One of the six trolley buses at Lucerne, equipped with Brown Boveri electrical equipment.

Trolley Buses are a Popular and Economic Public Road Transport Vehicle.

Their high degree of comfort, noiselessness, and high speed have rapidly made these modern electrical municipal transport vehicles very popular with the travelling public. Other road-users appreciate their navigability and the fact that they are not tied to a fixed track, thus avoiding traffic jams. From an administrative point of view they are of interest owing to their being highly economical and requiring no imported fuels. It is these properties which have given the trolley bus its wide application in recent years. Six of these vehicles, all provided with Brown Boveri electrical equipment, are already in operation at Lucerne. In addition there are also two Diesel trolley buses which can be run either as trolley buses or Diesel-electric omnibuses, for which the Company also supplied the electrical equipment.
1.1 million volt a.c. flash-over on string of eighteen suspension insulators in the Brown Boveri high-voltage laboratory.

EXTRA-HIGH VOLTAGE TEST PLANTS for

RESEARCH INSTITUTES
INDUSTRIAL UNDERTAKINGS
OFFICIAL TESTING LABORATORIES
POLYTECHNICAL INSTITUTES, etc.

BROWN, BOVERI & CO., LTD., BADEN (Switzerland)
NEW DESIGNS OF TRANSFORMERS AND CHOKE COILS.

With the ever-increasing voltages and powers the limits of construction of the conventional designs of transformers are gradually approached. Hereafter two methods of solving future problems are described. One consists in the use of cable-like insulation with the newly developed splayed flange, thus enabling a large amount of material to be saved without increasing the specific stressing of the active parts. The other method is the utilization of radially-laminated transformer limbs with lateral yokes, which, inter alia, result in a reduced overall height, so that, as calculations have shown, a single-phase unit for a 240 MVA, 400 kV bank can be made to conform to the railway loading gauge. Both the splayed-flange and the radially-laminated core have already proved their worth in practice.

I.

In such a simple piece of apparatus as the transformer no revolutionary improvements are to be expected, since the magnetic and electrical properties of the iron core and winding have been well known for decades.

It is true that lamination manufacturers managed gradually, in the course of the years, to reduce the loss factor. This facilitated the cooling problems in connection with large cores and avoided the designer having to introduce new and complicated features in an endeavour to keep the temperature rise within admissible limits. In view of the saturation phenomena, however, it was practically impossible to increase the flux density any further. In recent years some reticence was even shown in the selection of the flux density, a consequence of modern loss evaluation. If solely the temperature rise had to be considered, the specific current density could still be considerably increased by subdividing the conductor cross-sections and by forcing the flow of the cooling agent. Here, too, however, the loss evaluation, as now practised, sets a limit, so that in many cases the current density even has to be reduced.

The last and only resource was therefore the insulation, with which it did actually appear possible to achieve something. In the case of the small distribution transformer for voltages up to about 20 kV it is true that not much is to be gained, the conventional winding clearances being not too liberally dimensioned for the natural flow of the cooling agent. A reduction of any importance is therefore out of the question, while very little material would be saved by paring the insulation.

Conditions are otherwise in the case of large transformers for voltages of 50—220 kV. Fig. 1 shows a typical section through the winding of a 150 kV transformer rated about 25,000 kVA. Bakelized paper cylinders are fitted at regular intervals in a relatively large clearance between the windings. At the ends of the windings angle rings are inserted between the cylinders, the flange of which serves as transverse insulation between the windings and the yokes. The cylinders and angle rings are spaced with impregnated beechwood, partly also with presspahn or transformer board.

The dielectric constant of the oil is about 2-2, that of the bakelized paper about 4—4-5. The electrical stressing is in inverse proportion to the dielectric constants. The oil clearances, therefore, carry twice as many kV per cm as the bakelized paper barriers. The higher breakdown strength of the bakelized paper is thus utilized neither during the insulation test nor
of course during service, as long as the oil clearances hold up. It is not until the oil clearances break down that the insulation of the bakelized paper is put to the test. The barriers have therefore generally been so dimensioned that they could stand up to the full test voltage for a short time alone. In calculating the distance between the windings which would enable the oil to stand up to its stressing, however, the configuration of the field had to be taken into consideration.

As a result there was far more oil between the windings than was actually necessary for cooling purposes. The higher the test voltage the more this winding clearance became a criterion for the dimensioning of the whole transformer with regard to the leakage voltage. We will revert to this point.

A glance at extra-high-voltage cable insulation has probably induced many a designer to attempt to employ oil-impregnated paper as main insulation for transformers. The selection of a suitable type of paper and the preparation of the insulation would doubtless have presented no difficulties by taking advantage of experience gained with oil-filled cables, as long as the less favourable conditions in transformers were taken into consideration by carefully dimensioning the winding clearances. However, the configuration of the field at the ends of the windings led one to anticipate heavy tangential stresses and, in consequence, surface flash-overs around the ends of the paper cylinders. There was no room for a fitting such as a cable sealing box in the space at the end of the winding. A practical arrangement had therefore first to be found which would prevent the surface discharges around the ends of the paper cylinders and which could also be well adapted to the design of the transformer.

A solution of this problem is provided by the splayed flange cylinder.

Selected insulating paper as wide as the insulating cylinder is long is wound on to a relatively thin bakelized paper cylinder as former. The diameter and thickness of the latter are chosen so that the space between the low and high-voltage winding is entirely filled up with the exception of a small clearance. Once the high-voltage winding has been fitted narrow strips of the paper continually formed by scoring the end of the cylinder are bent over radially outwards around the protecting ring on the front of the winding. The scores are displaced from layer to layer so that the paper strips overlap well. From time to time the layers of paper are distanced by means of spacers cut from insulating material such as transformer board. This splaying gives the end of the insulating cylinder...
the necessary strength against surface flash-overs. As a rule all of the paper is bent over to form a splayed flange measuring axially many times the radial thickness of the paper cylinder.

Fig. 3 shows the difference between the surface discharge voltages at the point of advancing discharge with splayed and non-splayed insulating flange. On the back of the left-hand flange the advancing discharge is forced forward by a constant, strong tangential field component until it finally unites with the surface discharge coming from the outer edge of the high-voltage protecting ring, and flashes over. In the case of the splayed flange on the right the tangential component rapidly dies away and entirely vanishes a short distance from the end of the low-voltage winding. The short tail end of the surface discharge can now be taken care of by a protecting ring or the like, since the remaining short distance to the end of the winding is sufficient for the low-voltage winding. The arrangement is then quite free from surface discharges, especially as now no discharge approaches the outer edge of the high-voltage protecting ring from the other side.

The form of the splayed flange results in the end of the paper cylinder becoming very thick. Since the paper runs from the main body of the cylinder into the flange, joints are avoided and the high breakdown strength of the oil-impregnated paper can really be utilized. Compared to cable conductors and lead sheathing the winding surface is inhomogeneous, which renders it advisable to select the insulating walls thicker than for cables to offset local stresses on the edges of the wire which might cause the surface of the cylinder to break down during the voltage test. The breakdown strength of the paper cylinder is therefore very high even when transient over-voltages or surges occur.

As exhaustive tests have shown, if the paper cylinder is correctly dried and degassed the angle of loss and temperature coefficient are sufficiently small to keep the critical voltage so high that no breakdown of the insulation is to be feared due to heating effects. Compared to cable insulation the stressing is nevertheless slight which enables the cylinder to be provided with one or more very thin oil ducts for extremely high working voltages, thus resulting in a critical voltage of two or more times that otherwise obtainable.

The introduction of the splayed flange cylinder has enabled the distance between the high and low-voltage windings to be reduced to less than half. The reduction in the weight of the oil required, the lower costs for the fixed insulating material, and the smaller dimensions of the oil tank, directly resulting from this feature are of far less importance than the indirect effects of the reduction of the width of the leakage field channel.

The percentage leakage voltage can only be varied within narrow limits in large transformers. Consideration of the voltage drops and rupturing capacity prevents too high or too low an impedance voltage. Parallel operation renders adaptation to other units necessary. As a result, the leakage voltage, which in the case of large transformers is practically the same as the impedance voltage, is generally a prescribed narrowly limited value.

The percentage leakage voltage is the relation between the leakage and main fluxes. With the conventional winding spacing, i.e. with the oil barrier insulation, this ratio would have become much greater than desirable if the designer had not increased the cross-section of the core. Due to this fact, and especially in the case of very large units, this resulted in a disproportion between the weight of the core and

1 See H. Hartmann: "Paper as High-voltage Insulating Material" and F. Beldi: "The Insulation of Machines and Transformers" on pages 235 and 224, respectively, of Nos. 9/10 of the Brown Boveri Review for 1943.
winding. To illustrate this point it may be mentioned that a 36,000 kVA, 11/252 kV transformer built in 1928 had an iron/copper weight ratio of 6:1. A more satisfactory ratio would be between 2 and 3:1.

The splayed flange enables this optimum ratio to be approached or completely attained, even for extra-high voltages. Where low unit ratings are concerned the practical effect of the new insulation is still considerable.

As an example the following comparison of two transformers supplied for the same plant and to exactly the same specifications is given. The second, with the

Comparison of a 10,000 kVA transformer with old type insulation and a 20,000 kVA transformer with new type insulation.

Forced cooled three-phase oil-immersed transformer.

<table>
<thead>
<tr>
<th>Year of construction</th>
<th>1931</th>
<th>1940</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation</td>
<td>old</td>
<td>new</td>
</tr>
<tr>
<td>Rating</td>
<td>10,000 kVA</td>
<td>20,000 kVA</td>
</tr>
<tr>
<td>Ratio</td>
<td>144,000</td>
<td>6835 × 10 × 85.5</td>
</tr>
<tr>
<td>No-load losses</td>
<td>40 kW (31 kW)</td>
<td>33 kW</td>
</tr>
<tr>
<td>Copper losses</td>
<td>86 kW</td>
<td>152 kW</td>
</tr>
<tr>
<td>Weight without oil</td>
<td>41 t</td>
<td>44 t</td>
</tr>
<tr>
<td>Weight of oil</td>
<td>25.3 t</td>
<td>24 t</td>
</tr>
<tr>
<td>Overall weight</td>
<td>66.3 t</td>
<td>68 t</td>
</tr>
</tbody>
</table>

1 Converted for the quality of the laminations of the new transformer

new insulation, has twice the rating of the other. Special note should be made of the no-load losses and the weight of the transformer and oil. The superficial area occupied by the more powerful transformer is practically the same as that required by the unit with only half its rating.

The small dimensions of the new 47,500 kVA transformers built into a rock cavern at the Innertkirchen Power Station are particularly striking compared to the 26,000 kVA outdoor transformers (Fig. 4) supplied in 1928. The weight of the new transformers, including the oil, is only 75% of the old one, while the output is 83% greater. A further notable feature is the direct connection of the 150 kV oil-filled cable to the transformer with the built-in disconnecting links. Fig. 5 shows the new transformer with the four built-on cable trifurcating boxes.

Fig. 6 illustrates the manufacture of the first flange of the paper cylinder. When assembling the active part in the works the time taken in making the second flange around the pushed-on high-voltage winding represents no loss, since the main insulation is then complete. The same remark applies to the happily rare case of a repair.

The splayed flange insulation of the described simple and reliable type naturally requires a more or less stable winding. Pre-aging, as adopted for windings with heavy wire insulation for some long time, is therefore always carefully applied here.

Recapitulating:

The exceptionally large savings in material and the improvements achieved in these large trans-
The ever-increasing transformer unit ratings and transmission voltages have so far been met with the conventional forms of core. In Europe the three-limbed vertical core has become standard (Fig. 7). Since round coils stand up best to the mechanical forces set up under short-circuit conditions the cross-section of the limbs was made to approach the circular form by more or less finely stepping down the width of the laminations. The yoke laminations must more or less correspond to the widths of the limb laminations, since care must be taken to keep the magnetic lines as far as possible within the plane of the laminations to avoid the heavy eddy-current losses caused by transverse fluxes.

Transverse ducts enabled large cores to be satisfactorily cooled. Care must only be taken that a lamination width concomitant with the specific iron losses is not exceeded between the cooling ducts. It is this fact which determines the number of cooling ducts.

From a manufacturing point of view there is no reason why larger and larger iron cores of the conventional type should not continue to be constructed.

It is only the transport problem which becomes acute. The chief difficulties are caused by the height of the iron core with its feet and clamps, and therefore of keeping the oil tank within the railway loading gauge. As a makeshift transformers have been more or less dismantled for transport purposes for some time past. The higher system voltages rise, however, the more complicated does this work become. For works tests at the manufacturers', transformers had to be completely assembled and all insulation, including the oil, well dried and degassed. After the test the thick paper insulation on the high-voltage leads had to be cut open and the joints unsoldered. Assembly on site frequently took weeks. During this work air and moisture again found ingress into the insulation. A second, comprehensive drying and degassing process had therefore to be carried out. Erection rooms and equipment on site were correspondingly large and costly.

No pains were spared in an endeavour to eliminate this time-wasting and uneconomic work by evolving designs conforming to the railway loading gauge, attention being paid in particular to the height of the yokes.

In the case of the conventional three-limbed core the height of the yokes is approximately the same as the diameter of the limb (D in Fig. 8). Where very large units with a limb diameter of 1 m are concerned, therefore, the two yokes alone represented 2 m of the maximum available height of 4·3 m. Feet and clamps, the bottom and cover of the tank, and possibly an oil conservator take up a further 0·5—0·8 m of the available height. The remainder, i.e. 1·5—1·8 m, would definitely no longer suffice for the length of the limbs of this large unit.

The remedy here was the five-limbed core. The correct geometrical distribution of the fluxes in this core entails only a \(\sqrt{3}\) times smaller cross-section than in the limbs, i.e. a yoke height of about 0·58 D. For single-phase transformers the four-limbed type or the single-limb wound shell type with 0·5 D as yoke height can be adopted.
Fig. 8. — Comparison of yoke heights of various types of cores of three-phase (top) and single-phase transformers (bottom).
Left: With these designs the yoke height is equal to the limb diameter.
Right: Designs giving a considerably lower yoke height.
A further reduction of the overall height can be achieved with the Brown Boveri radially laminated core (cf. Fig. 10).

Even in this case, however, the designer is still restricted where large units in the 100 MVA range for extra-high voltages are concerned. Interleaving of the limb and yoke cores, which enables the yoke plates to be dispensed with, mitigates the difficulties still further, so that the Brown Boveri concern actually succeeded in building three-phase mobile transformers with tertiary winding for a high voltage of 220 kV having a rating of 100 MVA or a type rating of over 140 MVA. In this case the transformer forms the bridge between the bogies of the transport truck (Fig. 9). The loading gauge is thus fully utilized in the vertical direction. And if voltages of 400 kV and higher transmission powers become the vogue, is a satisfactory solution to be found? The reply is definitely in the affirmative. At the outset it will be agreed that a type rating of considerably more than 150 MVA would impose excessive demands on a rail vehicle. The three-phase transformer must therefore here give way to a bank of three single-phase units, which provides a good opportunity to employ a type of core which has hitherto not found application in the construction of large transformers.

We thus come to the radially-laminated core with annular magnetic return circuit (Fig. 10). The idea of using laminations of stepped-down width arranged in sectors radially and thus forming a really circular limb and return magnetic circuit connected to or interleaved with the shell was known from patent applications of Berry forty-five years ago. The technology of the radial core, however, was not discovered, so that it attained no importance at the time. The development of electric welding has now enabled this to be realized.

Since the magnetic flux no longer passes through the front of the limb a closed iron ring can be welded on the active laminations there, thus giving a stable limb construction. If the return circuits are combined into U-shaped packets, connecting links can also be welded on to their upper and lower end surfaces. As shown in the sketch this enables the return circuit yokes to be conveniently pressed on to the limbs by means of non-magnetic bolts, thus economizing material. This gives the advantages of the butt joint core. Care must now be taken that no connection takes place across the layers of laminations on the inner surfaces of the U-shaped packets, which ensures no parts of the magnetic fluxes being short-circuited.

The ratio of active cross-section to circular surface, the space factor, is about the same as with the earlier transformers.

The individual limbs are of different cross-section, but the surface of the limb laminations serving to
transfer the flux to the yoke laminations is the same for all limb laminations. It is true that this results in a compensating transverse flux from the large to the narrow limb laminations. Seeing this compensating effect only takes place in very thin packets of laminations, very slight eddy-current losses occur, as has been proved by calculation and tests. These are more than offset by the radially-laminated limbs not being affected by bolt-holes, while the return circuit cross-sections are allocated to the limb lamination sectors absolutely uniformly. The shell surface of the limbs has a number of small insulating gaps. The circulating voltage of each single packet of laminations is only one-twelfth to one-eighth of the turn voltage, according to the number of yokes. Bolt short circuits are eliminated.

There are thus a number of reasons why iron troubles are less to be feared than with the conventional core.

Now comes an important point: Since the flux transfer from the limbs to the yokes takes place over a surface with the largest circumference as base, a yoke height of only about 0.2 times the limb diameter is necessary. Assuming a limb diameter of 1 m, no less than 0.6 m is gained for the active limb length compared to the conventional four-limb shell core.

The mean path of the flux is shorter and the weight of iron thus favourable. Moreover, the U-shaped return circuit yokes also serve as winding support.

Further, the cylindrical form of the whole yoke and core system results in a very advantageous basic type of oil tank, a cylindrical case. No heavy strengthening irons are necessary, while empty spaces are avoided. The transformer thus requires very little oil. Careful calculations have shown that three single-phase transformers of this type are only slightly more expensive than the corresponding three-phase transformer for large outputs. (A bank of three single-phase transformers of the conventional type usually costs 20—30% more than a three-phase unit, for which reason the latter has held the field in Europe.) Whereas large single-phase transformers have hitherto been most advantageously built with two wound limbs, one only is preferable in the case of the radial core. The bank of three transformers has therefore only three wound limbs instead of six. Apart from the few additional design parts required this is the reason why the new arrangement proves so advantageous at high voltages, especially when the extra-high-voltage system is operated with solidly earthed neutral point, so that the single-phase transformer only requires one large bushing. Fig. 11 shows a unit for a 240 MVA bank of transformers for a 400 kV system, with the transport wagon. (Here, however, only a project.)

Is the sphere of application of radially-laminated cores restricted to large plants? When the advantages are set against the slight drawbacks — a little
more space required and in some cases slightly increased no-load losses compared to a three-phase transformer — one is obliged to come to another conclusion. The new design is particularly interesting for outdoor erection even for outputs down to as low as 30 MVA three-phase output, apart from a series of special applications. If a standby is considered necessary one single-phase unit suffices, i.e. a third of the power.

Now let us turn our attention to a number of illustrations of this design already constructed:

Fig. 12 shows a choke coil rated 25 MVA, 150 kV. In the case of transformers only the suspension device, which here also has to serve for clamping the limb sections on the gap inserts, has a slightly different appearance.

Fig. 13 portrays the core for a small motor-coach transformer rated 410 kVA, 16⅔ cycles, in its oil tank. The round form of the tank is somewhat obscured here through the extension visible at the rear for the many secondary bushings, and the radiators arranged on the side to take advantage of the windage

of the vehicle. The transformer is mounted under the floor of the coach and is therefore of particularly low design. Due to the very low height of the yokes vertical limbs were able to be retained here, an advantageous arrangement from the point of view of the winding.

Fig. 14 depicts the iron core of a large locomotive transformer for high-voltage control. The lower part takes the regulating winding with the numerous tappings, the top part the main windings without tappings. The cut-away section at the front serves for bringing out the leads.

This and the previously illustrated smaller design are characterized by very low weight and the small amount of oil required, very valuable items where modern rail vehicles are concerned. While on the subject of traction transformers the opportunity is taken to show a design with rotatable radially-laminated limbs and rotatable, bare secondary winding for current collection by rollers, for stepless regulation of the voltage (Fig. 15).

In special cases the design with two radially-laminated limbs and transversely laminated yokes may be of advantage (Fig. 16). The height of the yokes is just as low here as with the design with annular return
Fig. 17. — Transformer rated 23 MVA, for high voltage of 150 kV, with three radially-laminated limbs in triangular formation and transversely laminated yokes.

Fig. 18. — Core of choke coil with parallel laminations and a multiplicity of small air gaps.

Fig. 19. — Adjustable limb stub with radial laminations on rotatable threaded spindle for a choke coil with stepless regulation.

magnetic circuit. This design may, for instance, prove useful for large mutator plants. The pressing on of the halves of the yoke is particularly well illustrated in the engraving.

A three-phase design with three limbs in triangular formation is also possible (Fig. 17). A 30 MVA unit has already proved its reliability over a long period. The transformer illustrated, which has a rating of 23 MVA with a high voltage of 150 kV, has now also turned out to be a reliable piece of apparatus after the initial shortcomings — which, however, had nothing to do with the radially-laminated core — had been overcome. The yoke plates each consist of three sectors of 120°, insulated from each other at their joints. The oil filling only weighs 8·5 t, manifestly a milestone on the way to the low-oil-capacity transformer!

With the triangular arrangement marked additional losses unfortunately occur due to the local rotation of the magnetic field in the centre part of the yokes. For this reason the author's company prefers splitting up the three-phase transformer.

The radially-laminated core has quite special fields of application in the regulating transformer with displaceable winding and the regulating choke coil with variable air gap. We will briefly consider these.

In the case of the conventional, parallel-laminated core of large choke coils (Fig. 18) the air gap always had to be split up into a very large number of small gaps. The lateral leakage lines partly leave the edges of the packs of laminations transversely and cause greater eddy-current losses the wider the gap. The latter is usually less than 10 mm. In view of the multi-
Fig. 20. — Core with adjustable radially-laminated limb stubs, annular return magnetic circuit, spindle bearings, and operating mechanism, for an arc suppression coil with stepless regulation.

Fig. 21. — Arc suppression coil with stepless current regulation and built-on mechanical position indicator.

Fig. 20. — Core with adjustable radially-laminated limb stubs, annular return magnetic circuit, spindle bearings, and operating mechanism, for an arc suppression coil with stepless regulation.

— in such a manner that the limb stub can move axially with only a slight clearance in the transverse yokes (Fig. 20).

A large number of such choke coils in the form of arc suppression coils with ratings up to 5000 kVA and over and current regulation up to 1:10 have been in service for a long time. Air gaps of nearly 1 m have been obtained without any trouble. In the design of the winding great attention must be paid to the large lateral leakage. It is here that the radial

Fig. 21. — Arc suppression coil with stepless current regulation and built-on mechanical position indicator.

core proves its insensitivity to leakage fields and its stability where magnetic forces are concerned. It gives a really round design, and not only for the oil tank! — The mechanical position indicator mounted on the progressively variable arc suppression coils permits the adjusted coil current to be read off (Fig. 21). A control for the motor operating mechanism, to enable the air gap to be automatically adapted to the momentary network conditions, has already been developed.

This brief survey of a number of designs shows that there is still room for improvement in transformer construction.

Translation of paper read at the Transformer Meeting of the Swiss Association of Electrical Engineers (SEV) on the 13th July, 1944, at Zurich by A. Meyerhans, Baden (E.G.W.)
EXCHANGE OF ENERGY BETWEEN RIGIDLY OR VIRTUALLY RIGIDLY INTERCONNECTED, BUT NEVERTHELESS INDEPENDENTLY OPERATED SYSTEMS.

The possibility is investigated of interconnecting two independently operated systems of different frequency in a simpler manner than with the conventional flexible sets incorporating rotor-fed induction machines or grid-controlled mutators. The arrangement suggested hereafter makes use of the so-called frequency-power regulation, which has already been tried out in practice and possibly has a still wider field of application before it.

In order to enable an exchange of energy to be made between two systems operated at different frequencies the networks in question must be interconnected by suitable means.

A little reflection will prove that the assumed difference in the rated system frequencies is not so important as might be supposed at the outset. Assuming that the ratio between the frequencies, i.e. equal to that of the rated frequencies, remains constant, the only difference between the cases of systems with similar and different frequencies lies in the type of interconnecting unit to be employed, i.e. in the first case transformers and in the second sets of synchronous machines. The first case is so common that it is rarely considered as constituting an interconnecting unit at all. Its superiority over the second class of equipment lies on the one hand in the lower cost referred to the specified continuous rating and on the other in its greater momentary overload capacity. The load peak which a transformer can cope with is determined chiefly by its magnetic leakage; it is the greater the smaller the reactance, including that of the associated length of line. In the case of synchronous machines the limit of stability is determined by the magnet-wheel angle involved for the transmission of the power. The larger this angle is in normal service the smaller will be the margin between it and the value of 90°, from which point onwards the torque begins to drop off, notwithstanding an increase in the magnet-wheel angle. Moreover, when load surges occur the over-swinging of the magnet wheel beyond the point of equilibrium corresponding to the new load must also be taken into consideration. The capacity of the interconnection unit, therefore, cannot be increased here simply by reducing the magnetic leakage, but it must at least be possible momentarily to reinforce the excitation, if a larger type of machine has not even to be selected.

These conditions, which can be computed mathematically, must be carefully checked over in each individual case. The smaller the exchange of power for which the converter is actually to be dimensioned (compared to the power of the connected systems), the more it must be over-proportioned to allow the necessary margin for dynamic disturbances.

While such stability problems can be solved — at least partially — by employing sufficient financial means, the operating questions which arise in connection with network interconnection demand further detailed technical consideration. An example of operating requirements is to be found in the article by A. Dudler on the Swiss Federal Railways converter set at Seebach, which has to meet the four following requirements:

1. Transmission of a constant power (8600 kVA), adjustable in magnitude and direction with a given or variable power factor, independent of frequency fluctuations in both systems.

2. Transmission of power as a function of the frequency in one or other of the systems. (The relation of the frequency to the power must have a similar characteristic as that of turbine sets. It manifestly meets practical requirements when always the system whose conditions are influencing the regulation takes an increased power from the other system when its own frequency decreases.)

3. Supply of an independent single-phase railway district.

4. Phase advancer operation of the two main machines either alone or both together.

From the second specification it is clear that the owners of the two systems (Swiss Federal Railways and Nordostschweizerische Kraftwerke) reserve to themselves the right to operate their networks with frequencies deviating in different degrees from the rated value. In consequence the interconnecting unit cannot take the form of two synchronous machines, but at least one of them must be of the asynchronous type. In the example quoted the Swiss Federal Railways machine is a synchronous and that of the Nordostschweizerische Kraftwerke an asynchronous one. In this case the asynchronous machine had to be combined with a Scherbius auxiliary machine (here directly coupled), otherwise it would not have enabled requirements 1

1 Bull. SEV, 1934, No. 3, p. 65.
and 4 to be met, while requirement 2 could not have been fulfilled economically with the specified slip of 4% with the interconnecting unit carrying full-load. This is an example of so-called flexible interconnection. (Flexible interconnection can also be achieved with mutators\(^1\), but will not be gone into here.)

As will be readily seen from the foregoing or in greater detail from the literature quoted, the flexibility of interconnecting equipment is only acquired at great expense. The designer will therefore ask whether it would not be possible to meet the requirements of practical service with rigid interconnection of the systems. To this end the ratio of the frequencies must be kept constant, i.e. equal to that of the rated frequencies. This ratio must naturally be a rational number in order to be realized on both synchronous machines with integer pole pair numbers.

Whereas in the case of interconnection by transformers the rigidity always had to be tolerated and, as experience has shown, proved no real obstacle when suitable methods of operation were adopted, the question has hardly ever been considered where systems of differing rated frequencies are concerned. The advent of combined power and frequency regulation, however, furnishes a solution to this problem\(^2\). Let us see how the four above-mentioned requirements can be met for the case of rigid interconnection with its help.

We will begin with item 4. If the rated frequencies are the same on both sides and advantage is taken of this fact to interconnect the two systems by means of transformers, the production of reactive power in the interconnecting unit naturally does not enter into consideration from the outset. Any reactive power machines which may prove necessary would then be installed at other points which for different reasons may be more convenient. If, however, the interconnecting set comprises two synchronous machines they can each naturally generate reactive power independently of the other within the limits of their rating. The only question is whether they are not also loaded by active power, and where this is the case with the established programme there is no other course but to restrict the generation of reactive power correspondingly. What happens, however, when uncontrollable and unintentional active loads occur? Assume that a sudden excess of power occurs in a system due to consumption falling off. This would tend to cause the frequency in this system to rise and as a result the magnet wheel of the synchronous machine of the system interconnecting unit would be advanced slightly. The interconnecting set then therefore transmits compensating active power and should this condition last for long its reactive load would have to be correspondingly reduced. This conforms entirely to the fundamental function of a rigid interconnecting unit which from its very nature tends to suppress all frequency differences between the two systems at the very outset by transmitting power. Since the power values coming into consideration are inherently unlimited, the relatively small overload

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capacity of the synchronous machines in this connection is a real hindrance.

A second risk of unintentional active power transmission would arise when several supply points exist and the systems to be interconnected have their terminal voltages mutually displaced in phase at one point of supply. Even in the case of transformer interconnecting units, however, a suitable mutual phase displacement of the terminal voltages is required, and undesired distribution of the power is compensated by means of quadrature regulating transformers. Such transformers could also be used to influence the phase displacement of the voltage at the point of supply where rigid interconnection by synchronous machines is concerned. In following this reasoning, however, we have already strayed from requirement 4, phase advance operation, to requirements 1 and 2, regulation of the supplied power.

It will be clear that the flow of active power through an interconnecting unit composed of two synchronous machines can only be influenced if the frequency of the system required to supply the energy is slightly raised above that of the other system for a short time to give the terminal voltage of the supplying system the necessary angle of lead. This would seem greatly to restrict the freedom of operation of the two systems. It will now be endeavoured to show that the consequences can be made acceptable by applying combined power and frequency regulation.

Assume, therefore, to begin with, that a constant power \( P_{12} \) is to be transmitted from system 1 to system 2. In contradistinction to flexible system interconnecting sets it is not necessary to regulate the interconnecting unit here, since, as mentioned above, the flow of power can only be influenced by adjusting the mutual phase displacement of the two systems. For one of the systems therefore absolutely rigid frequency regulation is now out of the question. In point of fact, however, such regulation is never actually possible in view of the static characteristic, which with the proposed equipment is adjustable within wide limits, will be determined by the requirements of practical service. The larger the value of the static characteristic the quicker will the supplied power be regulated. On the other hand the load fluctuations of the generator sets will be greater.

The question as to whether all machines should be equipped with frequency-power regulating gear is of no great importance. Fundamentally, this would be the correct policy, while the cost of a complete equipment will always be much less than that of the flexible interconnecting sets required hitherto. If only individual sets are provided with frequency-power regulation, care will have to be taken that their effectiveness is not impaired by the regulation of the other machines. Even where these other sets are concerned, therefore, regulation to an absolutely constant frequency will be out of the question, but fixed powers can be allocated to each machine. A proviso, however, is that the machines provided with frequency-power regulation are large enough to maintain the frequency not only at a constant value, as is usual for a frequency regulating machine, but to the above-mentioned static characteristic as a function of the supplied power. It is of course not necessary for the machines provided with frequency-power regulation to furnish the whole of the required power themselves; on the contrary, this can be shifted over on to some of the other machines by increasing the fixed amounts of power allocated to them.

All that has been said for system 1 naturally also applies to system 2. No matter whether only individual machines or all of the machines in the latter are provided with frequency-power regulation they will tend to maintain the supplied power at the specified values, which naturally facilitates regulation of system 1.

Requirement 3 can be easily fulfilled with a set of two synchronous machines. It is self-evident that a synchronous machine driven by any means is capable of supplying any system as generator alone without any new frequency or load distribution problems being involved.

From the foregoing it will be clear that the restriction of operation of systems interconnected through synchronous-synchronous converters, referred to at the beginning of these notes, can be mitigated by applying frequency-power regulation. The important problem of stability has already been touched upon. For full details the reader is referred to Gaden and Keller. It should, however, be pointed out that the design of the frequency-power equipment is of vital importance and that such a problem can only be solved with direct-acting regulating equipment for the supplied power. It cannot be contested that a flexible converter set consisting of one synchronous and one

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asynchronous machine is to a certain extent superior on the score of stability. Its use in connection with frequency-power regulation is by no means impossible. If an auxiliary commutator machine is dispensed with the interconnected systems must operate with a certain relative frequency difference as a function of the exchanged power. In the interests of stability it may be worth while tolerating this drawback, especially when the rating of the converter is low compared to the total system power. A disadvantage is naturally the fact that the reactive load can no longer be regulated on the side on which the ordinary asynchronous machine is installed.

On the other hand this gives the simplest control for starting the set. With a synchronous-synchronous set conditions are a little less favourable, since if the inevitable high reactive load surges occurring with asynchronous starting cannot be tolerated, the set must be equipped with a special starting motor. The synchronous machine connected to the same system can then be switched in with the help of a rapid synchronizer which limits the power surge.

The switching-in of the other synchronous machine of the converter set can also be advantageously effected with such an equipment. For the sake of safety, however, this must be supplemented by frequency compensating control gear, which is readily possible since the converter is connected with the turbines of at least one group of systems through the frequency-power regulating equipment.

The cycle of operations can be readily followed on the diagram on page 102.

Where a synchronous-synchronous set is concerned starting is effected with a separate motor Da (see diagram) fed from the a.c. side. This may comprise a conventional slip-ring motor with the same number of poles as the main machine and enables speed regulating equipment to be dispensed with for paralleling purposes. The paralleling operation is taken care of by the rapid synchronizer SSI with the slip entailed by the starting motor. As shown in the diagram the other synchronous machines are also paralleled by a rapid synchronizer. Under certain conditions, i.e. upon the occurrence of faults, the frequency difference may exceed the admissible range of \( \Delta f = \sim 1.2\% \) required for high-speed synchronizing. In this case, however, the remote regulating equipment is available which permits the frequency of system A to be controlled from the converter. The frequency of the synchronous machine C is then transmitted over the control apparatus F instead of the supplied power P to the point of regulation of system A.

If the main machine of the converter on the same side as system B is of the asynchronous type it may be possible to dispense with the special starting motor and to employ the main machine itself for starting purposes. With this arrangement, however, design difficulties would have to be overcome. This applies particularly where high-power asynchronous machines are concerned, since in view of the slip-ring and short-circuiting gear the rotor standstill voltage cannot be selected as high as would be desirable to cope with the current. These conditions therefore involve the use of a starting transformer. Since, moreover, as has already been shown, the regulation of the supplied power also entails certain departures from standard practice to maintain the frequency, synchronous-synchronous interconnection is doubtless preferable for the method of system regulation envisaged here.

If towards the end of these notes the authors have emphasized certain difficulties which are encountered in the realization of the idea put forward, it was not with a view to overstressing them. Every technical innovation involves the solution of certain individual problems. From experience no unsurmountable obstacles are encountered as long as the original idea on which the whole scheme is founded is sound. The authors are convinced that this assumption also applies in the present case.

(MS 606) Th. Boveri and R. Keller. (E. G. W.)
TRANSMITTING STATIONS FOR POLICE FORCES AND FIRE BRIGADES.
THE PRESENT STAGE OF DEVELOPMENT AS ILLUSTRATED BY PAST AND RECENT EXPERIENCE.

The Company's high-frequency department has been studying the design and construction of wireless transmitting stations for police forces and fire brigades for a number of years. According to prevailing conditions, short or ultra-short waves, both of which are excellently suited for such purposes, have been applied with great success. Plants supplied by the Company are mentioned in this article and special reference is made to the employment of frequency modulation for ultra-short-wave operation, by which means maximum intelligibility is obtained for two-way communication due to the low level of interference.

Wireless equipment specially suited for employment by police forces and fire brigades was already included in the first programme laid down for the design and manufacture of high-frequency material. Such equipment, supplied by the Company, was used by the municipal police force of Zurich for the first time for the control of traffic during the Swiss National Exhibition in 1939.

The initial successes were so striking that they acted as an inducement to proceed with the development of wireless stations for police forces and fire brigades along systematic lines. The result is that equipments fulfilling any demands made on them can now be supplied for all cases occurring in everyday practice. The police wireless station in Zurich has been systematically extended in the course of time and recently a wireless station for the municipal fire brigade has been added to it, this being possible without appreci-
Fig. 2. — Police patrol car.
The frequency-modulated U. S. W. wireless equipment, assembled from a number of individual units and working with a small inconspicuous aerial, allows of continuous two-way telephonic communication with the headquarters' station during the whole journey, thus considerably simplifying duties.

Fig. 3. — Fire-engine with wireless installation for two-way telephony.
The fire-engine is fitted with the same type of U. S. W. equipment as the police patrol car and it is always possible, even while travelling, to establish contact with headquarters or with another mobile unit by way of the wireless control room at headquarters.

Fig. 4. — Parked police cars with U. S. W. wireless equipment.
The wireless equipment is the same as that of the patrol car shown in Fig. 2.
This installation for two-way telephonic communication is also of the same design as that mentioned in the text of Fig. 2. Without wireless communication, cooperation with headquarters would be impossible. Wireless communication enables requests for assistance or reports to be transmitted at any time.

The officer in charge of the car can be called up from headquarters by means of the loudspeaker. As soon as he takes up the telephone, the loudspeaker is automatically disconnected and a two-way conversation can be conducted in the same way as with the normal telephone.

In the case of the police wireless station in Zurich, the stationary installation at headquarters consists of a short-wave transmitter with an output of 125, 250 or 500 watts, which is remote controlled from the central control station. For the various mobile stations installed in motor-cars and motor-boats, 8-watt frequency-modulated ultra-short-wave stations are used. In addition, light portable short-wave receivers are provided for individual policemen on beat. In order to ensure reliable wireless communication with mobile stations in a distant quarter of the city, a

Any desired number of men provided with these receivers can be called up at any time from headquarters by means of a buzzer. New orders can therefore be given quickly and many a useless walk avoided.
remote-controlled receiving station is installed to establish communication with headquarters from certain points where propagation of the waves is not favourable. The smallest output of the stationary transmitter mentioned above, namely 125 watts, is used normally for police work, while the output of 500 watts on a definite wavelength is provided for announcements to the public living within a certain radius from the city of Zurich. Experience gained from the operation of this installation over a period of several years has shown that the adoption of a two-wave wireless communication system, using short waves for the central control station and ultra-short waves for the mobile stations, provides excellent two-way telephony and has proved to be reliable and suitable in every way. The small portable receivers are also highly esteemed by the police authorities, since they enable isolated policemen to be reached at any time and new orders to be issued to them. The choice of ultra-short waves and frequency modulation for the mobile stations has, apart from the extremely low level of interference, the additional advantage that only very small aerials, which do not attract attention and which have a short length corresponding to $\frac{\lambda}{4}$, have to be mounted on the vehicles.

Quite recently, for example, wireless equipments employing exclusively ultra-short waves were supplied to the municipal fire brigade of Basle. In this case, both the transmitter of the headquarters station and also the mobile transmitters operate with ultra-short waves in close proximity to one another in the band below 10 m. Frequency modulation, as used for the mobile ultra-short-wave units in Zurich, was again successfully applied. Experience has shown that disturbances due to motor-cars, radio therapy apparatus, atmospherics, etc., can be reduced to a minimum by the adoption of good-quality frequency modulation. Sufficient emphasis cannot be laid on this fact in the case of a municipal wireless network, since all stations involved would only have a limited value if good wireless communication were not possible at all times. With regard to the employment of wireless
communication for police forces and fire brigades, the present-day situation is generally as follows:

**Police Wireless.** A modern reliable wireless communication system will be indispensable for police forces in future. In earlier days the police forces were quick to take advantage of the service offered by the public telephone system and to-day wireless communication represents an urgently required complementary service. In all those cases in which wires can no longer be laid, it is often possible to combine the police and fire-brigade wireless stations as has been done in Zurich. Various interesting details of wireless installations for police and fire brigades are contained in the texts of the photographs illustrating this article, and it is therefore not necessary to repeat them here. In conclusion, it is perhaps permissible to draw attention once again to the invaluable assistance that such wireless communication systems can provide for police and fire brigades.

(H. Labhardt. (D. S.))

NEW TYPES OF SMALL TURBINES FOR DRIVING MARINE AUXILIARIES.

After the war water-tube boilers will be frequently used also for small merchant vessels. The resulting increase in pressure and superheat, as well as the necessity of feeding these boilers with a condensate free from oil make it necessary that all ships' auxiliaries should be driven by turbines, if they are not electrically driven. Newly developed types of small turbines having a very simple construction are described: these turbines operate safely at all steam conditions encountered in practice and their operation and supervision make no greater demands on the crew than a simple electric drive.

A little more than ten years ago a series of lighting turbo-sets for powers of 0.5—20 kW1 was brought on to the market. As a result of their safe operation and simple attendance they have been employed in considerable numbers on steamships and as emergency sets for industrial plants. During the last few years, Brown Boveri have constructed a new and also very simple series of auxiliary turbines for driving all kinds of auxiliaries, as many as possible of the constructional features of these well-tried lighting sets being incorporated in these new designs. Great importance has been attached to safe operation, low steam consumption, small weight, and simple dismantling. Furthermore, these small turbines are so designed that they comply with the regulations of the various classification companies.

**DESCRIPTION OF SET.**

Types DAW 40 and 50 have single-stage impulse blading. To improve the steam consumption a reversing segment is located in the cover of the turbine casing whereby the steam flow is directed back on to the rotor for a second time. The larger type DAW 65 is provided with double-stage impulse blading on the rotor. All blading is made of stainless steel. The shafts are supported in two bearings of the ball or roller type filled with grease having a high flow point, and two small fans mounted on the shaft provide adequate cooling of the bearings by subjecting them to a stream of fresh air. When operating with high superheat temperatures or in particularly hot engine rooms, the annular chamber which is cast into the bearing support of all types of turbines is connected to a cooling water pipe.

The shafts are fitted with labyrinth glands having axial and radial sealing and allowing for back-pressures up to 2·0 kg/cm² abs. The gland is screwed into the turbine casing and the axial clearance can be adjusted by turning the gland when the turbine is at a standstill.

The speed regulating mechanism of the turbine consists of a centrifugal governor with transmission rodding and a balanced double-seat valve. The governor is of the type used successfully for many years on all small turbines and lighting sets. The speed can be adjusted during operation by about ±5% by means of a handwheel. Protection against excessive operating speeds is afforded by the safety governor which operates independently of the speed governor and the quick-acting valve. The actuating impulse for the safety governor is transmitted to the quick-acting valve by means of a pipe filled with steel balls.

According to the kind of machine which is to be driven by the turbine, for instance in the case of pumps and blowers, a safety governor is sufficient and the speed is then adjusted by hand with the quick-acting valve which acts as a regulating element.

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With smaller generators often only a speed governor is provided, whilst for larger sets the turbines are usually fitted with speed and safety governors.

Types DAW 50 and 65 are also fitted with a hand valve which is opened in order to obtain an overload or for the purpose of maintaining normal power with a decreasing live steam pressure. The hand valve is located after the regulating valve, so that when this latter is closed by the speed governor due to a decrease in the load or as a result of the overspeed protective gear coming into operation, the steam supply to the overload nozzle is cut off.

The Brown Boveri geared couplings supplied with these small turbines allow for axial and to a small extent also angular displacements, so that slight deformations of the baseplate or inaccuracies of assembly in no way have any detrimental effect on the operation of the set. The baseplates can thus be of a lightweight welded construction. Grease is used to lubricate the coupling.

If the speed of the auxiliary machines lies below about 3000 r.p.m., a helical gear is provided between the turbine and the auxiliary machine, this gear being flanged on to the turbine casing. In such cases the turbines are run at speeds of 5000—5500 r.p.m. in order to reduce steam consumption as much as possible. The gear is lubricated by means of an oil pump and provided with ball or roller bearings. For small ratings the heat due to energy losses is conducted away by the surface of the casing, whilst for larger powers a water cooling coil or oil cooler is provided.

### TYPES AND FIELDS OF APPLICATION.

The main technical data of the different types is given in the table below.

These small turbines weigh only 2—4 kg/kW and are suitable for driving all kinds of marine auxiliaries such as:

- Generators for direct and alternating current.
- Cooling water pumps.
- Condensate and feed-water pumps.
- Lubricating and fuel oil pumps.
- Boiler room and suction fans.

<table>
<thead>
<tr>
<th>Type DAW</th>
<th>40</th>
<th>50a</th>
<th>50b</th>
<th>65a</th>
<th>65b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rating kW</td>
<td>35</td>
<td>50</td>
<td>100</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>Speed range r. p. m.</td>
<td>3000—5500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam conditions for cast-iron construction</td>
<td>up to 20 kg/cm² abs. 350°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam conditions for cast-steel construction</td>
<td>up to 40 kg/cm² abs. 420°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back pressure max.</td>
<td>2 kg/cm² abs. 5 kg/cm² abs.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction of rotation</td>
<td>Clockwise looking towards the driven machine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of turbine with speed regulation kg</td>
<td>180 260 270 470 990</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight of safety governor and quick-acting valve kg</td>
<td>25 30 40 55 75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The turbine can be of the horizontal or vertical type, with direct or geared drive, depending upon the construction and speed of the auxiliary machine which is to be driven. The exhaust steam from the turbine can be used to produce hot water, or used for feed water preheating or distillation purposes. A special advantage of the steam turbine is that the condensate is free from oil. With the increasing use

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of water-tube boilers pure feed water is of paramount importance for the safe operation of the boiler, so that for instance reciprocating engines with cylinder lubrication can hardly be considered any longer for such services. Even on ships where the majority of the auxiliaries are electrically driven, the most important emergency sets must have a turbine drive for reasons of safety. In all these cases it is necessary that turbines should be available which, even after they have been out of operation for long periods, can be immediately started in a simple manner. The new Brown Boveri small turbines satisfy these requirements and their operation and supervision can be left in the hands of even unskilled staffs. Attendance is confined to a periodic renewal of the lubricating grease in the bearings, which has to be done once or twice a year depending upon the number of service hours.

Fig. 2. — Simplest type of small turbine for driving marine auxiliaries.

Fig. 3. — Cooling-water pump set with small turbine drive for marine service.

Fig. 4. — Three sizes of the new small turbines for rated powers up to 500 kW.
BROWN BOVERI EXHAUST GAS TURBO-CHARGERS.
SERVICE EXPERIENCE AND NEW DEVELOPMENTS.

Despite the war, many favourable reports are still received concerning plants with Brown Boveri exhaust gas turbo-chargers, some of which have been in service for 15-20 years or more in all parts of the world. Charging sets have been developed from the former heavy slow-speed two-stage construction into the modern standardized high-power charger which develops a maximum pressure ratio of about 2-0 in a single stage and thus enables the power to be increased by 100%, or more. Lubrication of the charger is now completely independent of the Diesel engine. The new standardized series of chargers can be employed in many ways both for normal and high-pressure four-stroke charging, as well as for two-stroke charging.

For more than twenty years Brown Boveri have built exhaust gas turbo-chargers for increasing the power of Diesel engines by the Büchi process. During the years 1928—30 thirty-two large chargers for a total charged engine output of more than 115,000 B.H.P. were supplied to British shipping companies. Although the requirements as regards efficiency, blade material, and blade construction, which had to be fulfilled by these plants were very high for the technical standards prevailing at that time, these sets already reached a high degree of reliability.

Recently one of the Company’s representatives had the opportunity of visiting a ship which was built in 1929 and equipped with Brown Boveri chargers. The charging sets are in very good condition and after more than fifteen years service work as well as on the first day they were put into operation. In the case of another motor-ship which since 1932 operates between Australia and New Zealand and is equipped with two charged four-stroke engines, the owners have recently overhauled one of the two exhaust gas turbo-sets for the first time after it has been in service for twelve years, because the charging pressure had decreased slightly. After a few minor defects had been repaired this set was put into service again, whilst the overhaul of the second set, which still operates perfectly, had to be postponed to a later date owing to lack of time. When judging these favourable results, the like of which have also been obtained on other ships equipped with Brown Boveri chargers, it is to be noted that these chargers quite generally require very little attendance and the temperature of the exhaust gas at the turbine inlet can reach 550°C or more.

It is interesting to compare former designs with present-day ones and to consider in which way and by what means the same problem is solved nowadays. If the aforementioned marine installations were equipped with modern chargers, it would for instance be possible to achieve the following improvements when compared with the sets at present installed in these vessels:

- A total saving in weight of about 8000 kg because both the existing chargers weigh about 6500 kg each, whilst modern charging sets for the same output, without using light metal, only weigh 2500 kg. There is thus a saving in weight of 4000 kg on each charger.

Reduction in space required to about a third of the original value (see Fig. 1).

Increase in the attainable charging pressure ratio to about 2-0 when necessary, compared with 1-5 with the old construction. If the engine and propeller shaft are suitable, the additional output of the engine compared with that of an uncharged engine can be increased from 50% to more than 100% with the new chargers.

![Fig. 1. — The size of an exhaust gas turbo-charger of the old type (above) compared with the new design (below) for the same range of operation.](image-url)
Increase in the overall efficiency of the charger by at least 20%.

The Company’s first turbo-chargers were fitted with overhung turbine wheel and the blower part was constructed with two stages (Figs. 2 and 3). The rotors of the new standardized single-stage charger series are supported at each end so that the bearings, which are the only elements subject to wear, are readily accessible and can easily be replaced (Fig. 4). This improvement was first of all achieved at the expense of providing particularly strong shafts in order to maintain the critical speed above the operating speed of the charger. Nowadays, as a result of the flexible fixing of the bearings in the bearing housings developed by Brown Boveri, this limitation has also disappeared, and the charging sets run practically free from vibration, despite the higher speeds required in order to attain higher pressure ratios. This great advance also has a favourable effect on the life of the bearings, this being particularly important and valuable as regards the small turbo-chargers with speeds up to about 50,000 r.p.m.

Originally, ball bearings were provided in order to improve the overall efficiency. For the same reason the parts of the casing through which the exhaust gases pass were not water cooled and the turbine part was only insulated to prevent heat radiation. Nowadays, the great improvements achieved in efficiency, design, and material of the active parts of the blower and turbine would enable the larger types to be provided with plain bearings and the turbine casing to be cooled. Nevertheless, ball bearings have been retained even for the newest types of chargers in order to be completely independent of the Diesel engine as regards lubrication and to avoid a lubricating oil circuit with oil cooling. The heat produced in the plain bearings of high-speed turbo-machines is several times greater than the heat generated in roller bearings and would be so great that the necessary oil coolers could no longer be located inside the charging set. When roller bearings are used the lubricating oil circuit and oil containers can, however, be arranged inside the charger itself. Even with roller bearings an entirely independent lubricating system for all sizes of chargers was, however, only achieved after special designs had
been evolved for this purpose. A short review of this development is worth mentioning here.

In the beginning, the lubricating oil system of the Diesel engine was used to lubricate the exhaust gas turbo-charger. This method was employed as long as the relatively low speeds of the first types of chargers enabled used lubricating oil to be utilized. Since a defect in the lubricating oil system of the engine usually resulted in the bearings of the charger also suffering damage, some other solution had to be found. Furthermore, the increase in charger speeds due to the universal use of the single-stage construction made it essential that only pure lubricating oil should be used for the bearings. It thus became necessary to separate the charger lubricating system from that of the engine. A gear-type lubricating pump mounted at each end of the shaft was soon found to be the correct solution for the larger sets. This arrangement could not, however, be applied to the smaller sets with normal speeds above 20,000 r.p.m. on account of the lack of space and the costs. The simple one-piece lubricating disc which was used for a short time did not prove satisfactory for the smaller sets with their high speeds, so that in this case a temporary solution was found by using the Diesel-driven circulating oil pump to supply pure lubricating oil to the charger. The final construction suitable for all speeds was discovered when Brown Boveri invented the patented double lubricating discs. At higher speeds the single disc cannot be used because the oil is forced away from the disc by the draught effect, whilst with a double lubricating disc a vacuum forms between the discs which causes the oil to be sucked in and ensures a supply of oil even at the highest speeds. These two processes are illustrated in Fig. 5.

The present Brown Boveri charger lubricating system has no external elements. The larger sets are equipped with gear-type lubricating oil pumps, whilst the smaller sets are lubricated by means of the aforementioned double lubricating discs. Fig. 6 shows that also the gear-type oil pumps driven by the charger, have been greatly improved as regards space requirements and weight. Finally, it is worth noting that the modern Brown Boveri chargers can be lubricated with the same brand and quality of oil as the Diesel engine, so that operation and attendance are further simplified.
The externally located rotor bearings are readily accessible and easily replaceable.

Each charger has its own lubrication system with self-contained lubricating devices and oil sumps, so that no lubricating oil pipes have to be arranged outside the set and no additional oil cooling is necessary.

The exhaust gas temperature in front of the turbine can be as high as 600 °C for continuous operation or reach 650 °C intermittently.

The standardized Brown Boveri charger is equally suitable for increasing the output of four-stroke and two-stroke engines. The addition of a charger, although of robust construction, increases the weight of four-stroke engines only by 1—2% and the absolute space requirements by maximum 5%, whilst at the same time the weight/power ratio decreases by 30—45% and the specific space requirements by 20 to 40%, depending upon the degree of charging employed. Fig. 7 shows that the Company's standard chargers fit in well with the general appearance of the engine which is to be charged. Finally, attention is drawn to the fact that nowadays the charged Diesel engine with Brown Boveri chargers can be sold more cheaply than an uncharged engine for the same power, because the series production of standardized charging sets enables prices to be considerably reduced.

(MS 605)

R. Stahel (Op.)
LONG LIFE OF ELECTRICALLY-HEATED ZINC-BATH FURNACES.

Brown Boveri supplied the first large electric zinc-bath furnaces to two important galvanizing works in Switzerland in 1937 and 1938. A few months ago the foreman of one of the works reported that the electric furnaces put into commission in 1938 had operated for over six years, i.e. for altogether roughly 4500 working shifts or 36,000 working hours with the same bath, which had not had to be changed once during the whole period. Such a long bath life was never achieved with the earlier coal firing. As a rule the baths had to be changed after one to two years, three years being the absolute maximum. New zinc baths cost 5000—8000 Swiss francs each, so that lengthening of their working life has quite a considerable influence on the running costs of the galvanizing works. Similar excellent reports of longer bath life have also been received from other galvanizing works.

Brown Boveri

Fig. 1. — View of a galvanizing works with three electrically heated furnaces for the galvanizing of hollow ware, rolled-section iron, and tubes by the hot-dip process. Rating 160 and 180 kW per furnace.

In the background will be seen the apparatus for the automatic regulation of the bath temperature which are enclosed in a fume-proof cubicle. Compared with fuel-fired plants operation is greatly simplified and reliability enhanced, which has an advantageous effect on the economy of an electrical galvanizing plant.

The above-mentioned favourable operating experience is due to the fact that electrical heating combined with automatic temperature regulation results in extremely uniform heating of the galvanizing bath. By suitable arrangement and control of the heating elements it is possible to utilize the outer walls for the heat transfer completely uniformly and with minimum excess tem-

peratures. The automatic temperature regulating gear positively prevents the furnace temperature exceeding the admissible limits. As a result the specified bath temperature of 450° C is accurately and automatically maintained constant immaterial of the quantity of ware passing through the bath, while the ware itself is covered with a uniform, minimum layer of zinc. In a large electrically heated zinc bath furnace plant it was found within a short time that there was far less tendency for hard zinc to form, while zinc con-
sumption proved to be much lower. It is clear that the lower and more uniform wall temperatures of the zinc bath must reduce its wear and thus considerably enhance the economy of electrically heated galvanizing plants.

The plant shown in Fig. 2 has been in continuous operation since 1937 with the exception of a short period when the bath was lengthened. The 7-5 m long bath with a capacity of about 50 t of molten zinc, originally provided, attained to a life of over seven years. The bath finally had to be changed owing to a side wall having developed a leak, partly due to natural wear and partly due to the well-known solvability of iron in zinc. The leak was immediately indicated by the built-in alarm device, so that it proved possible to ladle out the whole contents within the space of about eight hours and to remove the bath. Both the heating elements and the brickwork of the furnace were still in excellent condition and showed no signs of wear after seven years service. Apart from the spot where the jet of molten zinc spurted into the furnace no repairs of any kind were necessary. After the available standby bath had been fitted normal service was resumed with the same plant a few days later. Where fuel-fired plants are concerned, however, extensive repairs to the brickwork are usually necessary when the bath is periodically renewed. This work takes several weeks and is extremely costly.

Due to the excellent experience made with the Company's electrically heated zinc-bath furnaces since the first plant was installed in Switzerland a total of 19 such furnaces with an aggregate rating of 3150 kW have been supplied. The largest zinc-bath furnace ever constructed has a bath length of about 13 m and a rating of 340 kW.

This development shows once again that electricity constitutes an economic substitute for ordinary fuels in many cases and that cost of energy need not necessarily conform exactly to the equivalent coal or oil price, since other factors favourably influence the working costs with electrical heating.

Fig. 2. — Electric zinc-bath furnace for galvanizing iron parts, tubes, and masts by the hot-dip process.

Dimensions of bath: length 7500 mm, width 1150 mm, depth 1250/600 mm. Maximum rating 255 kW. Contents of bath about 50,000 kg of molten zinc. Bath temperature 450—460°C. Electrical heating permits of more uniform heating of the bath which lengthens its life. Due to the automatic temperature regulation zinc consumption is reduced to a minimum.

(MS 593)

H. E. Meuche. (E. C. W.)
A Rush Job.

Decimal Index 621.577 ; 621.181.63

It was only after it became possible to ascertain that an abundant crop of pears and apples would be available in 1944, that permission was granted to put in hand this evaporating plant with thermo-compressor. For this reason the order for same was only placed at the beginning of August of that year. Nevertheless, thanks to the closest cooperation between the various design departments and workshops concerned and to special steps taken to expedite manufacture, the thermo-compressor set was dispatched from the works in exactly two months after passing the order.

Immediately afterwards work was started on erection and as soon as this was completed, the plant was put into continuous, twenty-four hour operation, practically without vibration it was possible to mount the set in an attic.

Up to the time of writing this installation has been mainly used for concentrating unfermented apple or pear juice, but it can also be used for handling other liquid food stuffs. Thanks to the exclusive use of rotating machines running without vibration it was possible to mount the set in an attic.

The plant is used for concentrating unfermented fruit juice or other liquid food stuffs. Thanks to the exclusive use of rotating machines running without vibration it was possible to mount the set in an attic. The normal evaporating conditions are as follows:

- Weight of water evaporated: 750 kg/h
- Power input at motor terminals: 56 kW
- Specific evaporating figure: 13.4 kg/kWh

Moderate operating temperatures — the whole plant working under vacuum — enhance the quality of the products treated by ensuring the retention of their flavour, aroma and vitamine content.

Apart from the air-tight sealing of the glands, the design of the thermo-compressor is the same as that of standard centrifugal blowers. The electrical equipment is also standard and comprises essentially a three-phase slip-ring induction motor with rotor starter and switch-box which drives the set over a single helical speed-increasing gear.

D. Marples.

Brown Boveri and the Technical Press:

The Heat Pump.

("De Warmtepomp"). By Prof. Ir. J. Muysken, "Electrotechniek" No. 9, 28th April, 1944, pp. 113—124.

The lively interest aroused by the heat pump in Holland is evident from this article, which gives the technical man a comprehensive idea of what Brown Boveri have so far achieved in this field. As an example of the application of cold-vapour heat pumps for heating purposes the plant of the Steckborn Artificial Silk Co., Ltd., Steckborn, is quoted where two Brown Boveri thermo-blocs, each designed for a heating capacity of 1—1.7 million kcal/h and each permitting 2100 t of coal to be economized annually, are installed; two-thirds of the above heat is extracted from the water of the Lake of Constance, only the remaining third being furnished by the electric current. An illustration of the air heat pump with a heating capacity of 115,000 kcal/h supplied by the Company to a Landquart paper mill for heating air for drying felts is also presented. Notwithstanding its relatively small capacity this machine also economizes 180 t of coal yearly. Here, the damp, warm, exhaust air of the paper making machine is employed as source of heat.

From comprehensive data it is proved that the heat pump permits the quantities of coal given in the last column of the abridged table reproduced hereafter to be saved per kWh of electrical energy expended. In calculating the tabulated values it was assumed that the fuel has a calorific value of 7000 kcal/kg and the boiler of the thermal plant quoted for purposes of comparison an efficiency of 0-72. In order to take into consideration the coal-saving effect of additional heat exchangers in modern fuel-fired plants the boiler efficiency must be multiplied by a coefficient F assumed to be 1.0, 1.2, 1.3, or 2.4, as shown in the table. The last figure applies to fuel-fired concentrating plants operating with three-stage evaporation. If the comparison were to be extended to two or
even single-stage evaporation the figures given in the last column would show up thermo-compression in an even more favourable light.

I. Air heat pump.

<table>
<thead>
<tr>
<th>Effective coefficient of performance</th>
<th>Coefficient F</th>
<th>1 kWh replaces kg coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Air conditioning and heating plants . . .</td>
<td>2.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Drying and production of hot water . . .</td>
<td>2.5</td>
<td>1.3</td>
</tr>
<tr>
<td>9.0</td>
<td>1.3</td>
<td>0.39</td>
</tr>
<tr>
<td>B. Heating with radiator temperatures of 70—90 ° C . . .</td>
<td>2.5</td>
<td>1.0</td>
</tr>
<tr>
<td>C. Heating with radiator temperatures of 50—70 ° C . . .</td>
<td>4.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

II. Cold-vapour heat pump.

| Evaporation . . . | 12.0 | 2.4 | 0.85 |
| 15.0 | 2.4 | 1.07 |
| 18.0 | 2.4 | 1.28 |

and for purposes of comparison

IV. Electric boilers.

<table>
<thead>
<tr>
<th>Boiler efficiency</th>
<th>Production of hot water 0.97</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wb. (E. G. W.)</td>
<td>1.0</td>
</tr>
</tbody>
</table>

The Heat Pump:

Its Method of Operation and Economy.

By U. V. Büttikofer “Wasser- und Energiewirtschaft” Nos. 4/5, 1944.

In order to familiarize as wide a circle of readers as possible with the heat pump the author restricts himself to a cursory description of its method of operation and applications, without entering into thermo-dynamic principles. It is shown in a readily-understood manner that in the form of a thermo-compressor, the heat pump can compete with coal-fired plants for the concentration of solutions at a pre-war coal price of 8 cts/kg and a coefficient of performance of 20 (which is rather on the high side) even when energy costs 9—10 cts/kWh. This comparative price for the energy includes the capital outlay for the thermo-compression plant. Since the energy rate allowed by power supply undertakings for this application is considerably lower, concentrating plants operating on the thermo-compression principle are economically superior to coal-fired plants, even at pre-war fuel prices. A number of illustrations of heat pumps supplied, including the plant of the Stockborn Artificial Silk Co., Ltd., Stockborn (Switzerland), with two Brown Boveri heating machines each permitting about 2100 t of coal to be economized annually, together with a list of Swiss literature, complete this contribution, which is really worth while reading.

The Future of the Gas Turbine

by B. Wood, M. A.,

“The Engineer”, 17th, 24th, and 31st March, 1944.

At the outset the author traces the development of the gas turbine from its application to the pressure charging of four-stroke Diesel engines, then as auxiliary of the Velox boiler and exhaust gas turbine in the Houdry oil cracking process to the first practical gas turbines with separate combustion chamber. He then points out that the whole of the successful commercial application is due to Brown Boveri or their licensees. The following table which is taken from the article in extenso shows the number and total rating of the machines built up to 1941.

Gas turbines manufactured by Brown Boveri and licensees up to 1941.

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Total capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Büchi pressure charging sets for four-stroke Diesels . . .</td>
<td>1500</td>
</tr>
<tr>
<td>Gas turbine compressors for Velox boilers . . .</td>
<td>90</td>
</tr>
<tr>
<td>Gas turbine compressors for oil cracking plants . . .</td>
<td>20</td>
</tr>
<tr>
<td>Gas turbine for electric power generation . . .</td>
<td>1</td>
</tr>
<tr>
<td>Gas turbine for locomotive . . .</td>
<td>1</td>
</tr>
<tr>
<td>Gas turbine for experimental establishment . . .</td>
<td>1</td>
</tr>
<tr>
<td>Gas turbines for blast furnace plant . . .</td>
<td>3</td>
</tr>
</tbody>
</table>

Following on this retrospect of the development of the gas turbine, the present and future possibilities of this new form of prime mover are discussed on a thermo-dynamic basis. The author shows that there are numerous applications where even with the efficiency of 18% obtainable without heat exchanger, with single-stage combustion and the gas admission temperatures permissible today, the gas turbine represents the most advantageous prime mover. In this simple design it may find application where fuel cost is of lesser account than low capital cost, rapid starting, small weight or dimensions, and independence of water supply. As an example, peak load electricity generation is mentioned, with the possibility of locating the station comparatively near to the load so that the transmission system could be relieved of load on the peak, thereby showing considerable savings. After the success of the gas-turbine locomotive the author is of the opinion that the possibility of the gas-turbine ship must be seriously considered.

At the time of writing his article the author was unaware of Brown Boveri’s latest suggestion, viz., to employ two-stage compression and combustion and also a new

type of relatively inexpensive heat exchanger allowing efficiencies of 30% and more to be achieved, and was therefore unable to discuss it. It is all the more interesting to find that on the basis of earlier publications only, this independent English expert should have come to the conclusion that the moment has arrived for this new prime mover to begin competing with other systems for marine propulsion purposes.

(MS 588) 

"Electrical Grass Dehydration in Switzerland",

Special Number of "Elektrizitätsverwertung" Nos. 1-3, 1944/45, Vol. 19,

Publishers "Elektrowirtschaft", Victorialaus, Bahnhofplatz 9, Zürich 1. Price of Special Number Sw. Frs. 7.50.

Decimal Index E11.364.2:631.2

The ever-increasing importance of artificial grass dehydration by electricity induced the editor of the "Elektrizitätsverwertung" to publish a voluminous and interesting special number covering this new field which is such an important factor in the food supply of Switzerland. It contains contributions representative of all the different circles in any way interested in grass dehydration, i.e. principally agriculture, and the electricity supply and other industries manufacturing grass dehydrating plants. Anyone desiring information on problems connected with the dehydration of grass will doubtless find much of interest in this special number. Apart from a summary on the significance of grass dehydration separate articles deal with: dehydrated grass as a complete concentrated fodder, rich in albumen and starch; the influence of dehydrated grass fodder on milk production; the experience obtained with various such plants; the development and present state of progress of green fodder dehydration; and finally a whole series of descriptions of dehydration plants on the Swiss market.

In view of the high energy consumption of some dehydration plants the cost of the electrical energy represents a large percentage of the total working costs. It is therefore well worth while pushing up the efficiency of the plants to the absolute maximum obtainable economically. Where the Brown Boveri grass dryer with heat recuperation is concerned it has proved possible to reduce the heat required per kg of evaporated water to 600—650 kcal and even lower. On the occasion of acceptance tests a consumption of only 589 kcal per kg of evaporated water has even been attained compared with 747—884 kcal/kg in the case of plants without heat recuperation.

A further considerable reduction in energy consumption to as low as 350—400 kcal/kg of evaporated water would also be possible, according to another article, with a grass dehydration plant incorporating a heat pump designed on principles proposed by the Institute for Thermo-dynamics at the Swiss Federal Institute of Technology. Here the drying air is compressed by a rotary compressor in a closed cycle and, after being saturated with moisture in the drying room, is expanded in a turbine directly coupled to the compressor, before it is again returned to the compressor through a water separator. An electric motor would provide the power lacking to drive the set, i.e. about a third of the entire compressor power. Due to the cooling of the air during the expansion process the humidity increases to below the dew point and separates out in droplet form, a process which could be accelerated by the injection of water in the same way as with non-condensing steam engines. Thus the grass dryer could operate at atmospheric pressure and the water separator under vacuum or the grass dryer under pressure and the water separator at atmospheric pressure. A similar air heat pump, but with an open instead of a closed air cycle and for recuperating heat from exhaust process air instead of for grass dehydration purposes, was constructed by Brown Boveri earlier. What is new in the arrangement put forward by the Institute for Thermo-dynamics is its application to grass dehydration and the method of separating the water out of the expanded circulating air.

Unfortunately space will not permit the application of the heat pump to this special field or the other subjects dealt with in the special number to be gone into here. The purpose of these notes is to induce the reader to study the articles in question himself. To make this easier for English or French speaking readers all of the explanatory notes to the illustrations are given in three languages, while a summary of the articles in English and French is given at the end of the journal.

(MS 592) 


2 "Trocknen mit Wärmepumpen" by M. Berchtold, Institute for Thermo-dynamics at the Swiss Federal Institute of Technology, Zürich; also appeared in the special number "Electrical Grass Dehydration in Switzerland".