Cords.
4. Millivoltmeter.

use has to be made of thermo-elements. As the name implies, the principle of this method is based on the difference of potential which exists between the free extremities of a conductor formed of two different metals when the temperature at the junction and the ends is not the same.

For a number of years, Brown, Boveri & Co. have employed in the testing department thermo-elements which are prepared in their own physical laboratory. These elements consist of a copper and a constantan wire of 0·5 mm diameter, whose length depends on the conditions for which they are intended. The joint between the two metals is silver soldered. The two wires are insulated from one another by a cotton covering—or asbestos when the temperatures are high—as far as the solder, and are also enclosed in a common covering. The differences of potential are naturally very small, and must, therefore, be determined by very sensitive and accurate instruments. The dial of the latter can be calibrated to show directly the temperature in degrees at the soldered joint if the same element is always used.

Fig. 1 gives a curve used for calibrating these thermo-elements, which enables the temperature at the soldered joint to be read off directly once the potential difference is known. The value shown by the millivoltmeter must, however, be first of all corrected by taking account of the resistance of the thermo-element and the millivoltmeter. The curve shown is based on an ambient temperature of 20° C at the free extremities of the wires; if this is not the case, the values have to be corrected. The thermo-element can be placed between the laminations of the active iron of machines and transformers, as well as in the windings, at contacts and bolts of switches, in carbon brushes and bearing pedestals. By boring a small hole, it can be embedded as deep as necessary in the insulation. If no high pressures occur during the tests — e. g., short-circuit tests on transformers and machines, or the determination of the temperature rise of switches — the thermo-couple can be soldered directly to the point whose temperature is to be measured.

Thermo-elements have rendered it possible to find out the temperature at different points inside windings (in long slots, for instance). As the insulation of the thermo-element inside the windings is difficult to ensure, particularly with high potentials, and as its failure might give rise to trouble, measurements of this kind are only effected on machines specially adapted for research work. The temperature distribution in a motor can be thus determined. For the rotor, in particular, the wires of the thermo-element go through the shaft, which is made hollow, and connected to the instrument by slip-rings.

Fig. 2 shows an arrangement for ascertaining the temperature rise of a large transformer. During this test, use was made of 51 thermo-elements, which were distributed in the windings and in the iron. The connections to the measuring instruments were made by means of vessels containing mercury, as can be seen in Fig. 3, in which the extremities of the thermo-elements are immersed by means of a system of cords. On account of the formation of amal-

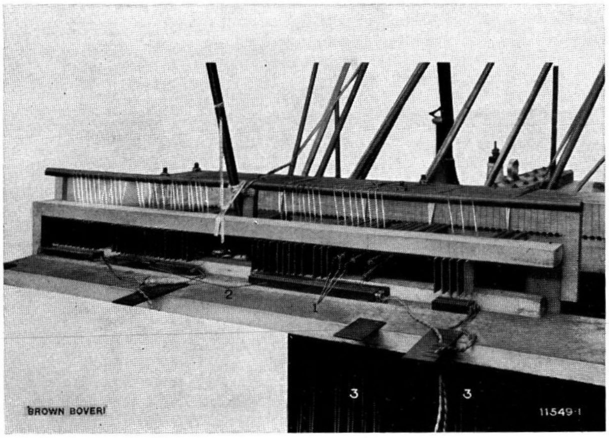

Fig. 3. — Details of the arrangement for measuring temperatures.
1. Wires of a thermo-element. 2. Vessel containing mercury. 3. Cords.

grams, the ends have to be thoroughly cleaned so as to ensure satisfactory contact.

Recently, for measuring temperatures, resistance elements have been employed, which can be made in narrow strips suitable for placing inside slots or transformer coils. In order to determine the change in the resistance of these elements, measuring bridges are used. In this case, the temperature at a given point is not obtained, but only the average temperature along the element. The insertion of these elements is not always easy, since they require more space than thermo-couples, and great care must be given to their insulation.

Another method consists in measuring the increase in resistance of the winding itself, but it only gives the average temperature, however. This procedure is mostly adopted with direct current, great care being exercised to ensure accuracy by making use of suitable instruments and taking account of all causes of error.

By knowing exactly the temperature rise to which different parts of machines are exposed, the most efficient use can be made of space and material, whilst ensuring the greatest reliability possible.

H. Knœpfel. (D. M.)

Low-tension automatic circuit breaker for small battery trucks.

Decimal index 621. 334. 4.

A DESCRIPTION of battery trucks which have been designed and standardised by Brown, Boveri & Co. for different gauges and various powers appeared in the Revue BBC, 1918, No. 1. A considerable number of these trucks has already been supplied, and one of the designs most commonly used is Type AP 531, which is equally well suited for hauling trucks on factory premises or on industrial sidings, as for transporting goods on its platform.

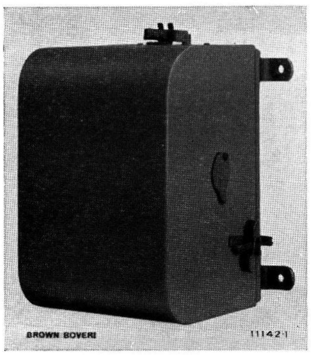

Fig. 1. — Low-tension automatic circuit breaker for battery trucks.

In order to surmount the shortcomings of fuses for battery trucks — such as the time lost by replacing blown fuses, for instance — this class of truck is now provided with an automatic circuit breaker, which has the advantage of being able to be closed again immediately after operation. The readiness for service is thereby greatly increased, especially on congested tracks, where shunting has to be carried out as expeditiously as possible. The circuit breaker must be placed within easy reach of the driver, and is therefore located on the platform, since the truck is without a cab. Protection against weather is consequently necessary, and this is ensured by a tight cover. Furthermore, this apparatus has to be of very rugged construction in order to be able to withstand the severe conditions encountered in service, e. g., impacts and vibrations, which are especially marked when crossing turntables or coupling up trucks, and to be absolutely dependable in its operation. On account of the difficulty in obtaining an apparatus of this description when these trucks were placed on the market, Brown, Boveri & Co. were obliged to design a circuit breaker which meets all these requirements. The breaker is illustrated in Figs. 1 and 2: in Fig. 1 the protecting cover is in place, whereas Fig. 2 shows the working parts. The apparatus is of double-pole design, and is connected between the battery and the traction motors. Such a construction has been adopted rather than one with two single poles, because when the two halves of the battery are connected in parallel — as is the case with trucks Type AP 531 when starting — the whole current is instantly interrupted should either half be overloaded. For this purpose, an overload release is provided for each pole, which causes the circuit to be opened independently of the load on the other pole, so that it is impossible for one half of the battery alone to supply all the current if the truck has to run for a considerable time at reduced speed with the other half cut out. Very efficient protection is thereby afforded against short circuits. The overload coils also serve at the same time to blow out the arc when the current is interrupted. The breaker is opened by a strong spring, which causes the movable contacts to be brought forward suddenly as soon as the pawl of the free-return clutch, that keeps the circuit breaker closed, is tripped either by an overload or by the driver with a special key. The free-return clutch prevents the circuit breaker from being closed as long as there is a short circuit in either of the battery circuits. The apparatus is dimensioned for opening with a maximum current of 300 A at 110 V, or 170 A at 220 V. The contacts are able to carry 150 A continuously, and the tripping current can be adjusted within wide limits by pointers, which alter the tension of the spring operating the release.

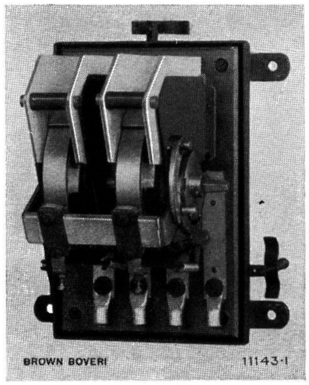

Fig. 2. — Low-tension automatic circuit breaker for battery trucks, with cover removed.

The circuit breaker weighs about 11·5 kg and its external dimensions are 235×220×195 mm. This apparatus has given excellent results in service. *M. Hiertzeler. (D. M.)*

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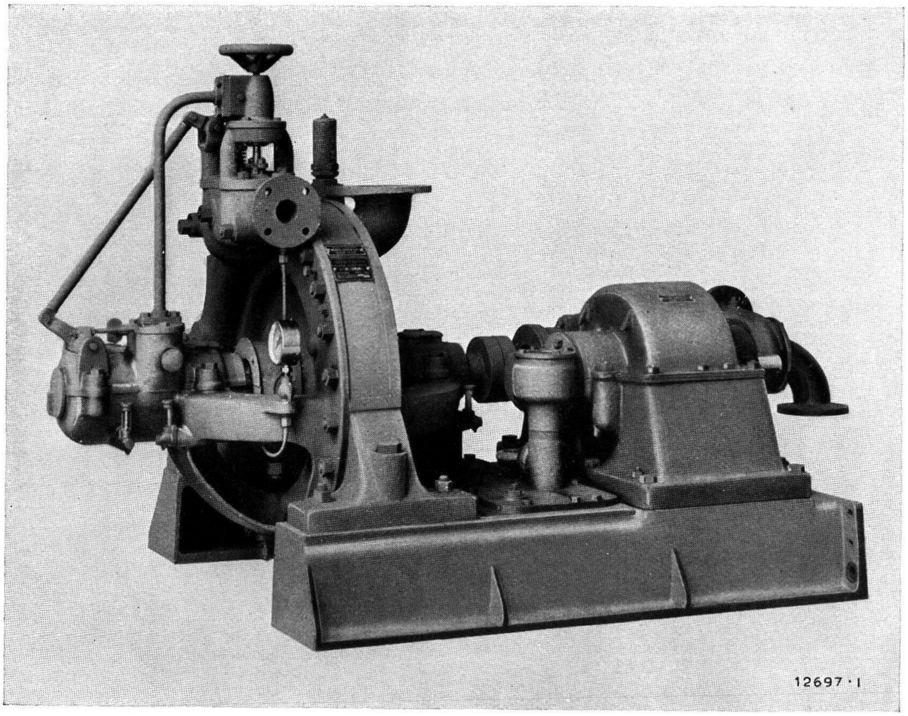

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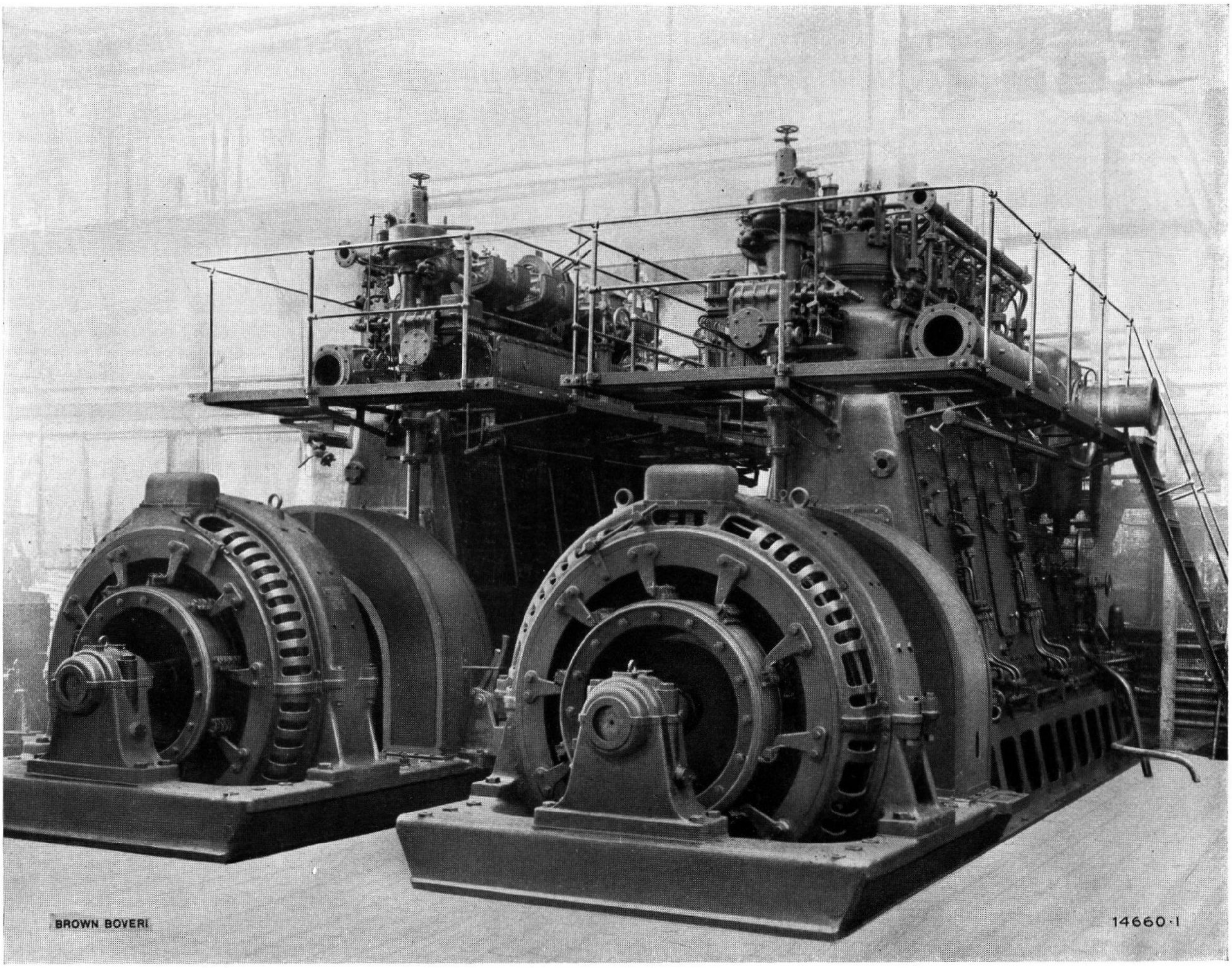

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