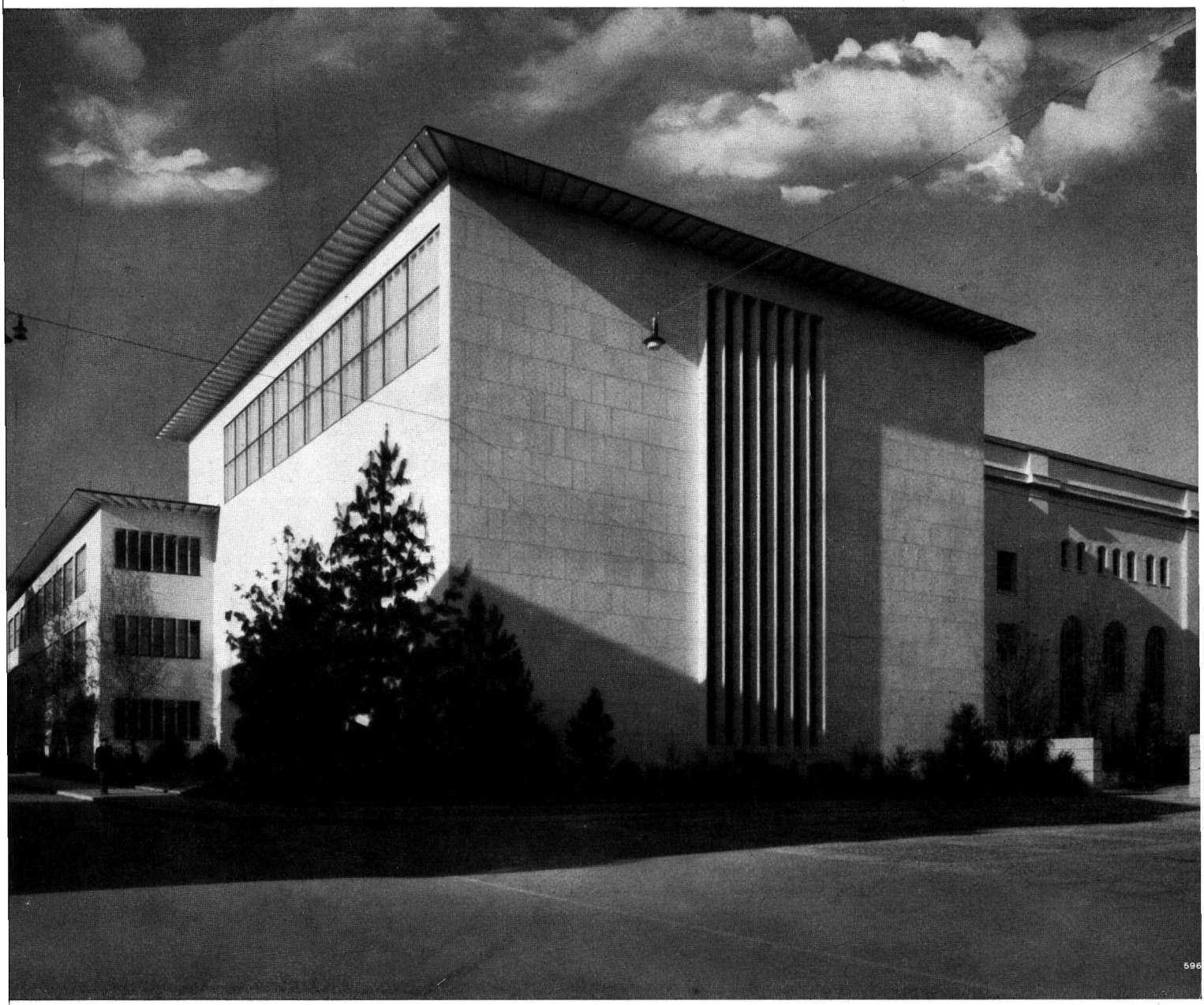
THE BROWN BOVERI REVIEW

5009.2
1944



The new Brown Boveri high-voltage laboratory

Progress and Work in 1943

BROWN BOVERI REV. VOL. XXXI | Nos. 1/2, pp. 1—100 | BADEN, JANUARY/FEBRUARY, 1944

Printed in Switzerland

CONTENTS

Page

INTRODUCTION 3

I. GENERATION OF ENERGY 5

A. Velox Plants 5
1. Velox Boilers 5
2. Separately-fired Velox Superheaters and Re-superheaters 7
B. Steam Turbines 8
C. Combustion Turbines 12
D. Governing Gear 13
E. Generators 15
1. Turbo-generators 15
2. Diesel-driven Generators 16
3. Hydraulic Generators 16
4. Generator Protective and Regulating Equipment 19
5. Research Work in the Synchronous Machine Field 21

II. POWER TRANSMISSION, DISTRIBUTION AND CONVERSION 25

A. Power Transmission over Long Distances 25
B. Transformers 26
C. Network Protection 29
D. Circuit-breakers 31
E. Relays 34
F. Switchgear 35
G. Mutators 36

III. BROWN BOVERI MANUFACTURES IN INDUSTRY, TRADE, AND AGRICULTURE . . 40

A. Motor Drives and associated Control Gear 40
Introduction 40
1. Drives in the Textile Industry 43
2. Drives in the Paper Industry and Printing Works 46
3. Industrial and Agricultural Drives and Switchgear 47
4. Drives for Materials-handling and Rolling-mill Equipments 56
B. Electric Welding 58
C. Electric Furnaces 60
D. Electric Boilers 65
E. Compressors and Blowers 66
1. Turbo-compressors 66
2. Blast-furnace and Steelworks Blowers 66
3. Gas Exhausters and Boosters 66
4. Turbo-compressors for Chemical Industries and in particular for Processes carried out under Pressure 70
5. Heat Pumps 70
6. Exhaust Turbo-chargers 72
(a) Pressure-charging of Diesel Engines 72
(b) Producer-gas Charging 74
(c) Chargers for Gas Engines 76
7. Axial-flow Compressors and Blowers 76
8. Aerodynamics 77
F. Gearing and Geared Couplings 77

IV. TRACTION 78

A. Electric Traction and Train Lighting 78
B. Gas-turbine Locomotives 85

V. HIGH-FREQUENCY AND COMMUNICATIONS ENGINEERING 86

1. Electrical Filters 86
2. Multichannel Communication and Directional Waves 87
3. Microwaves 88
4. Construction of Valves 89
5. Transmitters 89
6. Supervisory Control 91

VI. MARINE INSTALLATIONS 94

A. Velox Steam Generators for Ships 94
B. Marine Steam Turbines 94
C. Gas Turbines for Marine Drives 94
D. Marine Auxiliaries 96
E. Electrical Marine Drives 100

THE BROWN BOVERI REVIEW

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

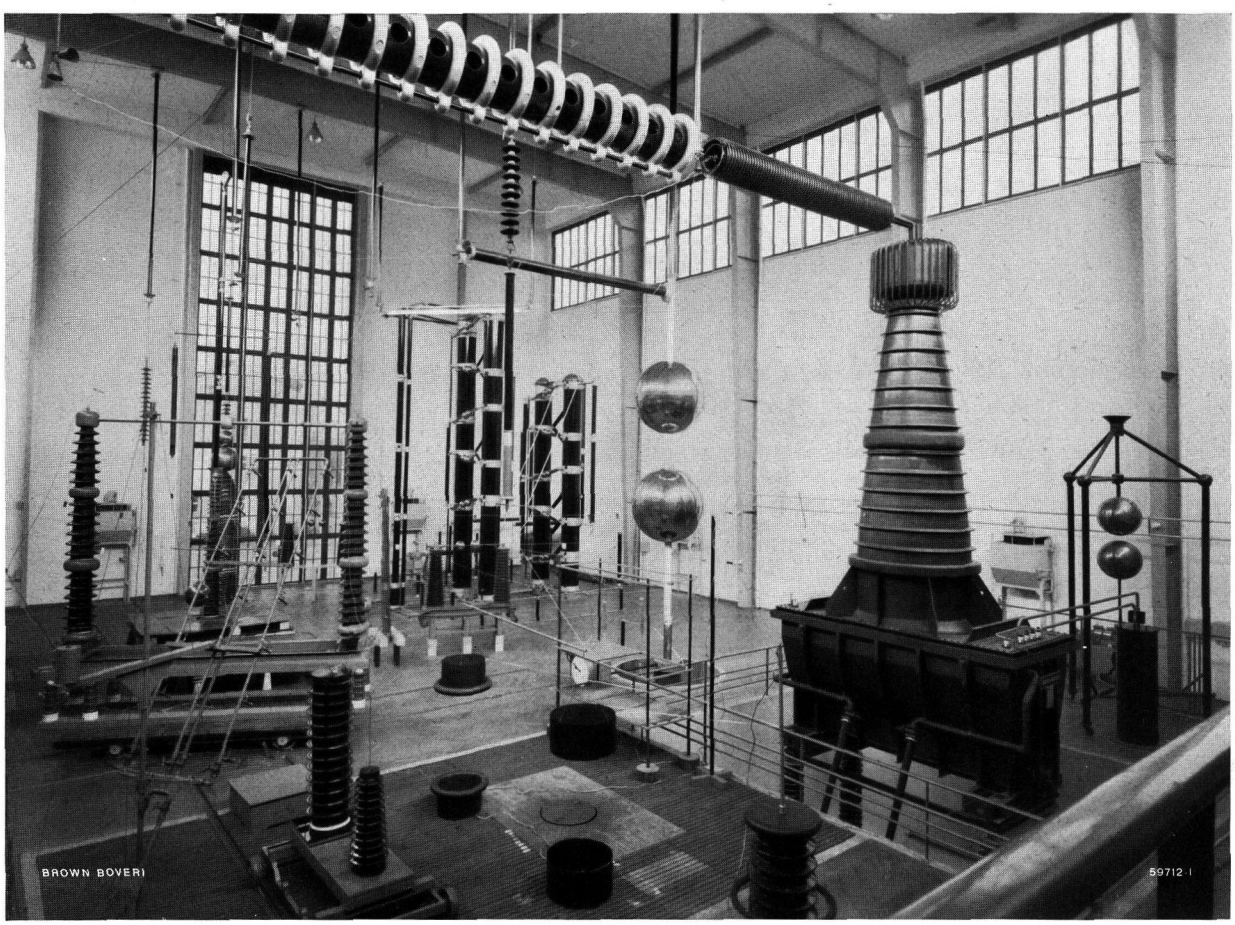
VOL. XXXI JANUARY/FEBRUARY, 1944 Nos. 1/2

The Brown Boveri Review appears monthly. — Reproduction of articles or illustrations is permitted subject to full acknowledgment.

PROGRESS AND WORK IN 1943.

INTRODUCTION.

IN the introduction to last year's review of progress and work an effort was made to analyse the laws governing technical development in large industrial undertakings, while allusion was also made to the important role played by the operating field, which in normal times continually supplies working experience and points the way to service requirements. Although much of the development work undertaken goes to the meeting of such needs, it was stated that the greater part concerns problems connected with future probable trends.



Inside view of new high-voltage laboratory.

In foreground on right 1200 kV testing transformer; in background 2400 kV impulse generator; suspended from ceiling new type of multi-needle rectifier for a blocking voltage of 2500 kV.

Actually there are two problems affecting Brown Boveri's range of manufactures which will play a preponderant part and require speedy solution in the post-war period. In the electrotechnical field there is the question of the transmission of big blocks of power over long distances which, with a view to the development and utilization of remote sources of power, may prove of primordial importance in many reconstruction plans. In point of fact, the transmission to the points of demand of the abundant supplies of energy available in certain districts will prove as great a problem as the distribution to the starving peoples of the excess agricultural production in other parts of the world. This, however, is practically certain to involve much higher voltages than have been employed hitherto, although the question of the relative economic merits of alternating or direct current transmission may be considered irrelevant at the outset. In this development, which may set in sooner than one is at present inclined to believe, Swiss electrical engineering, true to its tradition, will have a big say. It was in order to be prepared for this eventuality that the new high-voltage laboratory described in an earlier number of this journal, was erected. On the occasion of its inauguration on the 18th November, 1943, the opportunity was taken of demonstrating the research potentialities it affords to a wide circle of electrical engineering experts and friends, although unfortunately only from Switzerland. Furthermore, a special high-voltage engineering number of this journal was issued [1] which contained a number of descriptions of work mostly carried out with the relatively primitive equipment available before the new laboratory was inaugurated.

In the thermal field a further important development stage of steam engineering is being entered upon, whereby solid fuels and their derivatives will be more rationally exploited, as outlined in an article entitled "Post-war Steam Power Plants" [2] which appeared during the year under review.

Moreover, exhaustive investigations into the economical prospects of the Brown Boveri combustion turbine have shown that the application of this machine to industrial and power station practice is one of the outstanding events in the thermal machinery field since the invention of the Diesel engine. In consequence, great attention is being paid to the field in question and no pains are being spared to further the development of this class of prime mover.

In both cases the work involved is of such a character that it may appear hazardous to enter upon it at a time when there are not only no signs of the war coming to a speedy conclusion, but when production potentialities have been restricted even still further through the tightening-up of the double blockade ring. Be this as it may, the fact that, through the dispositions of a kindly Providence, Switzerland has so far managed not to become involved in the world-wide conflagration seems to impose on us a moral obligation to promote technical development by every possible means in readiness for the post-war reconstruction period.

[1] The Brown Boveri Review 1943, Nos. 9/10, p. 211 ff.

[2] Dr. Ad. Meyer: Schweiz. Bauztg. 1943, I, p. 149 ff., The Brown Boveri Review 1943, Nos. 7/8, p. 131.

I. GENERATION OF ENERGY.

A. VELOX PLANTS.

1. *Velox Boilers.*

Exhaustive investigations and development work led to the extension of the range of Velox boilers for land plants during the year to include a boiler with a high rate of evaporation and very high steam pressures, which resembles the marine design in many respects. It goes without saying, however, that due attention was also paid to the perfectioning of the Velox steam plants with rates of evaporation of 15 to 100 t/h, pressures of 15—50 kg/cm², and superheat temperatures up to 500° C. In this respect reference may be made in passing to the simplification of certain components, such as evaporator elements, wall linings, pre-heaters and the like.

The marine type of Velox described on pages 251 to 255 of the special marine number of this journal in 1942 has proved very suitable for very high rates of evaporation, i. e., about 100—200 t/h at any steam pressure, or for very high steam pressures, i. e., over 75 kg/cm² with any rate of evaporation. The salient feature of this design is the evaporator elements of single tubes heated by the flue gases exclusively on the outside and enclosed in a special casing. As a result of this arrangement the largest quantities of flue gases can be readily dealt with and, what is more, the requirement that no evaporator tubes in contact with hot gases shall have a wall thickness of over 8 mm, fulfilled. Even where the very highest pressures are concerned all heating surfaces take the form of readily interchangeable elements or nests of tubes, notwithstanding the fact that this involves more welded joints than flanges.

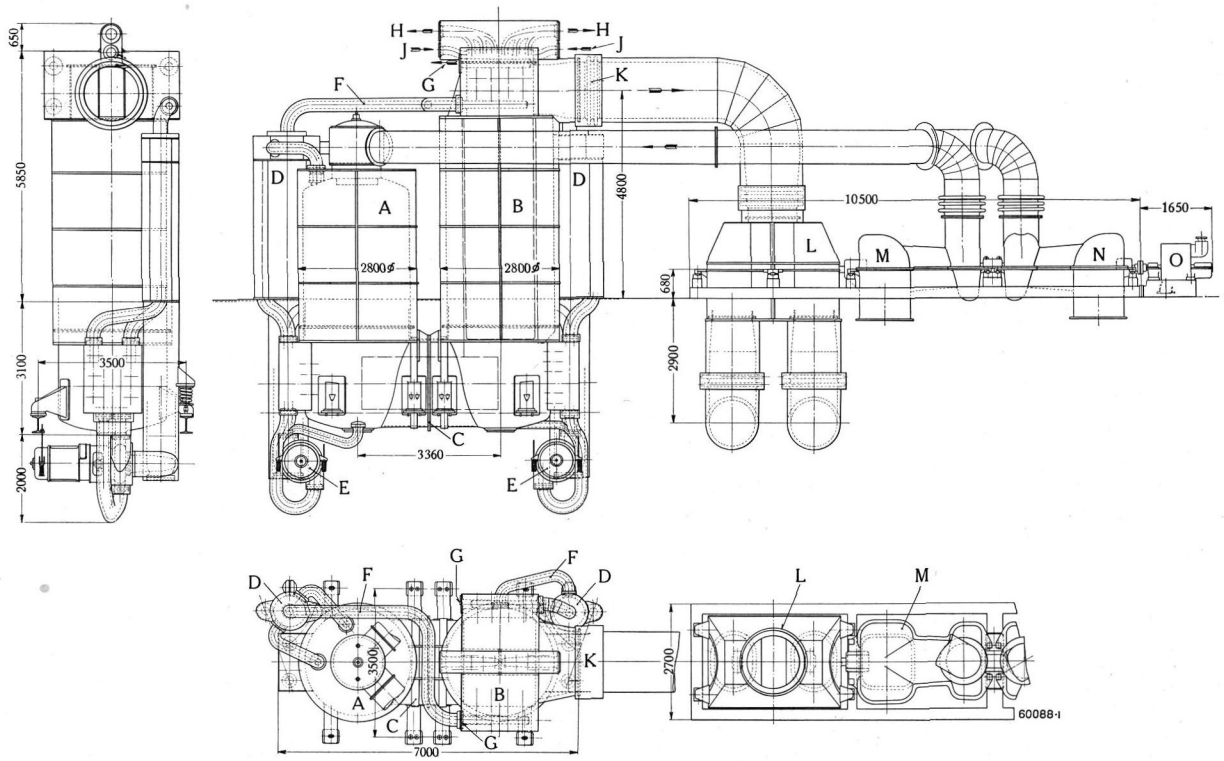


Fig. 1. — External view of Velox boiler for high rates of evaporation and high steam pressures.

The dimensions given refer to a boiler fired with low-grade gas and having an evaporation of 135 t/h at 130 kg/cm², 500° C. It also embodies a re-superheater for raising the temperature of the steam to 425° C after expansion. Fired with oil or high-grade gas a rate of evaporation of about 165 t/h would be attained. The boiler comprises casings (A) and (B), the former containing the combustion chamber, and the latter the superheater. The main evaporator tubes are arranged horizontally in the lower part of the casings and in the part (C). The walls of the combustion chamber and the superheaters are also formed by evaporators. The boiler has two separators (D) and two circulating pumps (E). The wet steam from the separators passes through the tubes (F) to the superheater. The two live steam connections are at (G), the inlet and outlet of the re-superheater at (H) and (I). The flue gases leave the boiler at (K). The plant being designed for low-grade gas firing the supercharging set has two blowers (M) and (N). The gas turbine (L) is of the double-flow type. (O) is a steam turbine for starting and governing purposes.

Note the small dimensions. The extremely small width, in particular, enables the boiler to be located between the turbines, which themselves are both wider and much longer. The short length of the pipes is particularly important from the point of view of re-superheating.

Velox boilers with rates of evaporation as high as 100--200 t/h are also relatively small and can be erected either alongside or at least in the same room as the turbine. An idea of the size of a Velox boiler is obtained when it is realized that for an evaporation of 1 t/h a combustion chamber of about $^1/_{10}$ m³, an evaporator with approximately 2 m² of heating surface, and flues with an internal cross-section of round about 50 cm² only are required. Due to the fact that the boiler house and sundry pipe-lines are dispensed with, a reduction in building costs as well as a saving in material for the boiler is effected. Should re-superheating prove necessary, especially in the case of very high steam pressures, and the re-superheater be embodied in the boiler, erection of the entire boiler installation in close proximity to the turbine is of particular advantage.

Fig. 1 again shows the outside view, with principal dimensions, of a Velox boiler having an evaporation of 135/165 t/h at a pressure of 135 kg/cm² abs., a live-steam temperature of 500° C, and re-superheated to 425° C, for firing with low-grade gases. Details of this unit were given on page 360 of the special mining and metallurgical equipment number of this journal in 1943.

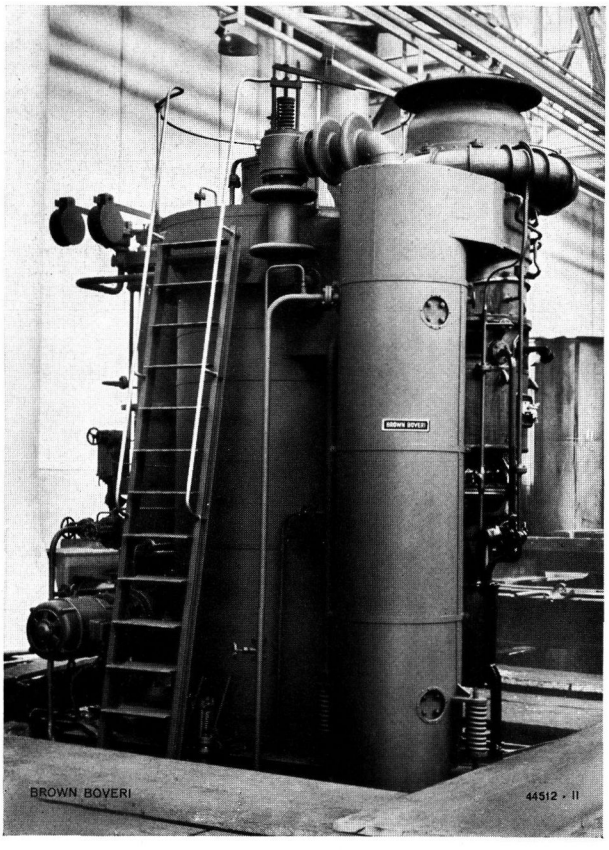


Fig. 2. — Velox boiler with an evaporation of 9 t/h at 24 kg/cm² abs., 420° C, converted from oil to natural gas firing.

Such a conversion is a relatively easy matter. Since natural gas is usually supplied at high pressure a special gas compressor can often be dispensed with. Compared to oil firing, natural gas, which is a high-grade fuel, involves no reduction in output. Even in the case of low-grade gas, however, the diminution is very small.

In cases involving very high pressures it is possible to enhance the efficiency considerably by heating the feed water with extracted steam, i. e., a large proportion of the heat of evaporation can be recovered. This possibility has so far never been availed of in the case of Velox boilers, the feed water, with its boiler inlet temperature of 80—100° C, being simply heated to a still higher temperature by the flue gases. As a result, the installation became smaller, simpler, and less expensive. The efficiency was sufficiently high, inasmuch as the Velox flue-gas feed-water heater, due to its high rate of heat transmission, permitted the flue gases to be cooled to a low temperature even with relatively small heating surfaces.

In cases where the steam pressure is very high and the existing or required turbine has several extraction points, however, the question may arise as to whether feed water heating with steam extracted at different stages would not also be advisable for the Velox boiler.

If the heat inherent in the exhaust gases is not utilized for feed water heating purposes, it must be put to another use. In the case of boilers fired at atmospheric pressure air preheating has been practically universally adopted. Where installations fired under pressure are concerned, however, this application does not come into consideration in that the combustion air is heated during the compression process and could thus attain temperatures up to 160° C (according to the charging pressure) before entering the pre-heater. It follows that utilization of the heat of the exhaust gases for air pre-heating is not possible to the same extent as with feed water heating. Nevertheless, even with the Velox boiler, air pre-heating is not entirely to be despised. Investigations in connection with the gas turbine have led to exhaust-heated air pre-heaters being devised which have to operate with considerably lower exhaust-gas temperatures and much higher air inlet temperatures than occur with the Velox boiler. Here, the rates of flow on both the gas and air sides of the recuperator of the gas turbine must be maintained low to keep the resistances down. With the Velox pre-heater, however, big pressure drops are available so that, as in the case of the Velox feed-water heater high rates of flow can be employed for both media, and the heating sur-

faces and flue dimensions thus kept small compared to those of a gas-turbine recuperator.

Every 20° C higher exhaust temperature involves a reduction of approximately 1 % in overall efficiency. If when employing an air pre-heater the exhaust temperature is, for instance, 40° C higher than with a feed-water heater the boiler efficiency is impaired by about 2 %. If at the same time, however, the feed water temperature is raised by extracted steam from, for instance, 100 to 160° C, a 4 % reduction in heat consumption will result, thus giving a net improvement in overall efficiency of about 2 %. This enhanced efficiency, together with the possibility of retaining an existing feed water lay-out, may prove the deciding factor for the selection of an air pre-heater, even when the latter involves slightly more material, greater weight, and higher costs than a feed-water heater.

Good progress has been made with the tests on the pulverized-coal-fired boiler. It is not intended to publish details, however, until such boilers are ready for the market.

As in the case of Diesel engines the shortage of liquid fuels has already entailed conversion of Velox boilers from oil to gas (natural gas) firing. Such conversions are not a difficult matter. The change-over to the new fuel involves no output reduction where high-grade gases are concerned and only a very slight one when gases of low calorific value are employed.

Fig. 2 shows a Velox boiler converted for gas firing, while Fig. 3 is a souvenir of one of the largest consignments of Velox boilers to be supplied overseas.

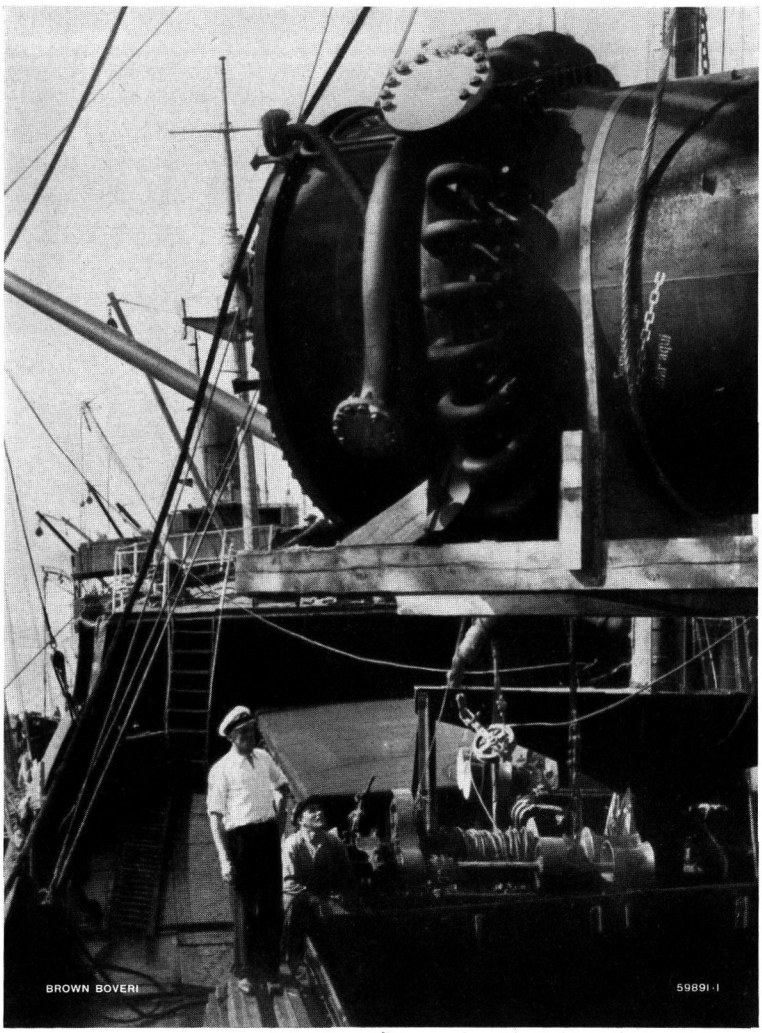


Fig. 3. — Combustion chamber of 80 t/h Velox boiler being lowered on to the S. S. "Maloja" for shipment overseas.

Not long after, this vessel was sunk while flying the Swiss colours.

(From the "Neue Zürcher Zeitung" No. 1796, 1943)

2. *Separately-fired Velox Superheaters and Re-superheaters.*

Apart from steam generation proper the Velox principle can also be applied to other heat transfer or transmission devices. It becomes advantageous as soon as large quantities of heat are to be transmitted, i. e., when conventional plant would become of such size that the resulting reduced cost of material and manufacture by far exceeds the outlay for the additional accessories involved, viz., the supercharging set, the automatic governing gear, possible circulating pumps or blowers, and the pressure-tight design of the casing. A heat transfer of round about 10 million kcal/h represents the lower economical limit. The Velox principle may perhaps also come into consideration for slightly lower rates of heat transfer in cases where special importance is attached to the smaller space requirements, enhanced efficiency, or good regulating properties, or where expensive materials, e. g., non-scaling and heat-resistant steels, such as are necessary when the cycle in question involves high temperatures, can be saved.

One of the applications of the Velox principle is the separately-fired superheater and re-superheater which will attain to importance in future when it comes to increasing the efficiency of super power stations

by superheating the steam to a far higher degree than at present practised. The steam generated at the normal temperature, i. e., not exceeding about 500° C, in the boiler is forced up to a value of, for instance, 600° C in the superheater and after expansion resuperheated, if necessary, to the same degree as the live steam.

A separately-fired unit for the high degrees of superheat has the advantage of enabling the temperatures to be better controlled, thus permitting the maximum admissible values to be approached. The Velox principle is employed in the design and operation of these superheaters because it results in plant of the smallest dimensions with good regulating properties and high efficiency, which is capable of erection in close proximity to the turbine. The reduction in heating surface, which is formed by tubes of highly heat resistant, non-scaling, and therefore very expensive steels, is particularly important.

Further applications of the same principle are blast heaters and chemical plants which are alluded to elsewhere in this issue (page 76). The reader is also referred to two articles on the same subject on pages 356 and 368, respectively, of the special mining and metallurgical equipment number of the Review for 1943.

B. STEAM TURBINES.

The two high-pressure back-pressure turbines, each rated 15,250 kW when operating with live steam at 125 kg/cm² and 490° C, against a back-pressure of 22 kg/cm² abs, mentioned in the Review of progress and work in 1941 as being in hand for a foreign power station, were put into service during the past year and have proved to be really excellent machines. A notable feature of these turbines is the improved automatic balancing of the thrust. As is common knowledge, this device comprises a dummy piston and a

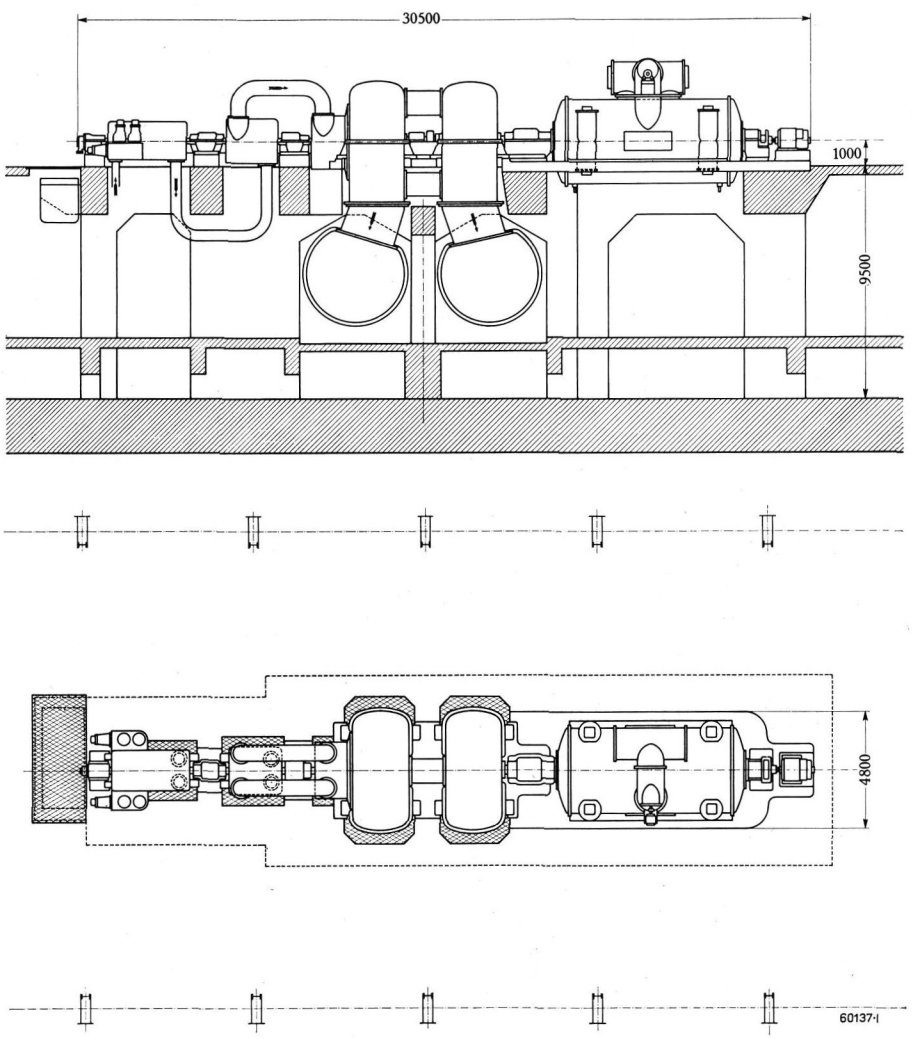


Fig. 4. — Elevation and plan of 100,000 kW, 3000 r. p. m. turbo-set.
This is a similar turbine to that shown in section in Fig. 5, but with re-superheating.

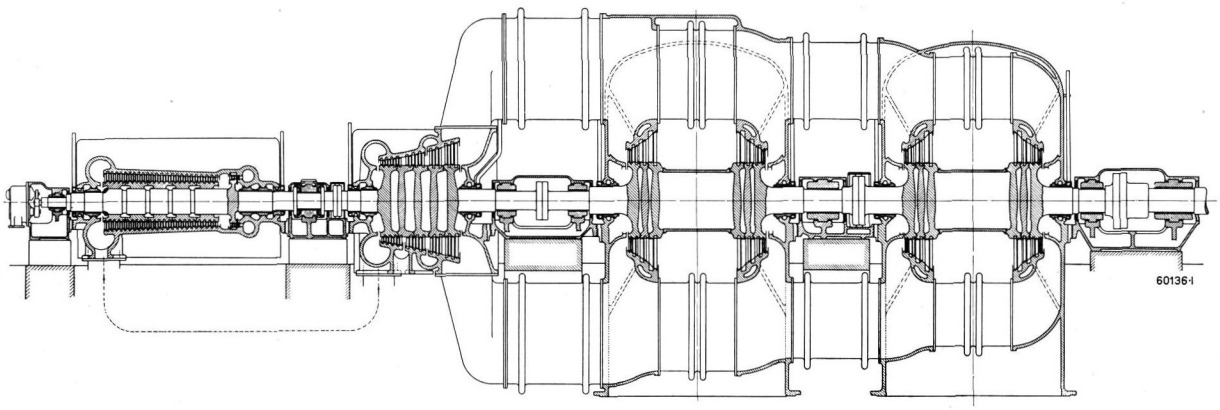


Fig. 5. — Longitudinal section through a 100,000 kW, 3000 r. p. m. turbine. Steam pressures 60—86 kg/cm², superheated to 500° C, without re-superheating.

The turbine is designed for maximum efficiency and high vacuum, for which reason it is provided with quadruple-flow steam outlet and two condensers. This arrangement permits of small rotor diameters. As a result and due to the splitting up of the heat drop between several cylinders and the fabrication of the rotors from rings and discs, it is possible to start the turbine quickly and also to start it again after short shut-downs. This is assisted by the rigid coupling of the shafts and the possibility of expansion of the casing which is mounted in a special manner on sliding surfaces.

compensating pipe fitted with a diaphragm which connects the space in the dummy piston on the bearing side to a certain stage in the turbine. To prevent oscillations of the thrust balancing device due to rapid pressure fluctuations, with the possibility of stripping the labyrinth packings, the turbine thrust bearing is provided with a damping arrangement. This is achieved with the piston-like supporting rings of the thrust bearings connected together by means of guide rods, which displace or suck in oil, thus providing a powerful, shockless opposing force to the movement of the shaft in the axial direction.

The purchase and running costs per kW of a turboset are generally lower the higher the unit rating. There is therefore everything to gain in selecting as large a unit as possible, although correspondingly large standby installations must be provided to ensure having a sufficient reserve of power should a machine be out of commission for any reason. The question of standby equipment is mitigated, however, through the ever-increasing interconnection of power supply systems, so that unit ratings of 100,000 kW can now also be considered for the European Continent. It is even to be assumed that there will be a definite demand for such large units soon after the conclusion of hostilities. As a measure of precaution, therefore, their study was taken up with the result that a 100,000 kW design has already been completely worked out. Fig. 4 shows an elevation and plan of, and Fig. 5 a section through, such a turbine. The turbine in Fig. 5 is designed for steam pressures of 60—86 kg/cm², superheating to 500° C, without intermediary re-superheating, and with feed-water heating in four stages to approximately 180° C. It is built for maximum efficiency and high vacuum, for which reason two double-flow low-pressure cylinders to which the two condensers are connected, are provided. A set of this type with a steam pressure of 130—140 kg/cm² abs, superheating to 500° C, feed-water heating to 185° C, intermediary re-superheating to 500° C, and cold cooling water, has a heat consumption of 2150 kcal/kWh. This corresponds to a thermal efficiency of about 40% from steam admission to terminals. The turbine components are of the firm's standard design. The rotor is built-up from rings, each lip-welded to the shaft. The intermediate- and low-pressure rotors are built-up by welding. Innovations are the completely rigid coupling of the four rotors and the method of admitting the steam to the two low-pressure cylinders. Particular care had to be paid to the question of the expansion of the shaft and casings, in view of the overall length of 22 m of the turbine. The fixed point of the turbine on the foundation is located in the feet of the first l. p. cylinder turned towards the i. p. cylinder. The casings are free to expand about this point on either side, whereby their feet, which lie at the height of the axis, glide on the bearing supports. In order to give adequate support to the shaft a thrust-bearing is provided between the h. p. and i. p. cylinders. The expansion of the shaft from this point and that of the casings — which is partly in the opposite direction — offset each other to such an extent that the relative positions of the shaft and casings remain virtually unchanged.

Details of the generator developed for the 100,000 kW set are given in section E on page 16.

Maximum economy will undoubtedly prove to be just as important as high unit-rating for steam-turbines in future. Coal prices are practically bound to remain

high long after the conclusion of hostilities and this fact coupled with the necessity of saving coal in the generation of energy and reserving it for other applications, e. g., chemical processes, will call for much greater economy than hitherto where large power stations are concerned. Of the possibilities of improving the economy of a steam turbine installation, however, only the increasing of the temperature drop remains, inasmuch as the steam pressure, the vacuum, the utilization of the heat of evaporation for feed water heating, and the quality of the machines have almost reached their practical limit. The increased temperature drop can be achieved both by raising the live-steam temperature and augmenting the degree of re-superheat to the highest permissible value, and must of course be combined with an increase in steam pressure to the maximum value consistant with good economy. That higher initial temperatures tend to improve economy was of course already known. What is new is that the realization of these high temperatures is now brought within the realms of possibility, on the one hand, through the progress made in the manufacture of heat-resistant and non-scaling steels and on the other through the practical experience obtained by the firm with high temperatures in connection with the gas turbine.

It is proposed to superheat both the live-steam, with a pressure of about 140 kg/cm² abs. and the partly expanded steam to 600° C, i. e., to a temperature which is about 100° C above the highest temperature ever employed in steam practice. In order to be able to control this temperature reliably both the live-steam superheating and re-superheating processes are transferred to a separately-fired heat exchanger operating on the Velox principle. On the other hand, an orthodox high-pressure boiler can be employed as steam generator in which the steam is raised to the conventional temperature of 460—500° C.

For units of at least 25,000 kW the steam turbine is of the four-cylinder type. The first two cylinders, in which the highly superheated steam is expanded, are of heat-resistant material, while their rotors, running at high speed, are coupled through gearing to the i. p. and l. p. turbines which turn at 3000 r. p. m. The parts coming into contact with the high-pressure, high-temperature steam are thus of the smallest possible dimensions, the high pressures thus being controlled without difficulty. All pipes, headers, and nozzle chests subjected to the high pressure are protected against the highly superheated steam by a lining of highly heat resistant sheet steel.

It is anticipated that such an installation working at a pressure of 140 kg/cm² abs. and a live-steam temperature of 600° C, re-superheating to 600° C, and feed water heating to 215° C in five stages by means of extracted steam, will have a heat consumption of about 2050 kcal per kWh at the generator terminals or a thermal efficiency of 42 %. If it is assumed that the economy of the boiler and superheater is 86 %, the total heat consumption, including the auxiliaries, will be about 2410 kcal per kWh at the generator terminals, thus giving an overall efficiency of practically 36 %. With a Velox boiler having an efficiency of 92·5 %, but feed water heating to a lower temperature (about 100° C) the heat consumption would drop to about 2300 kcal per kWh at the generator terminals, while the overall economy would be raised to over 37 %, thus rivalling the long strived after efficiency of the Diesel engine. Further details of this interesting plant, which is already being given serious practical consideration, will be found on pages 133—145 of the Review for 1943. Fig. 6 shows the influence of the live-steam temperature on the heat consumption of an installation with and without feed water heating and re-superheating.

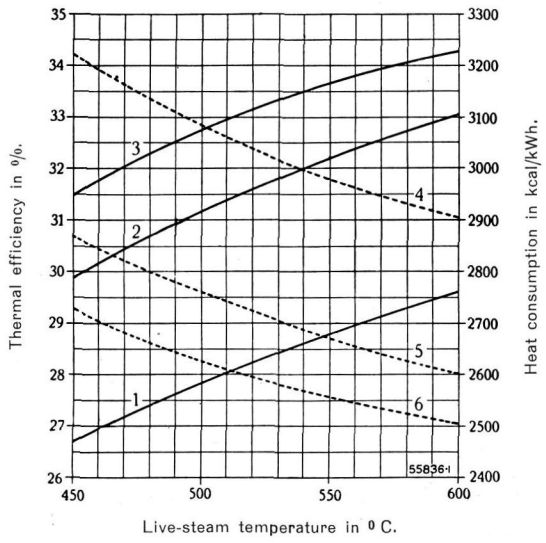


Fig. 6. — Thermal efficiency and heat consumption of a 50,000 kW turbo-set as a function of the live-steam temperature.

— Thermal efficiency
..... Heat consumption

} from coal to generator terminals, including feed-pump and condensing plant auxiliaries. Re-superheating to live-steam temperature. Feed-water heating to about 215° C by extracted steam. Boiler efficiency assumed to be 86 %.

1 and 4 refer to an installation with neither feed-water heating nor re-superheating.
2 and 5 refer to an installation with feed-water heating, but without re-superheating.
3 and 6 refer to an installation with feed-water heating and re-superheating.

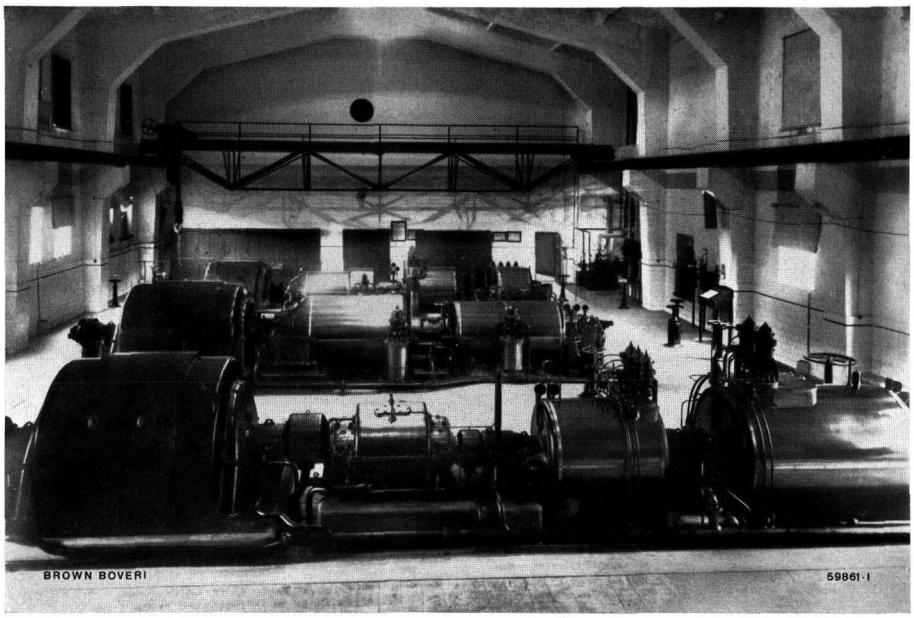


Fig. 7. — View of engine room of large foreign paper mill.

Three Brown Boveri turbo-sets of different years of construction, viz., 1942, 1934, and 1930, were supplied. The latest machine, in the foreground, is a high-pressure, extraction and back-pressure turbine of two-cylinder design, with a rating ot 5000 kW at a pressure of 120 kg/cm² abs., 480° C. The back-pressure is 4·5 kg/cm² abs., while in addition steam can be extracted at 37 kg/cm². — The machine in the centre is a double-extraction two-cylinder turbine rated 4500 kW with extraction points at 13·5 and 3·5 kg/cm² abs. — The unit in the background has a rating of 2500 kW. It is a three-cylinder mixed-pressure turbine for 36 and 13·5 kg/cm² abs. with controlled extraction at 3·5 kg/cm² abs.

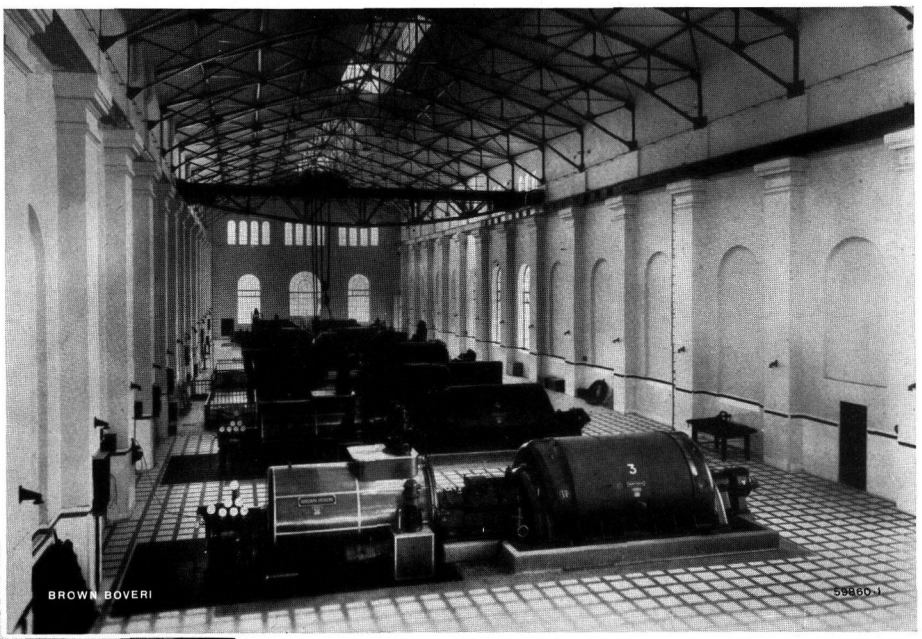


Fig. 8. — Steam power station of a foreign electricity supply undertaking.

This comprises seven Brown Boveri turbo-sets, five of which are straight condensing machines each rated approximately 20,000 kW with steam at 20 kg/cm² abs., while the remaining two are primary turbines having a rating of 15,000 kW each with steam at 125 kg/cm² abs. superheated to 490° C. They exhaust into the existing 20 kg/cm² abs. steam mains.



Fig. 9. — Three-cylinder turbine rated 25,000/31,000 kW, 36 kg/cm², 425° C.

There is still a demand for Brown Boveri three-cylinder turbines, since they have proved to be thoroughly reliable machines. To date a total of 102 such turbines with an aggregate rating of 2·5 million kW have been supplied. For the foregoing conditions a two-cylinder model, which is quite the equal of the three-cylinder type, is now usually supplied.

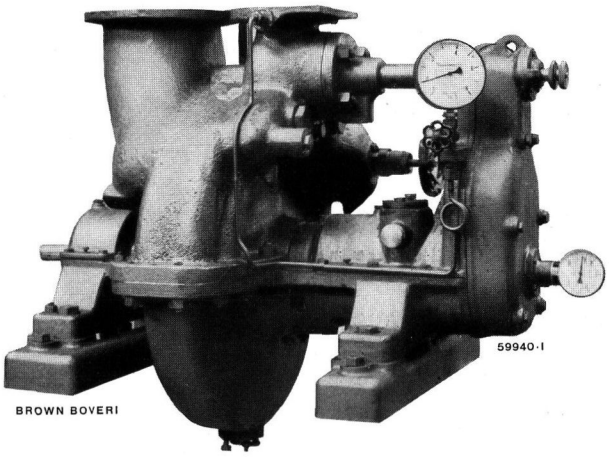


Fig. 10. — Small turbine for outputs up to 500 kW and speeds between 3000 and 5500 r.p.m.

Maximum steam pressure 40, back-pressure 5 kg/cm² abs. This turbine has a governor (on the right) which operates directly on the admission valve through the intermediary of the horizontal rodding visible behind the pressure gauge. This type of turbine is mostly employed for the drive of generators, pumps, blowers, and the like, usually without gearing.

Figs. 7 and 8 depict plants recently extended through the addition of new sets, while Fig. 9 confirms that purchasers are still to be found for the approved Brown Boveri three-cylinder turbines.

Notwithstanding the strong tendency to concentrate on the development of large turbines the smaller models were not neglected. Fig. 10 shows a design for special purposes.

C. COMBUSTION TURBINES.

As in the case of the Velox boiler, work in the gas turbine field was chiefly confined to development and to the elaboration of quotations for which there was a real interest, while the completion of installations mentioned in earlier years had to be put back for more urgent contracts due to the abnormal conditions. The research work has been pursued in three principal directions: firstly, on the combustion turbine for special applications, where operating conditions are particularly in favour of the gas turbine; secondly, on installations with which combustion turbines in their simplest form are employed and pre-heaters or recuperators of suitable proportions enable efficiencies to be attained which not only equal, but even surpass those of large steam installations; thirdly, on plants of very high output where the generator and compressors are driven by separate gas turbines, the compressors being of the centrifugal or radial-flow type, if desired, and their power consumption kept low by cooling.

As an example of the first application there is the proposal for an industrial plant in which a rich CO gas is available from the furnaces of a metallurgical process. After cooling, the gases are supplied to a gas turbine which, with correspondingly proportioned recuperators, attains a thermal efficiency of 26% and delivers a net output of approximately 900 kW. The exhaust of the gas turbine, which still has a temperature of about 180° C, is employed to dry casting moulds, so that the actual utilization of the liberated heat is substantially better than the 26% mentioned above.

Since, in the case under consideration, importance is attached to high efficiency at partial loads two gas turbines were put forward, one for driving the generator at constant speed and the other for the variable-speed drive of the compressor.

Although such gas turbine installations differ in many respects from the gas turbines and chargers used for chemical or metallurgical processes both the machines employed and the operating conditions are virtually the same. It may therefore be recalled here that many Brown Boveri gas-turbine driven chargers are already running in chemical works — some with more than 50,000 operating hours to their credit — and give entire satisfaction. Notwithstanding its almost unbelievably high operating temperatures the gas turbine is a simple and reliable machine.

The fact that within a certain output range efficiencies can now be quoted for the simplest type of combustion turbine which can compete with those of large steam installations is due to the liberally proportioned recuperators employed.[1] The heating surfaces necessary to transmit the heat content of the exhaust gases to the air are extremely large; they may attain 0·5—1·0 m² per kW net output of the plant. The size of the recuperator or, what practically comes to the same thing, the overall efficiency, depends on the cost of the heater which can be economically allotted to the plant in question, whereby according to the size of the plant and the duration of the load different values may apply. Apart from the question of fuel the prospects of the simplest form of combustion turbine depend, therefore, on the success attending the endeavour to evolve less expensive and more suitable recuperators.

It goes without saying that every effort has been made to solve this problem. It is not so much the semi-finished parts, e. g., the tubes, which are the most expensive, but their assembly. Now that suitable manufacturing methods have been developed, however, the cost of the recuperator should no longer prevent high efficiencies being attained with gas turbine plants.

[1] See also "Die Wärme", 1943, pp. 200/201.

concerned, however, the amplitude of the vibrations is only two thousandths of a millimetre.

It was chiefly due to these very favourable results with built-up rotors that extensive studies were taken up during the year with a view to the design of two-pole turbo-generators with ratings of 100,000 kVA and over.

2. *Diesel-driven Generators.*

In this field the *emergency sets*, already referred to on several occasions in this journal, are still meeting with a big demand. A special small set has been devised for the lighting and ventilation of air raid shelters, which comprises an electric motor, a fan, and a declutchable Diesel engine. As long as the lighting supply to the shelter is available the electric motor drives the fan for the ventilation of the room, the Diesel engine being uncoupled. Should the supply fail, however, the Diesel engine is started and automatically coupled to the set which it then drives. In such cases the motor operates as generator to supply the lighting of the shelter. A condenser connected in parallel to the motor provides the excitation during transition to generator service, thus enabling a standard squirrel-cage machine to be employed. As a result the whole equipment is simple and inexpensive.

A new method of electrical output governing was developed for emergency sets generating direct current. The impulse for the control of the engine is imparted by the voltage of the direct-current machine in that a voltage-dependent regulator directly controls the governing valve of the engine via a rotary magnet, a centrifugal-type governor being dispensed with. This new electrical governor operates both rapidly and free from hunting, and considerably simplifies the operation of direct-current sets.

3. *Hydraulic Generators.*

Of the hydraulic generators built during the year the following are worthy of special mention: —

In the *Martigny-Bourg* power station the existing sets were replaced by units of higher capacity. Brown Boveri supplied three three-phase alternators of 8000 kVA, for 10,000 volts, 750 r. p. m., of the enclosed, horizontal two-bearing design. The windings of these machines are of copper, but due to the impossibility of obtaining forged steel shafts of the required dimensions, a novel kind of rotor design was resorted to, consisting of cast-steel shaft-stubs bolted to the rotor body by means of amply dimensioned flanges. Notwithstanding its comparatively high cost, this new design, which is as good if not better than the old from a mechanical point of view, will have to be retained as long as cast-steel deliveries are quicker and more reliable than would be the case with forgings. Fig. 17 shows the engine room of the power station with the new generators.

At the beginning of October last year the *Mörel* power station of the *Aluminium Industrie A.-G., Lau-*

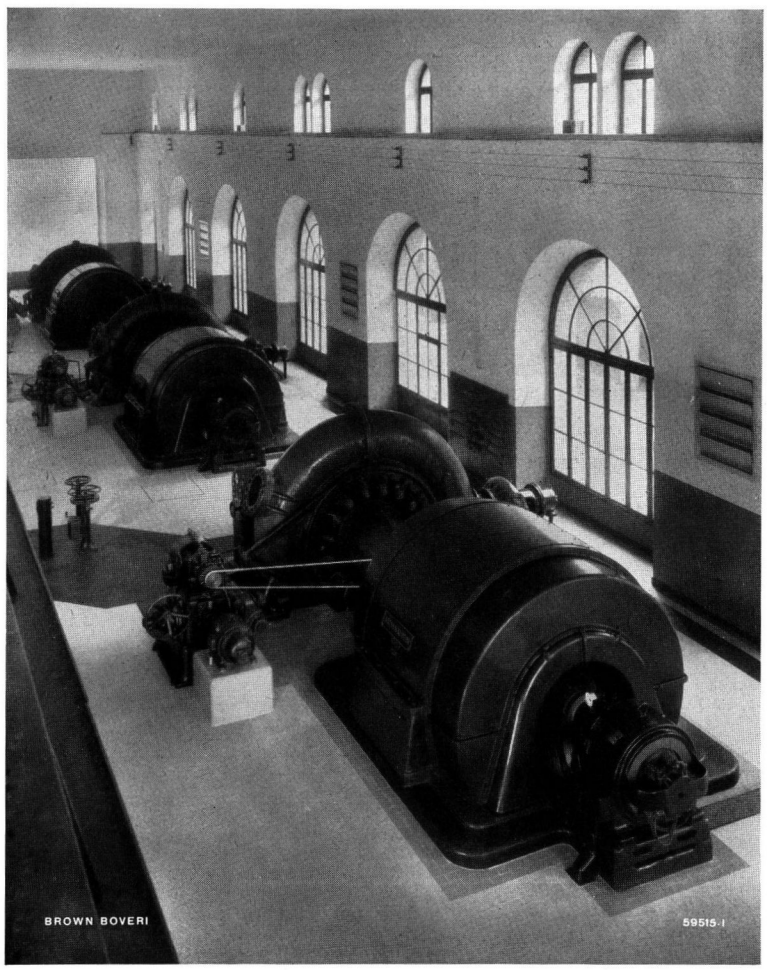


Fig. 17. — Engine room at Martigny-Bourg Power Station (Valais, Switzerland).
View of the three three-phase alternators rated 8000 kVA, p. f. 0·75, 10,000 ± 10% Volts, 50 cycles, 750 r. p. m., from the exciter end.

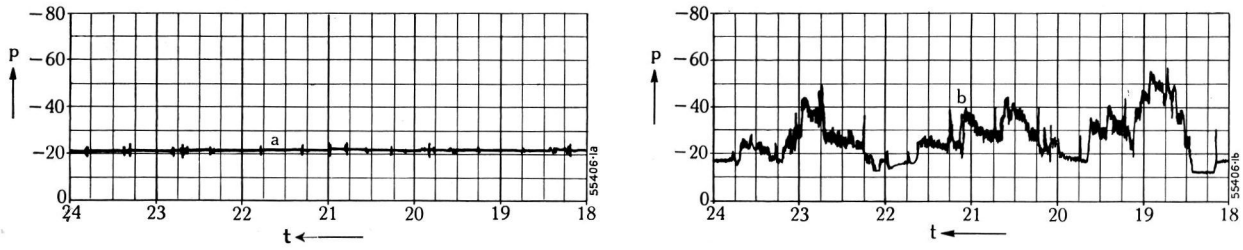


Fig. 15. — Pressure characteristic in a pipe the gas exhauster of which is regulated (a) with the new regulator, (b) with a hitherto conventional regulator.

The abscissæ t represent a period of six hours, the ordinates p the gas pressure in the pipe in mm w. g. As will be seen the regulator maintains the pressure constant within 1 mm w. g.

Apart from the equipment a new regulating process has also been developed for gas distributing and collecting systems. For the coarse regulation of such systems it was hitherto the practice to employ regulators to maintain the pressure constant in the distribution or collecting pipe until it became too high or too low for the pressures to be maintained by the fine regulators, this condition being indicated to the attendants by signals. After the blower had been adjusted to the new pressure, operation was continued under these conditions until a fresh signal demanded a further alteration. It is clear that with this method of coarse regulation, apart from the moment at which re-adjustment was called for, the delivery pressure was invariably higher and in consequence the power consumption of the blower greater than absolutely necessary.

The aim of the new regulating system is to avoid this extra expenditure of energy. With this method of regulation the delivery of the blower is reduced step by step at regular time intervals by means of an electric time switch, except at the moment the signal of one of the fine regulators shows that further reduction of the delivery pressure is impermissible. From this point onwards the delivery is increased instead of decreased in steps. The delivery pressure is thus made automatically to follow in a fine zig-zag line the limit pressure just sufficing to maintain the pressure required by the fine regulators.

After installation of the necessary equipment any gas collecting and distributing system can be made to operate in the most economical manner with the new system. The initial outlay involved is negligible compared to the savings which can be realized.

E. GENERATORS.

The upward trend in the construction of power stations, which began in 1942, was maintained during the year under review, thus affording an opportunity of supplying a considerable number of generators of all sizes with the necessary protective gear.

1. *Turbo-generators.*

Twelve years ago built-up cylindrical rotors were devised for large turbo-generators with a view to putting an end to the difficulties continually encountered in the manufacture of homogeneous single-piece rotor forgings of great length and correspondingly large diameter, which in practically every case resulted in delay in delivery. Under present conditions, when such forgings are so difficult to obtain from abroad, this design has proved particularly advantageous. During the year under review a 50,000 kVA, 3000 r. p. m. turbo-generator with the largest built-up rotor so far constructed was set to work. It proved to run so quietly that also on this score built-up rotors appear to equal if not to surpass the one-piece construction. An idea of the quiet-running properties of the machine is given by the amplitude of the vibrations measured on one of the bearing pedestals during the overspeed test. As proved by Fig. 16, from starting to normal speed back down to standstill the amplitude of the vibrations attains its maximum value of about $1^1/_4$ hundredths of a millimetre at around 2000 r. p. m. Where the normal revolutions of 3000 r. p. m. are

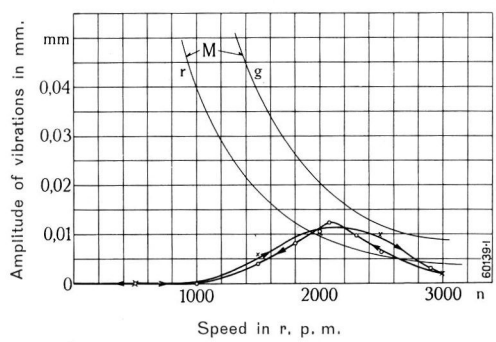


Fig. 16. — Investigations into running of built-up turbo-rotor from a mechanical point of view.

Characteristic of lateral vibration of external bearing pedestal as a function of the speed.

M. Curves of running properties of a machine.
g. Permissible.
r. Very quiet.

good coarse regulator has been felt. When designing such a regulator it is not so much the question of sensitivity which causes the greatest difficulty as the stability conditions due to the length and capacity of the connected pipe-lines. In consequence, a regulator giving a permanent speed rise and a temporary statism variable within wide limits had to be devised.

Fig. 12 shows a section through such a regulator. It is of extremely compact design. Parts entailing friction are

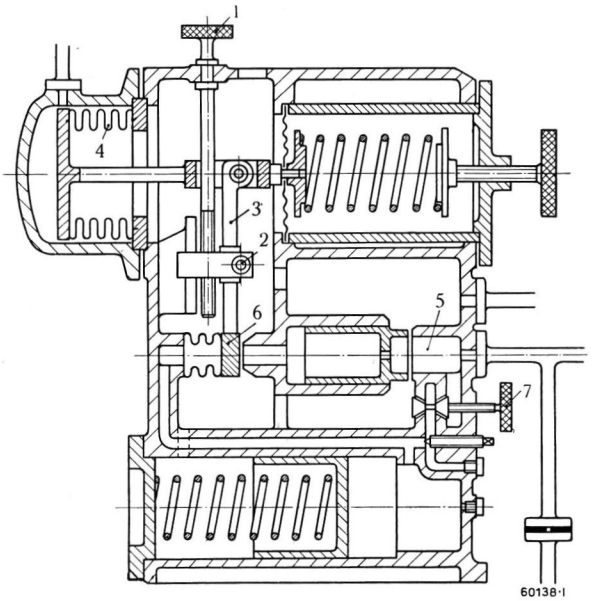


Fig. 12. — Pressure regulator for difficult stability conditions.

The regulator incorporates contrivances for varying the permanent speed rise and temporary statism and therefore finds application where the temporary statism has to be adapted to the actual stability conditions and the permanent speed rise must be small to enable the specified regulating accuracy to be adhered to. Both the permanent speed rise and temporary statism are varied by altering the ratio between the pressure to be regulated and the pressure of the governing oil corresponding to the revolutions of the machine. This alteration is achieved with screw (1) with which the fulcrum (2) of the balance beam (3) can be varied so that a variable oil pressure in (5) corresponds to the pressure on the diaphragm (4). Further correction of the permanent speed rise can be effected by altering the pressure of the oil acting on plate (6). This is achieved by throttling the oil with screw (7).

avoided. Where articulations could not be obviated so-called band couplings or ball bearings are employed. Notwithstanding its small dimensions the regulator has a large capacity, since it contains an amplifier enabling several control pistons to be directly operated simultaneously. In cases where the regulator only has to control one piston the amplifier is dispensed with.

The regulator can be employed for a large number of different duties. A number of orders have already been executed for, e. g., extraction and back-pressure turbines, for gas turbines for supervision of the gas pressure, etc. The external construction of the regulator is depicted in Fig. 13. A simplified design is shown in Fig. 14. Such a regulator was also supplied to a municipal gasworks for the coarse regulation of the collecting pipe of the gas exhauster. Due to the excellent service given by the regulator this delivery led to a repeat order. Fig 15 gives comparative charts of this coarse regulator.

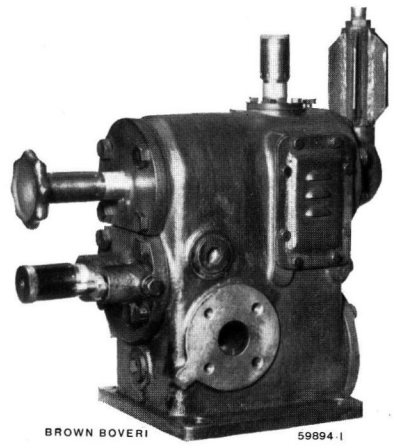


Fig. 13. — External view of pressure regulator in Fig. 12.

The regulator is of extremely compact design. The adjusting devices are on the outside and therefore accessible,

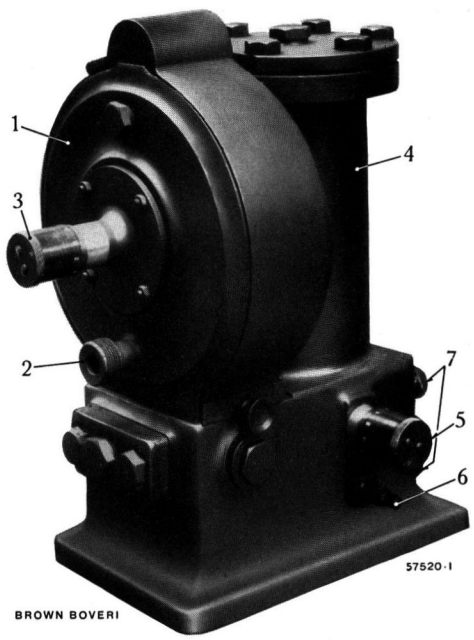


Fig. 14. — Suction pressure regulator with permanent speed rise and temporary statism adjustable independently.

The insensitivity of the regulator is about 1 mm w. g.

1. Diaphragm casing.
2. Connection for impulse pressure.
3. Adjusting screw for specified pressure.
4. Air dash-pot.
5. Adjusting device for permanent speed rise.
6. Adjusting device for temporary statism.
7. Connection branches for governing oil inlet and outlet.

Large installations, i. e., of over 5000 kW rating will comprise several machine sets with compressor and turbine split up into two or more pressure stages. The air will preferably be cooled between the pressure stages and the driving gases reheated to approximately 600° C between the turbine stages through the interposition of a further combustion chamber. Where ratings up to about 10,000 kW are concerned such a gas turbine plant surpasses high-class steam installations on the score of economy. Not only is fuel consumption lower, but the gas turbine plant is simpler and less expensive and requires less cooling water.

For outputs between 10,000 and 20,000 kW a combustion or steam turbine may come into consideration according to the conditions of the case in question. In the authors' opinion outputs over 20,000 kW still remain the undisputed field of the steam turbine. As to efficiency, initial outlay, fuel consumption, and space requirements the steam turbine has the advantage over all types of gas turbines where large outputs are concerned.

All of the foregoing particulars are based on operation with gaseous or liquid fuels. The tests with pulverized coal have not yet been concluded. Some time is bound to elapse before the pulverized-coal fired turbine is ready for sale. Details of combustion turbines for locomotives will be found in section IV on page 85 and for the propulsion of ships in section VI on page 94.

D. GOVERNING GEAR.

During the year various governing problems were dealt with, while an opportunity of trying out notable improvements also presented itself.

One of the new designs is an output limiter which operates with a time-lag to enable outputs lying above the value set on the limiter to be maintained for a short period. This device is employed to prevent excessive overloading of turbines.

With delayed output limiting transient overload surges have no effect and in the case of slow increases the limiting is effected only after the elapse of a certain period. This characteristic is achieved through a piston valve embodied in the output limiter. Upon the occurrence of sudden load fluctuations this valve is thrown out of equilibrium by the governor or the oil under pressure, and moves so slowly that it is only after the elapse of a certain period, e. g., 3—30 seconds, that it opens the oil outlet which regulates the pressure of the value corresponding to the adjusted limiting output. Electrical remote control gear can be employed to adjust the limiting output, e. g., from the switchboard.

Fig. 11 is an external view of the limiter.

A similar piece of apparatus—as far as design is concerned—is employed for a very different duty, i. e., to prevent racing of turbines when the load is suddenly thrown off. Instead of leaving the adjustment of the pressure of the governing oil exclusively to the governor the oil pressure is temporarily regulated by a device directly dependent on the output of the generator. The governing oil pressure is thus immediately adjusted to correspond to the new load, i. e., before any noticeable alteration in the turbine revolutions has taken place or the governor can intervene. As soon as the latter has adjusted itself to the new load conditions, however, it again takes charge of the turbine.

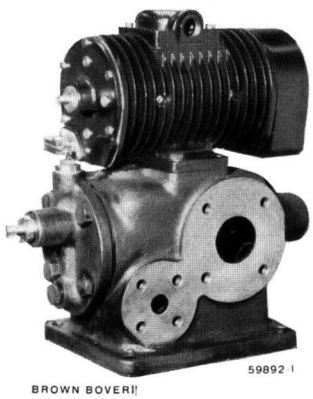


Fig. 11. — Output limiter for steam turbines.

The limiter operates with a time-lag and has no effect until some time (3—30 sec) after the overload has occurred. For instance, it permits the steam turbine to utilize the reserve capacity of the boiler and only limits the output when the steam pressure begins to fall noticeably. The output at which the limiter is required to function can be adjusted from the switchboard.

Further improvements have also been made to the regulating equipments for gas distributing and collecting systems, e.g., for the supply of gas over long distances or in coke-oven plants. Since the pressure is usually required to be maintained constant within narrow limits in the various consumers' systems or at the points of supply, regulation is effected at two independent points, the one, the so-termed fine regulator, before each branch pipe, the other, the coarse regulator, in close proximity to the blower in the collecting pipe.

Details of a precision regulator having a sensitivity within 1 mm w. g. and therefore suitable for systems of the type referred to above, were given in an earlier number of this journal.[1] In the interim, however, the need of a

[1] The Brown Boveri Review 1940, p. 171 and 1942, p. 11.

sanne, was put to work. This station utilizes the head of the Rhone between Fiesch and the Swiss Federal Railways Massaboden power station just above Brig.

The station is equipped with three horizontal three-phase alternators driven by Francis turbines, each rated 20,000 kVA, 9000 ± 7 % volts, 750 r.p.m., 50 cycles. Two house sets driven by Pelton wheels, each rated 300 kVA, 1000 r.p.m., 400 volts, 50 cycles, supply the station auxiliaries. The design of the main alternators was to a large extent affected by war-time conditions, particularly the windings, which are entirely of aluminium. The numerous connections between the half coils are made by a new soldering process, which is sheet steel of the required dimensions, the stator frames had to be made of cast iron, a recourse to design principles prevailing for over four decades, until superseded some years ago by the fabricated construction, which in normal times is more economical. The high degree of purity of the atmosphere permits of dispensing with air filters, the cooling air being conducted directly under the end bells by means of ducts; from there it is drawn in by means of axial-flow fans fitted at both ends of the rotor and expelled radially into the stator casing through a large number of air ducts in the core, finally escaping underneath into the hot air duct. The journal bearings are ring-lubricated, the



Fig. 18. — Engine room at Mörel Power Station (Valais, Switzerland).

View of three three-phase alternators each rated 20,000 kVA, 9000 volts, 50 cycles, 750 r. p m., from the exciter end. The alternators with main and pilot exciters are directly coupled to the turbines. Totally-enclosed self-ventilated pattern. The windings are of aluminium and were installed on site. The winding heads were soldered by the new Brown Boveri process with a non-hygroscopic flux. The bearings are ring-lubricated, the alternator and turbine bearings of each set having a common oil circulating system with oil pump and cooler. This power station operates in parallel with the Turtmann and Chippis stations to supply the system of the Aluminium-Industrie A.-G., Lausanne.

absolutely non-corrosive. The customer, one of the large aluminium producers, accepted the new method only after exhaustive tests in his laboratories had proved its superiority beyond doubt. Another problem which required careful analysis was the supporting of the aluminium windings in both rotor and stator, which was complicated by the comparatively large dimensions of the stator coils. The rotors are designed along the same lines as those of the Martigny-Bourg generators described above. Due to the difficulty of obtaining oil being recooled in a closed circuit cooling system common to turbine and generator. A pilot exciter combined with a 2 kVA three-phase alternator which feeds the driving motor of the turbine governor, is coupled to the directly built-on main exciter. The two house generators of the standard horizontal one-bearing design are also equipped with aluminium windings and are driven by two-bearing Pelton wheels. Fig. 18 shows the engine room of the new power station.

An order was received from the "Aare-Tessin A.-G. für Elektrizität", Olten (who owns the Olten-Goesgen power station, besides several others on the southern slopes of the St. Gotthard) for two horizontal three-phase alternators, each rated 32,500 kVA, 500 r. p. m., 12,000 volts, 50 cycles, together with transformers and switchgear for the Airolo power station of the *Lucendro hydro-electric development.* The carrying through of this scheme despite the greatly increased building costs and the corresponding risks is a commendable example of the spirit of enterprise still permeating privately owned undertakings. The first stage of the high-head development will be ready for service early in 1945 and should thus help to mitigate the danger of a recurrence of the shortage of energy experienced in Switzerland during the winter of 1941/42.

Apart from this heavy equipment a large number of small generators were also supplied *for the modernization of antiquated industrial and other power stations.* In such plants it is often possible to replace the existing and by now uneconomical turbines by modern ones which with the same or but slightly increased water flow will develop more power at the coupling and by replacing the generator at the same time more kW at the generator terminals. Such modernization schemes are usually well worth the expense involved. In order to reduce the cost of such conversions, a simplified design of vertical-shaft generator has been developed with journal and guide bearings combined into one self-cooled unit. This arrangement simplifies operation, and together with the straight axial ventilation, reduces the overall height. The method of ventilation mentioned presents the added advantage of not requiring radial cooling air ducts in the stator laminations.

A very special case was the modernization of the second 1240 kVA, 93 r. p. m. alternator of the *Aue Power Station at Baden (Switzerland),* where it was decided to replace the exciter. The latter was mounted on the generator shaft directly below the rotor instead of above and was, therefore, quite inaccessible. As a matter of fact, it could not be dismounted without first withdrawing the whole pole wheel. On account of the slow speed of the machine, it was found impracticable to place the exciter above the rotor, while a separate vertical-shaft belt-driven exciter was equally undesirable on account of the complications due to the drive, the corresponding maintenance and other complications. Finally, a motor-driven exciter fed from the generator terminals through a three-phase transformer was decided upon. This set is small, of good efficiency and can be located anywhere. For starting up, the generator is temporarily excited from the station battery with automatic change-over to the exciter set, when the normal voltage is reached. After a study of system conditions, a persistent drop in the generator voltage on account of external faults seemed very unlikely and to overcome temporary voltage drops, the exciter set is designed with an increased flywheel effect. The instruments and change-over equipment for the exciter are lodged in a desk structure close to the set.

This arrangement is not only to be recommended for alterations, but should be just as advantageous for new equipment where the slow speed of the machine would otherwise lead to disproportionately large and expensive exciters, or in cases where separate erection of the exciter would simplify the design of the alternators, as for instance of parasol types, or facilitate mounting the turbine governor.

The motor of the governor oil pump and of the electric primary governor are connected to the same transformer as the exciter set, eliminating thereby all belt drives. The *primary governor* (Fig. 19) is the

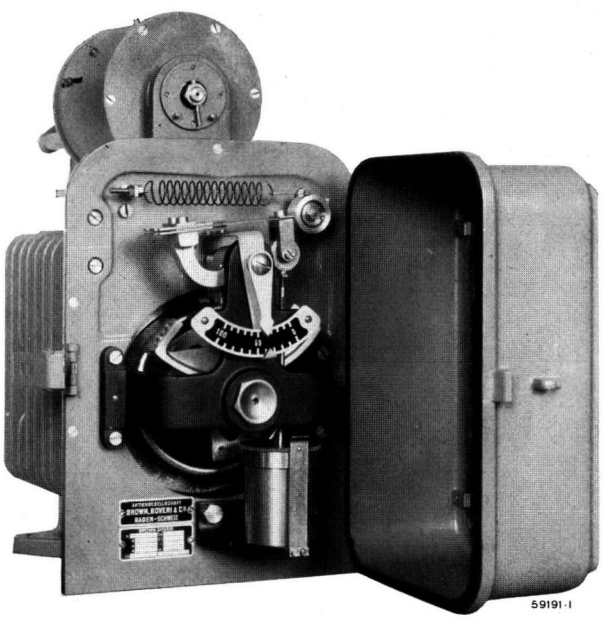


Fig. 19. — Electric primary governor for mounting on the Escher Wyss servo-motor of the second 1240 kVA, 93 r. p. m. Francis turbine set at the Aue Power Station, Baden (Switzerland).

Both this primary governor and the governor oil pump are connected to the generator terminals through a transformer, so that the set has now no belt drives whatsoever.

second to be installed in this power station. The inherent simplicity of the drive, together with the excellent record of the first governor placed in service in May, 1941, were the deciding factors leading to this choice when the original mechanical governor had to be replaced.

4. *Generator Protective and Regulating Equipment.*

Protective equipment for preventing or eliminating external faults was considered an essential element of electrical systems from the very beginning of electrical engineering and in consequence its development has kept pace with the progress of the art, culminating in the Brown Boveri high-speed distance relay equipment, which satisfies all practical requirements. On the other hand, it took some time before power station operators realized that internal faults in generators and similar machines merit just as much if not greater attention than faults on the other side of the machine circuit-breaker, because the former are often of a more serious nature and can as a rule not be remedied by simply opening a circuit-breaker for a limited period, as would be the case with an ordinary flash-over on an overhead line.

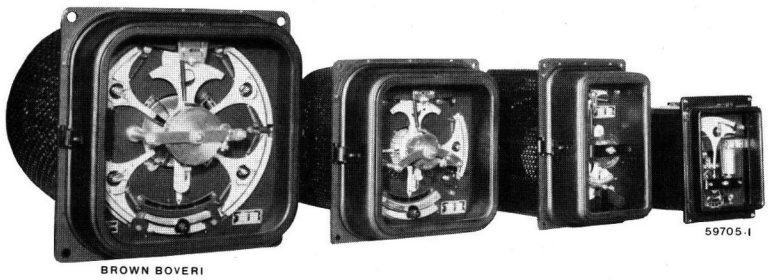
Even when the importance of rapidly de-energizing the machine in case of internal faults was finally recognized, such equipments were often confined to the largest units and even these were not always protected in this way. The reason for this reluctance of operating engineers to specify generator protective equipment was largely due to the fact that although certain internal faults could be controlled with relatively simple means (for instance differential relays) there was no equipment of the necessary simplicity and reliability available to give full protection against ground faults.

In consequence, many an operating engineer reasoned that in view of the trustworthiness of the generator manufacturers, internal faults were extremely unlikely and they preferred to risk serious damage and a prolonged shut-down in the event of such an occurrence, due to delayed de-energizing of the machine, instead of providing protective equipment, which after all could not take care of all possible faults, but only of those occurring in a restricted part of the winding. Moreover, it had to be considered that such equipments were often rather delicate and might, therefore, be the cause of undesirable shut-downs. They also presented certain difficulties for routine checking.

To-day, however, due to continued and systematic development work and progressive adaptation of the protective gear to the operating requirements, i. e., simplicity and reliability, the position is quite different. In point of fact, hardly a single Brown Boveri medium or large-sized generator is now taken into service without complete generator protecting gear.

Whereas relatively simple *differential equipment* for the protection of generators against internal short circuits between phases is well known, it took a long time to devise an *earth fault relay* capable of protecting the whole winding. Such equipment, however, is of paramount importance, since faults between phases often originate as breakdowns to ground, in which stage, if the protective gear is correctly designed, the generator suffers either no harm whatsoever or only damage which can be readily repaired. One of the main difficulties of the problem is that the neutral voltage generally employed to detect the ground fault, as well as the fault current fluctuate between zero and a value determined by the full phase voltage, according to whether the fault occurs at the neutral point or near the terminals. This places very severe requirements on both the rating and the sensitivity of the relays to be employed. In consequence, the zone of protection had to be restricted to about 80 % of the entire winding unless the operating range of the relays could be artificially modified by the introduction of elements of doubtful reliability, as for instance hydrogen-iron stabilizers.

The recently developed Brown Boveri *generator earth-fault protecting gear* is based on fundamentally new principles, the variable neutral voltage being only employed in a subsidiary manner to determine the point of fault. As a result the entire equipment consists of robust elements on which only moderate and readily acceptable requirements need be placed as regards operating range. Nevertheless, a range of protection of 95 to 99 %, never before achieved by simple means, has been obtained. We are convinced that this new ground fault protection represents a considerable advance compared to older schemes and we trust that it will give a fresh impetus to the tendency to fully protect important alternators.



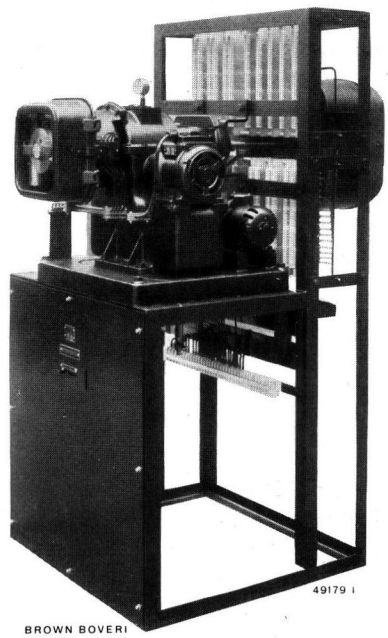


Fig. 20. — Brown Boveri quick-acting regulators.

Four models with rocking sectors and the oil-servo-motor high-capacity regulator on the right form the complete line of Brown Boveri quick-acting regulators for continuous regulation. There is a suitable regulator for every size of machine and every regulating problem.

Simultaneously with the above equipment, we have developed a new relay, capable of discerning short circuits between turns of one and the same phase, characterized on the one hand by extreme sensitivity and on the other hand by not being influenced by switching asymmetries and harmonics.

Further, we have also developed a new system for detecting ground faults in the field circuit.—Special equipments are also available for protecting split-phase machines, single-phase generators and similar special cases.

An essential element of this kind of equipment is a simple and reliable field suppression device, utilizing the main field switch, which should be installed on all machines equipped with internal fault relaying.

Finally, it should be mentioned that by partly or fully replacing straight overload relays, it is possible to utilize to the full the thermal overload capacity of existing machines, in order to overcome a temporary shortage of generating capacity, without endangering the machines due to excessive temperature rise.

That our efforts in the field of generator protection are meeting with recognition is proved by the numerous orders received in Switzerland and abroad. All large power stations recently built in Switzerland and many smaller ones have been equipped with Brown Boveri generator protective gear.

The line of *automatic quick-acting voltage regulators for a. c. machines* has been completed by a small single-sector regulator intended for alternators below 50 kW. Its sensitivity compares quite favourably with that of the larger types. It permits economic voltage regulation of small machines, enabling even power companies with limited means to avail themselves of the advantages of a constant voltage (Fig. 20). Besides the four types with rocking sectors for low to medium exciter outputs, a high-capacity quick-acting regulator is available for the largest exciters.

In the review of progress covering the year 1941, reference was made to a new *high-speed automatic synchronizer*[1]. In the meantime such devices have been set

[1] See The Brown Boveri Review 1942, page 23.

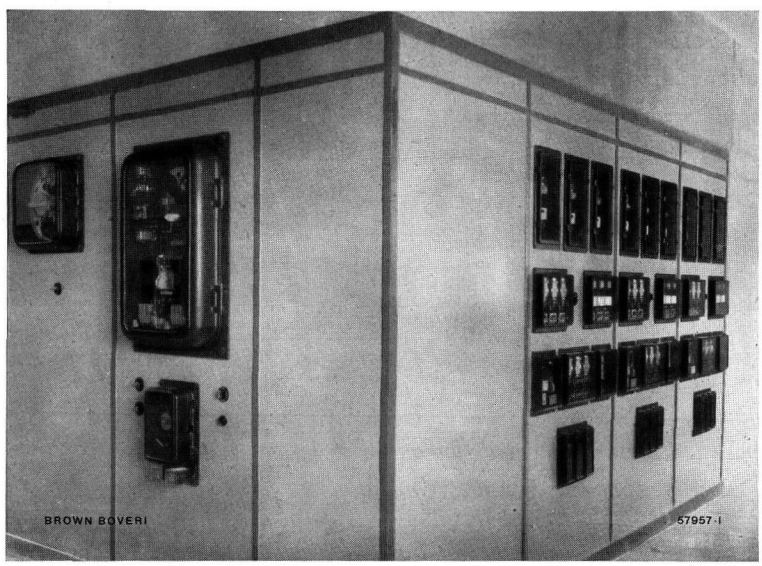


Fig. 21. — High-speed synchronizing equipment (on left) and protecting relays for the three alternators in the Verbois Power Station owned by the City of Geneva.

The complete protective gear, including the meters, can be lodged on one panel per machine. These comparatively simple equipments protect the alternator against the persistence of internal faults, thus preventing severe damage. All large or otherwise important generators should be fully protected against external and internal faults.

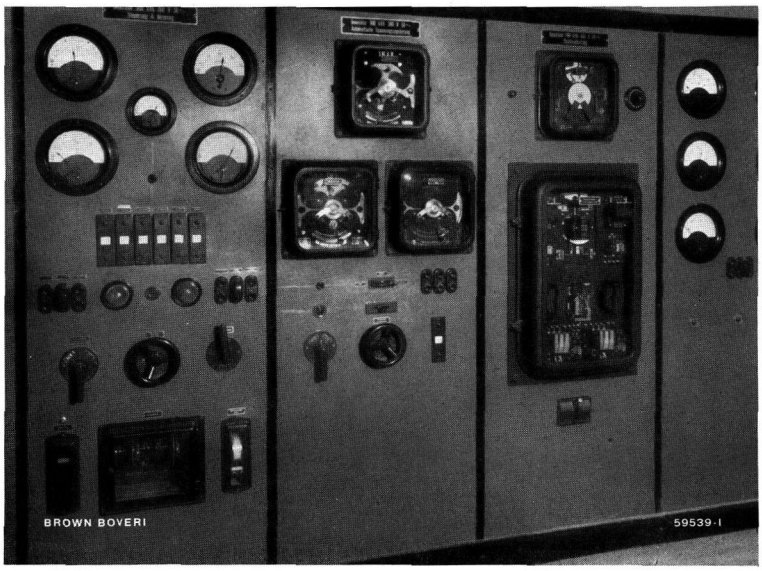


Fig. 22. — High-speed synchronizing equipment in the Bözingen automatic power station of the Vereinigte Drahtwerke A.-G., Biel.

Even with frequency differences of 1%, i. e., when the synchronoscope makes one complete revolution in two seconds, the high-speed automatic synchronizer permits trouble-free paralleling, since the contacts of the switch it controls always make contact exactly at the moment of phase coincidence.

to work successfully in the Verbois and Bözingen power stations (Figs. 21 and 22). Service tests corroborated the works test results, i. e., that even with a slip up to 1% between the frequencies of alternators and systems to be paralleled, the power surge does not exceed a few per cent of the alternator output, because the contacts of the switch controlled by the synchronizer invariably make contact at the moment of phase coincidence. Service experience shows conclusively the great advantages of the automatic synchronizer which functions reliably and smoothly, even when service voltage and frequency are somewhat different from the rated values.

5. *Research Work in the Synchronous Machine Field.*

Small rotor-fed synchronous motors have been found to have a strong tendency to hunt, and this has frequently given rise to operating difficulties. The trouble was traced to *mechanical rotor oscillations*, but the cause remained to be cleared up. Theoretical and experimental investigations, which will be more exhaustively dealt with later in a separate article show that the oscillations are due to the unavoidable ohmic resistance of the a. c. winding of the machine. The resistances of the supply leads must also be considered up to the point where the system can be said to be "solid". The higher these resistances the greater is the likelihood of such oscillations being set up.

To mitigate this risk, increasing of the synchronous capacitive reactance of the machine can be resorted to. Machines with smooth cores are less subject to hunting than machines with salient poles. Great care must be taken always to keep ohmic resistances, especially in the supply leads, as small as possible. The angle between the field spider and rotary field axes is of decisive importance. As the angle increases the less the risk of oscillations becomes. In consequence, machines running light have a particularly strong tendency to hunt; the same applies to strongly excited machines. The frequency of the rotor oscillations is relatively small, lying between five or six oscillations per second for a machine in solo operation. Should the type of hunting described here occur in service it can be suppressed by reducing the excitation, connecting in a low-resistance choke coil, or increasing the cross-section of the supply leads. Large moments of inertia increase the duration of the oscillations, whereby a reduction of the torque causing the oscillations can simultaneously occur. For this reason hunting is chiefly observed in the case of small machines.

As already stated the problem of *generator earth-fault protection* has also been fundamentally studied. In this connection exhaustive investigations into the occurrence of higher harmonics in the phase voltages of synchronous machines were necessary. It must not be forgotten that even where pure sinusoïdal line voltages are concerned higher harmonics of the order of $3k$ ($k = 1, 3, 5, \ldots$) can occur in the voltages between phases. In the case of a 5000 kVA machine with salient poles third harmonics up to 50% (of the fundamental wave) and in the case of a 1875 kVA machine with smooth core 7% were measured (Figs. 23 and 24).

This fact can be explained as follows: —

Given a constant air-gap the stator ampere-turns which with a good approximation are distributed in sine form along the air-gap would produce an approximately sinusoïdal armature field. Due to the saturation and the space between the poles, however, the magnetic resistance and, in consequence, the effective air-gap around the periphery is not constant. The armature field is thus distorted and must contain a pronounced third harmonic which shows up in the phase voltages. Hence it is clear that the magnitude of this third har-

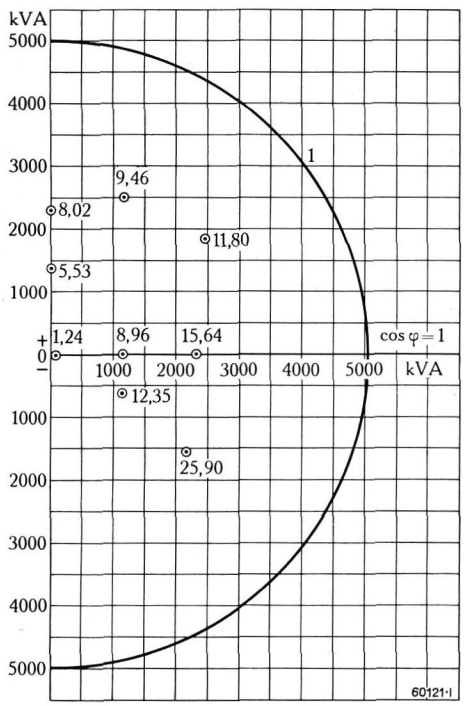


Fig. 23. — Percentage of third harmonic in phase voltage, referred to fundamental wave, at different loads.

Tests on a 5000 kVA machine with salient poles. The position of the test points shows the load on the machine, while the figures near them indicate the magnitude of the third harmonic in the phase voltage as a percentage of the fundamental wave.

1. Rated output of machine, below the axis of the abscissæ, underexcited; above the axis of the abscissæ, overexcited.

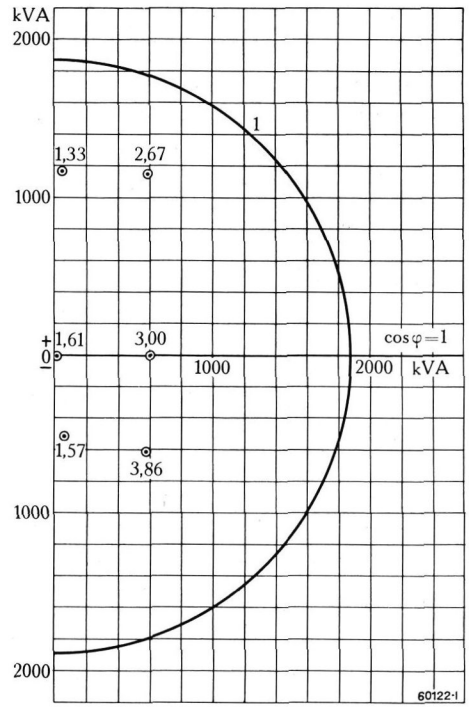


Fig. 24. — Percentage of third harmonic in phase voltage, referred to fundamental wave, at different loads.

Tests on a 1875 kVA machine with smooth core. The position of the test points shows the load on the machine, while figures near them indicate the magnitude of the third harmonic in the phase voltage as a percentage of the fundamental wave.

1. Rated output of machine, below the axis of the abscissæ, underexcited; above the axis of the abscissæ, overexcited.

monic and for that matter all 3 k harmonics increase approximately in proportion to the load current.

As a practical consequence of these conditions it results that the potential difference between the neutral point of a healthy machine and earth is far from being zero, but under certain conditions may be of considerable magnitude.

Another problem which occupied our attention was the *value of the capacitive loading of a synchronous generator up to which auto-excitation can be prevented by means of a quick-acting regulator* when the latter changes to "negative excitation" at the moment of switching in the machine. The clearing up of this question appeared important because, as is common knowledge, the energizing of an unloaded or lightly loaded transmission line throws a more or less capacitive load on the generator according to the capacitive reactance of the line. For purposes of test a 32·5 MVA alternator was employed to which a pure capacity was connected to simulate a long transmission line. A further aim of the tests was to see whether the auto-excitation process could best be controlled with a rolling-sector type quick-acting regulator, a high-capacity regulator, or a combination of a high-capa-

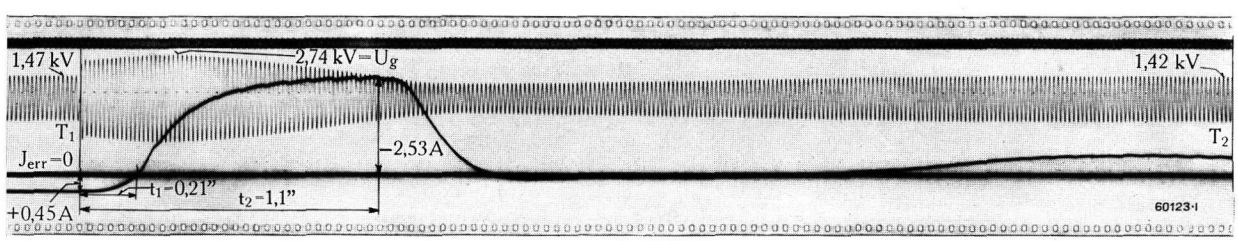


Fig. 25. — Voltage and exciting current characteristics when switching capacitive currents (control by high-capacity regulator).

T_1. Moment of switching in. T_2. Moment of switching out. U_g. Alternator voltage. J_{err}. Exciting current of main exciter.

city regulator with a contactor control for "negative impulse excitation".

To this end the alternator was run up light to the permissible voltage of the condenser, i. e., about 1 kV, corresponding to 10% of the voltage rating of the generator, and thereupon the condenser cut in. The behaviour of the alternator voltage and the exciter current to be regulated was followed on instruments and also oscillographically (Fig. 25).

The result of the tests may be summarized as follows: —

Auto-excitation was controlled by the regulators in every single test up to a maximum capacitive load of 36·5 MVA (referred to the rated voltage), i. e., 112% of the rated output with a synchronous reactance of the machine of 6·56 ohms = 148%. [1]

The regulating process proper, i. e., the change-over from positive to negative excitation, had fundamentally the same characteristic for all tests with the different regulators. An essentially quicker variation of the exciting current with a view to reducing the over-voltages occurring after switching is not possible with contactor controlled "impulse excitation" either, because it is the time constant of the excitation circuit and not the rapidity of response of the regulator which is the deciding factor. When employing a high-capacity regulator in combination with contactors the maximum over-voltage amounts to 170% of the no-load voltage with a capacitive load of 36·5 MVA.

The conclusions to be drawn from the test results are as follows: —

Synchronous alternators of the present design with salient poles and equipped with a high-class voltage regulator to suppress the tendency to auto-excitation can be capacitively loaded up to their rated output when thrown on to transmission lines under no-load conditions. The over-voltages occurring at the moment of switching cannot, it is true, be prevented by "negative impulsion excitation", but by diminishing the alternator voltage before switching in the machine a rise beyond the rated voltage can be prevented.

Finally, equipment for directly indicating the power developed by turbines was devised during the year under review. In the case of a turbine driving an electric generator its power can be very accurately determined from the generator output and losses. Where a turbine is employed to drive, for instance, a compressor, or gearing is interposed between the turbine and generator, however, this method of measurement is impossible or at least extremely inaccurate. In such cases the turbine output must be determined directly, which assumes that both the speed and torque are known. Some time ago *electric torque measuring equipment was devised for a small steam turbine running at a very high speed.* During the past year similar equipment was designed for large, slow-speed machines (Fig. 26). In consequence, all machines of not too low a rating can now be equipped in this manner. The new measuring equipment is based on the principle that when transmitting the output of the turbine the machine shaft is slightly distorted elastically in proportion to the torque, which can be measured electro-magnetically. The device can of course also be employed to determine the load on a turbine driving a generator. In certain special cases such a direct check may be desirable and is rendered possible by the high degree of accuracy of the contrivance.

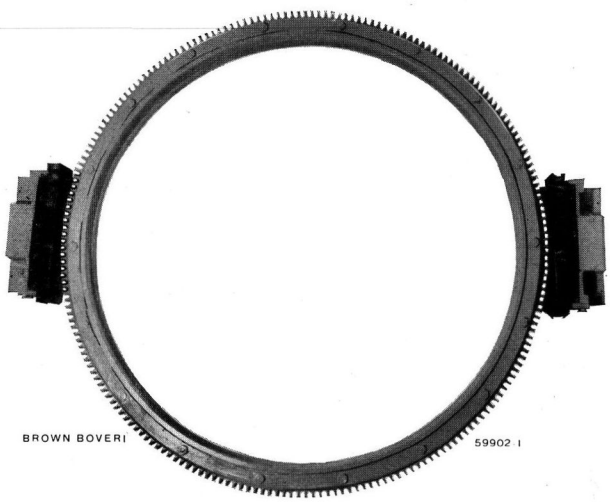


Fig. 26. — Device for directly measuring the torque of prime movers (steam and water turbines).

This allows the transmitted torque and in consequence the output to be accurately determined from the elastic distortion of the driving shaft. The device is suitable for incorporation in any machine of not too low a power.

[1] $100\% = \frac{\text{Rated voltage}}{\sqrt{3} \times \text{rated current}} = \frac{12{,}000}{\sqrt{3} \times 1570} = 4{\cdot}42$ ohms.



Engine room of modern hydro-electric power station with Brown Boveri generators,

seen from the control room where the most suitable Brown Boveri equipments for the operation, regulation, and protection of the machines are concentrated.

II. POWER TRANSMISSION, DISTRIBUTION AND CONVERSION.

A. POWER TRANSMISSION OVER LONG DISTANCES.

At the informal meeting of the Swiss Association of Electrical Engineers (S.E.V.) held on the 13th December, 1941, Brown Boveri engineers advanced the opinion that exhaustive theoretical investigations. backed up by practical tests, would be necessary to clear up the question of the most suitable current system for the transmission of big blocks of power over long distances. It was also stated at the time that operation with high-voltage d. c. appeared to be more economical than a. c., even at the extra-high-voltages which were to be anticipated, as long as the costly voltage boosters involved by the latter system could not be dispensed with. Already then, however, it was thought that it should prove possible to solve the problem of the stability of long a. c. transmission lines without boosters, by employing asynchronous instead of synchronous alternators at the supply end and providing for synchronous conditions at the far end[1]. In the year under review, a further stage in the systematic study of the whole problem, the case of asynchronous power transmission, was given attention. From the outset it was obvious that a conventional asynchronous machine could not supply the line with its "natural" load, since, as is common knowledge, machines of this class absorb reactive power under all operating conditions. In order to be able to operate the line with its natural load, therefore, a compensating voltage of appropriate magnitude and phase must be impressed on the asynchronous alternator.

For purposes of test an orthodox induction motor rated 102 H. P. at 1000 r. p. m., 220 V, 50 cycles, was employed as asynchronous alternator, being driven by a d. c. motor with a wide range of speed regulation and supplying, through a current transformer, an artificial line representing a system 1000 km in length without boosters. Through the intermediary of an induction regulator the current transformer fed a frequency changer directly coupled to the asynchronous machine and its driving motor, thus converting the compensating voltage to be impressed on the rotor of the asynchronous machine via its slip-rings, to slip frequency.

From the test results the transformation ratio of the current transformer and induction regulator can be adjusted once and for all to give stable operation throughout the entire output range up to the pull-out torque without undue slip (Fig. 27). On the other hand the setting of the induction regulator can be varied as a function of the power to be transmitted,

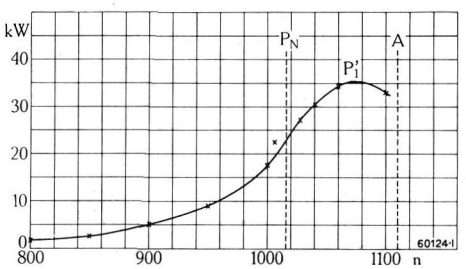


Fig. 27. — Asynchronous power transmission.

Power P_1' at supply end of line (current transformer terminals) as a function of the asynchronous alternator speed with constant compensating voltage.

A = Limit of stability. n = R.P.M. P_N = Natural load.

i. e., the load on the consumers' side of the system, either with the same or a different current transformer ratio (Fig. 28). The asynchronous alternator in this case operates very close to synchronism up to a load greater than the natural load. The fact that there is practically no slip at any load is of vital importance where the economy of the system is concerned, inasmuch as it enables the rating of the compensating machine to be kept down to a minimum.

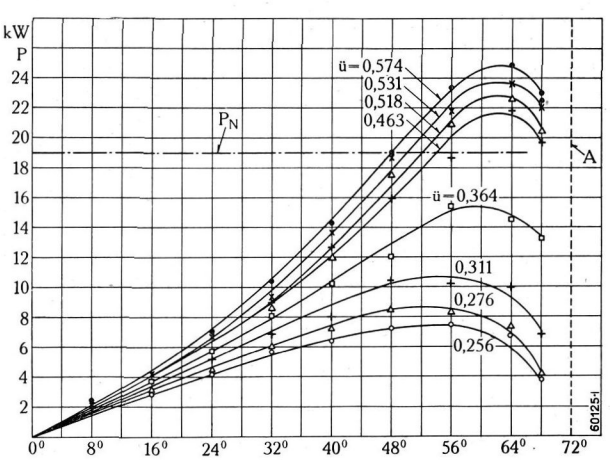


Fig. 28. — Asynchronous power transmission.

Power P at end of line as function of induction regulator setting with various current transformer ratios.

A = Limit of stability. P_N = Natural load. ü = Current transformer ratio.
Abscissae: Induction regulator setting.
Ordinates: Power P in kW at end of line.

[1] Dr. W. Wanger: Bull. SEV. 1942, p. 129.

In order to obtain an idea of the dynamic stability of the asynchronous method of power transmission two- and three-pole short circuits were initiated along the artificial line (Fig. 29). In contrast to synchronous transmission, however, the stability of the machine was affected in no single case. It is merely necessary to provide a means of protection against the over-voltages occurring on the slip-rings of the asynchronous alternator during short circuits. This is probably the first time that absolutely stable operation of such a long a. c. line has been achieved up to the natural load without boosters and with a number of machines which appears by no means intolerable.

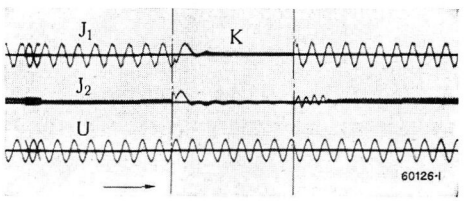


Fig. 29. — Asynchronous power transmission.

Oscillogram of a three-phase line short circuit with 0·102 Ω resistance in rotor circuit.

J_1 = Stator current.
J_2 = Rotor current.
U = System voltage.
K = Three-phase short circuit.

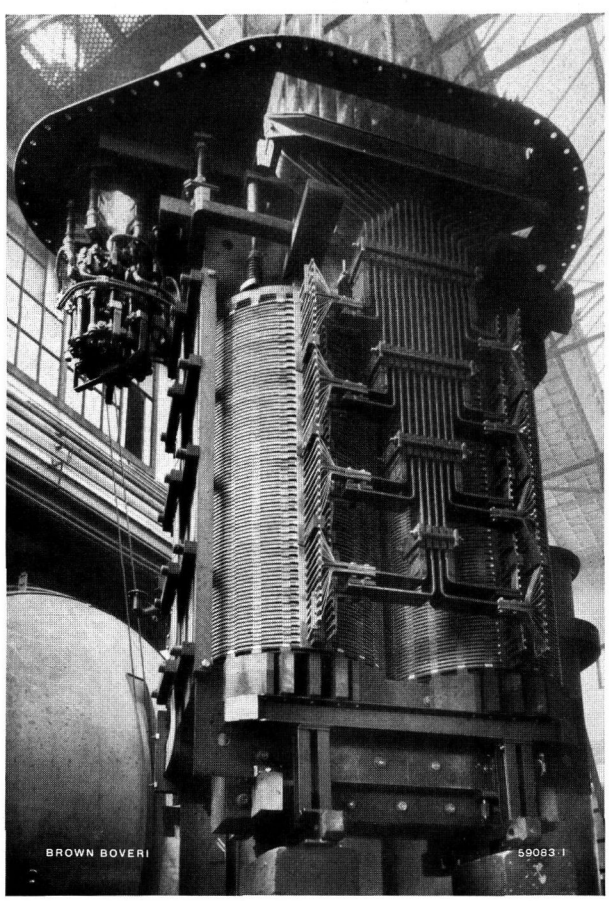


Fig. 30. — Single-phase furnace transformer with aluminium winding for a large metallurgical works.

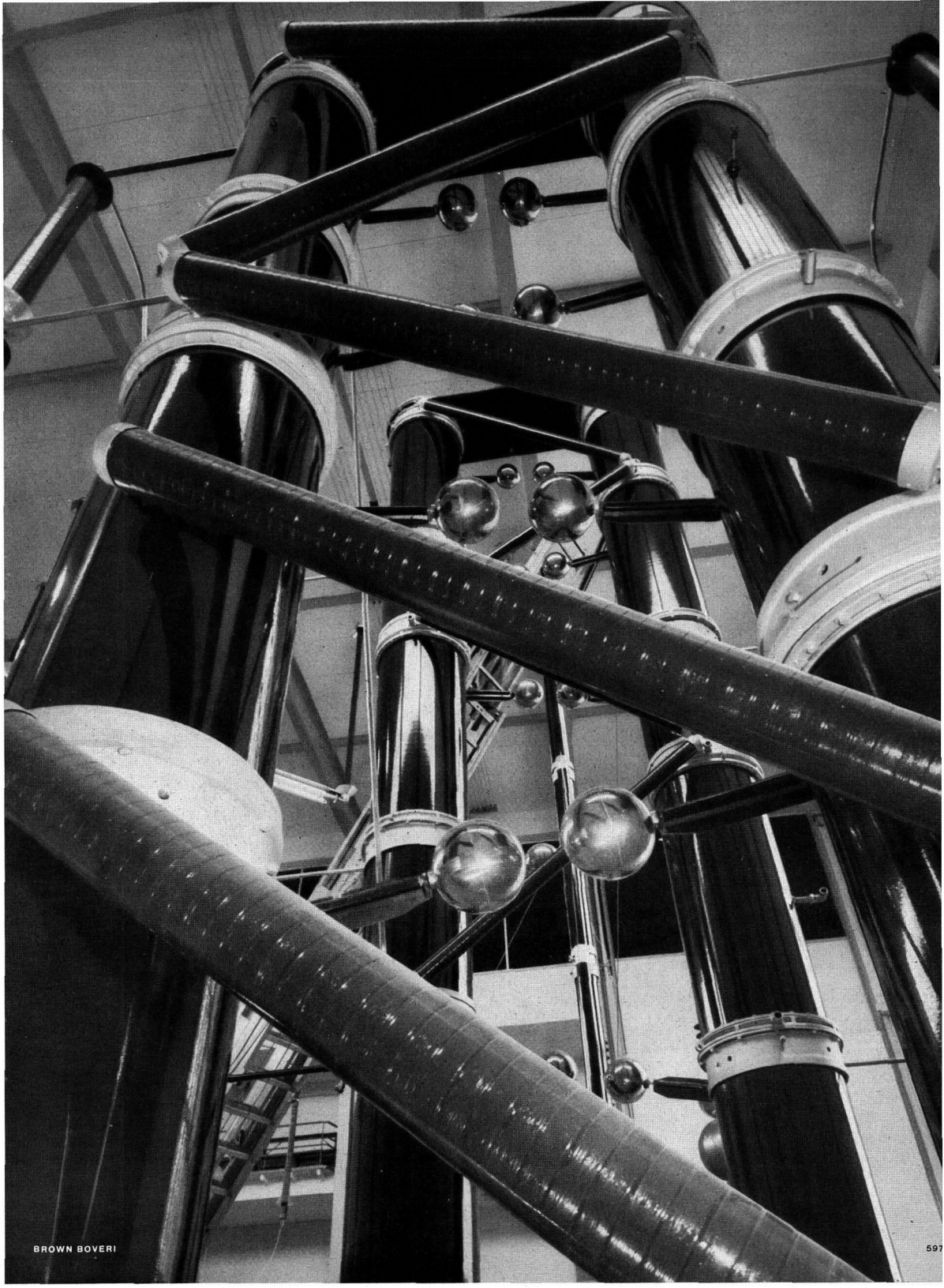
A typical representative of this class of transformer with on-load tap-changing switch on the high-voltage side and the numerous secondary connection bars for a furnace current of 28,400 A.

B. TRANSFORMERS.

In this field large power transformers together with distribution transformers and low-voltage regulating transformers on the infinitely-variable principle, were again of chief interest.

As cursorily stated here last year the recent trend of development work in transformer construction is to abandon conventional designs and to apply new principles with a view to overcoming the present shortage of materials without impairment of the quality of the finished product. Maximum dimensions and weights are of very little interest to the transformer designer nowadays. The deciding factor is the most rational utilization of the available materials. The laminations and winding material required per kVA of transformed energy, together with minimum oil consumption, have become more and more a criterion for the economically-minded transformer designer. A fundamental proviso, however, is that the saving in material shall in no way detract from the quality of the transformer.

Exhaustive investigations in the research laboratory and large-scale tests in interested customers' plants have furnished principles for the solution of present requirements as well as for the rapid developments to be expected during the post-war period. As is common knowledge, the insulating distances between the individual windings and the yokes of extra-high-voltage power transformers vitally affect the dimensions of the whole transformer. Hitherto, these distances had to be selected much greater than actually required for adequate cooling of the active parts. A novel arrangement of the high and low-voltage windings as well as of the insulating sleeves and flanges has permitted the overall dimensions and in consequence the weight of the core, the volume of oil, and the cost of the transformer to be substantially reduced. A further outstanding technical advance in the construction of large power transformers for extra-high voltages has been achieved with the introduction of the radially-laminated core having a novel form of return magnetic path. This arrangement enables three-phase banks of transformers, comprising three single-phase transformers, of the highest outputs and voltages to be dis-



An unusual view of our impulse generator for steep-wave front impulses of 2,400,000 V.

Together with a testing transformer plant for power-frequency voltages up to 1,600,000 V and a rectifier for d. c. voltages up to 1,200,000 V employed in combination with it this generator forms one of the most important pieces of apparatus in our new high-voltage laboratory and enables lightning strokes on electrical installations to be experimentally imitated.

patched by rail completely assembled. This is naturally of great advantage from an operating point of view, especially when one and the same bank is required to be employed at various points in the system according to load conditions.

In this connection a 100 MVA mobile transformer with tertiary winding, designed for a high voltage of 220 kV, is worthy of mention. The two main windings, together with the cooling equipments, are designed to give the transformer a continuous secondary rating of 100 MVA at 0·7 power factor with supply voltages between 200 and 250 kV,

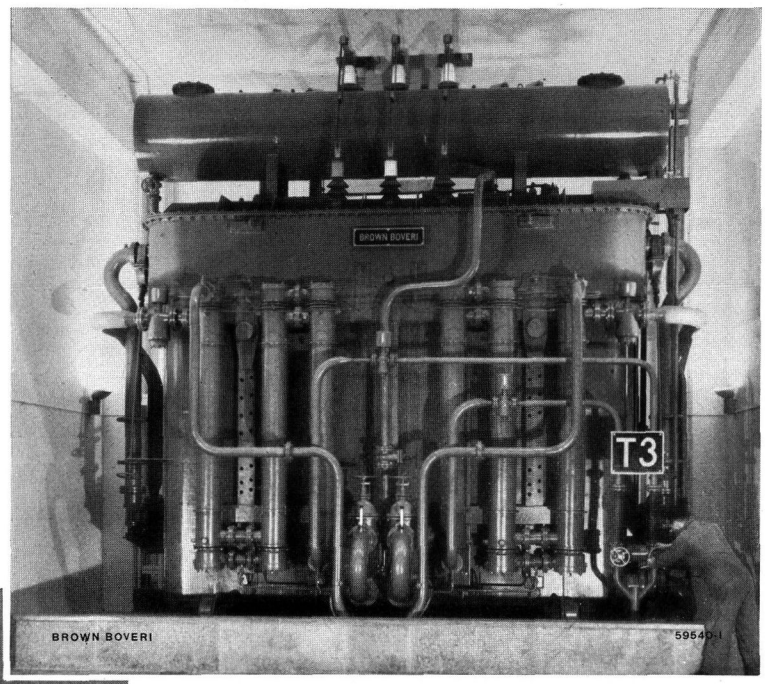


Fig. 31. — Three-phase transformer rated 47,500 kVA at 150 kV/12 kV, with built-on tubular coolers for the fresh-water cooling of the insulating oil, supplied to the Oberhasli Power Co. The unit is built into a recess in the rock structure of the Innertkirchen Power Station.

The tubular coolers, through which the oil and cooling water flow in opposite directions, give very effective cooling with minimum space requirements.

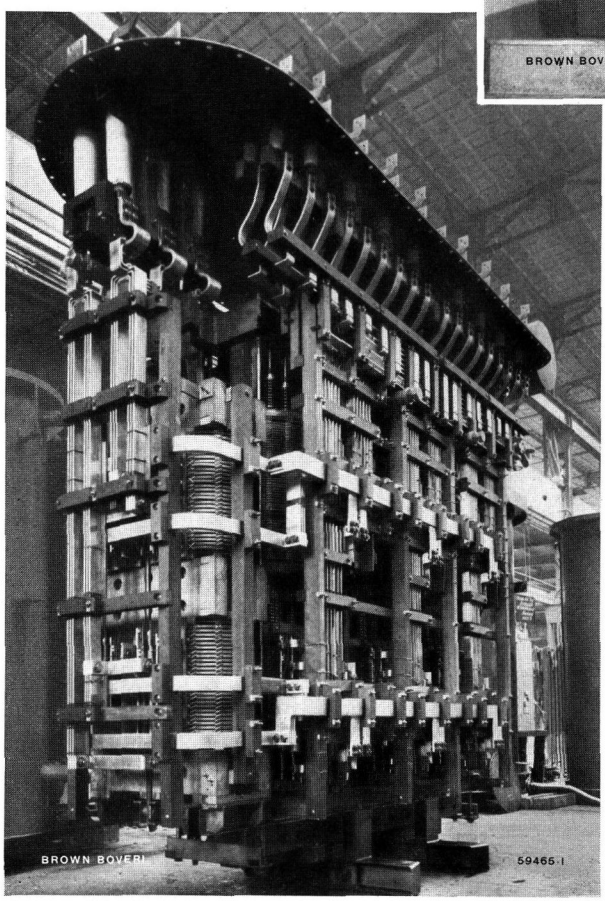


Fig. 32. — Mutator transformer with aluminium winding for a metallurgical works.

The illustration gives an excellent idea of the demands made on the skill of modern transformer designers and workmen. Eighteen-anode mutators are connected to the 2×18 secondary winding leads. To reduce interference with the supply system to a minimum the transformer is of the twelve-phase twin type. The neutral points of the two six-phase systems, which are mutually displaced by 30 electrical degrees, are each connected to special high-current terminals above the cover via separate interphase reactors incorporated in the transformer (see left-hand side of illustration). These form the negative pole of the direct-current system.

whereby the temperature rises in the windings and oil do not exceed the specified limits. A tertiary winding rated 33 MVA at 10 kV is provided for the connection of choke coils to compensate the charging current of the transmission line on light loads. In consequence, the dimensions of the transformer are greater than would actually conform to the rating of its main windings, and correspond approximately to a 150 MVA transformer. The unit is of the mobile type and can be dispatched, complete with oil, practically ready for service, in a contrivance suspended between two special nine-axle trucks. Experience made during the development and construction of this transformer has shown that the maximum output is still obtained, notwithstanding rigorous application of the new design principles. Should future demands call for three-phase banks of still higher ratings and transmission voltages, these would have to be built up from single-phase transformers of special design, as already briefly inferred. From the point of view of standby equipment, however, this would even be an advantage.

The transformers shown in Figs. 30 and 32 have aluminium substituted for copper throughout. Alumi-

nium can now be considered a high-quality alternative for copper in transformer construction and even in complicated designs no longer creates any difficulties in the workshop. Several years' working experience with a large number of transformers of similar construction, i. e. with aluminium windings, is now available and proves without exception that the unsatisfactory experience made during the last war can no longer be employed as an objective argument against the use of aluminium in transformers.

C. NETWORK PROTECTION.

In last year's review of progress and work the marketing of new *lightning arrestors* with their numerous mounting arrangements was mentioned. Due to the greater adaptability of the arrestors to system conditions and in particular to their excellent technical properties—which were corroborated by the official tests of the Swiss Association of Electrical Engineers High-voltage Research Commission—sales of Resorbit arrestors have increased during the year, notwithstanding the many economic difficulties. The development of an arrestor for a service voltage of 220 kV and a discharge current of 10,000 A (Fig. 33) together with the improved design of the arrestors for 45 kV and 50,000 A (Fig. 34) has contributed to this success.

It is gratifying to be able to record that ten years after the introduction of the first Resorbit arrestors this over-voltage apparatus is looked upon as an absolutely reliable, effective, and indispensable means of protection. Most operating engineers have already recognized this fact and now systematically fit arrestors in their systems.

In addition to the *discharge counters* mentioned in the review of progress of the year before last, which indicate the operation of an arrestor or set of arrestors, a new design with integrating gear has been developed which considerably extends the sphere of application of this handy apparatus. The extremely simple and robust counters need neither an auxiliary supply nor attendance, and thus form a most reliable aid for operating engineers.

The research work in the over-voltage protective gear field during the past year was dominated by the problem of *coordination* (grading of the insulation), a term with which designers and operating engineers alike are now well acquainted. The investigations undertaken in this connection in various systems have in most cases led to the arrestors being better adapted to the prevailing conditions and in this manner faults more readily avoided.

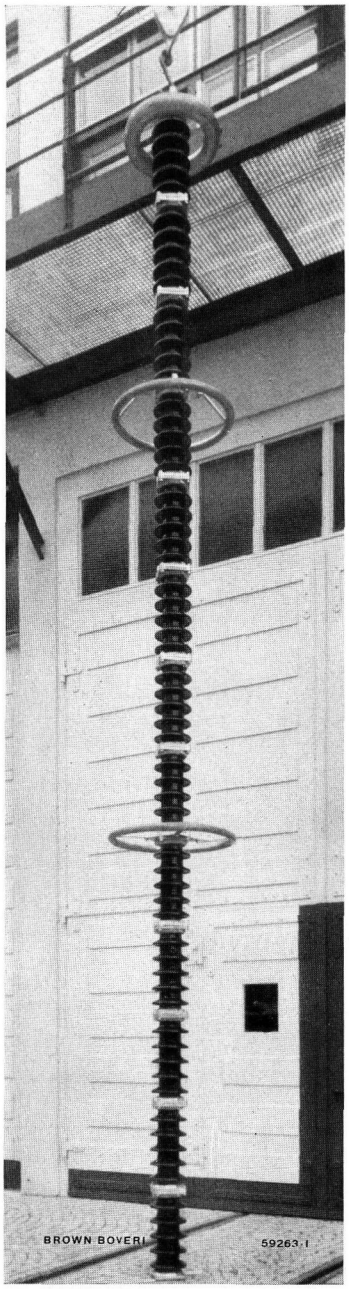


Fig. 33. — Lightning arrestor with a voltage rating of 220 kV and a discharge current rating of 10,000 A.

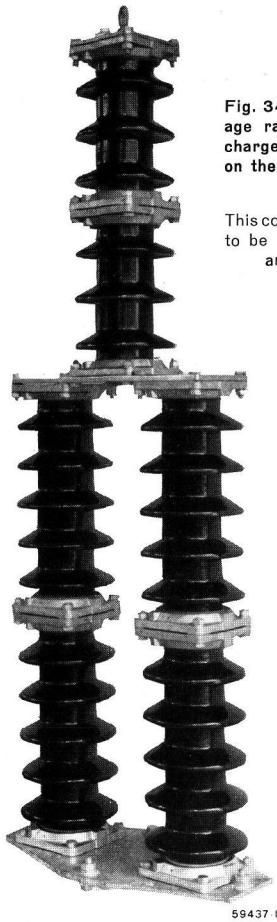
A feature of these arrestors for very high voltages is the control elements to achieve uniform stressing.

It is particularly to be regretted that present conditions should render international collaboration impossible in just this very field.

During the year the first *arc suppression coil with fully automatic regulation* was taken into service, whereby two facts are of particular interest. Firstly, the automatic control gear operated absolutely correctly and blocked itself in case of earth faults. Secondly, it was again found that impermissibly large unsymmetrical voltages can occur due to unsymmetrical conditions and inadequate damping. There are, however, sufficient means available for reducing the unsymmetrical voltages.

Moreover, tests on a small artificial line have definitely shown that automatic control can be resorted to even in cases where there are several adjustable arc suppression coils in the same system.

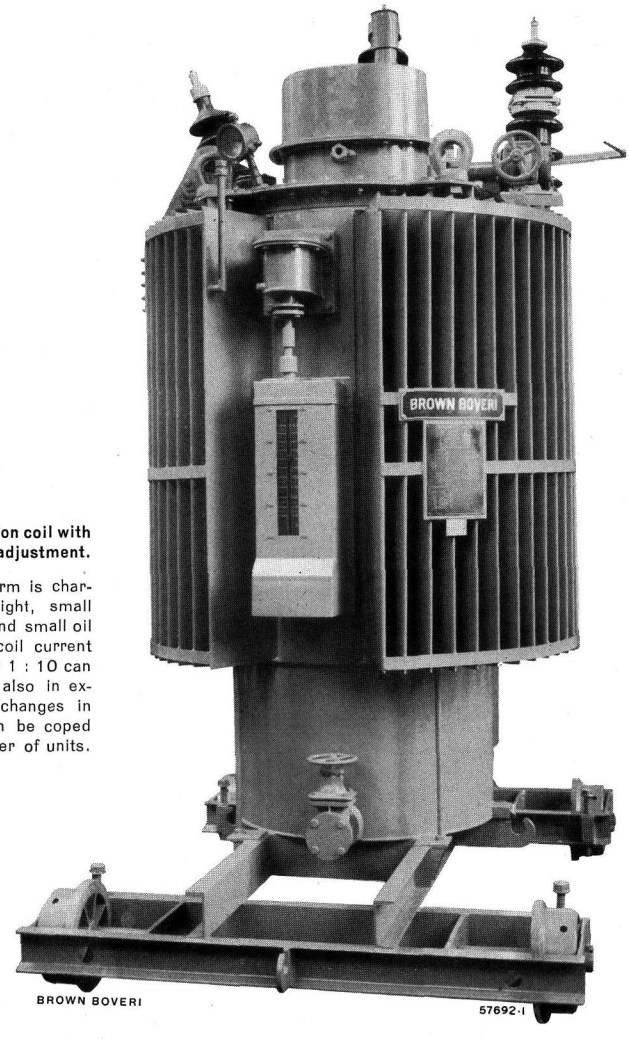
The excellent working experience with arc suppression coils having progressive current adjustment under load have led to this feature being adopted for smaller coils (Fig. 35).



59437-I

Fig. 34. — Arrestor with a voltage rating of 45 kV and a discharge current rating of 50,000 A on the cascade connection principle.

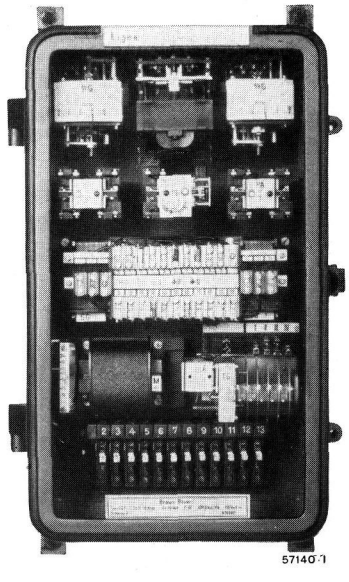
This construction enables arrestors to be built for any rated voltage and discharge capacity.



BROWN BOVERI 57692-I

Fig. 35. — Arc extinction coil with progressive current adjustment.

The pleasing round form is characterized by light weight, small space requirements, and small oil volume. With such a coil current ranges of 1 : 8 or even 1 : 10 can be obtained, so that also in extensive systems big changes in system conditions can be coped with by a small number of units.



57140-I

Fig. 36. — High-speed distance relay for the protection of systems with service voltages up to 37 kV.

This relay protects the line against all faults with the exception of earth faults. It picks up on excessive currents, a rotating field relay recording the distance and direction of the fault.

The design of a series of coils with ratings between 80 and 2000 kVA was completed during the year under review.

The range of *high-speed distance relays* has been extended by a greatly simplified model. With the new relay (Fig. 36) the distance to the fault is measured and its direction indicated by one single element, the rotary field relay. The picking up of the distance relay equipment is effected by an over-current relay in two phases instead of a minimum impedance relay in each phase. The earth-fault relay is dispensed with, while the time relay has only four instead of five steps. The simplified high-speed distance relay protective gear is specially suited to systems where the short-circuit current occurring substantially exceeds the service current occurring at maximum load. This applies in particular to distribution systems with rated voltages up to about 37 kV in which the lowest load lies inappreciably below the full-load voltage. Its application is to be particularly recommended in the case of transmission lines carried on wooden poles where earth

faults are relatively infrequent. In view of its low price and small dimensions the new high-speed distance relay panel has already met with great appreciation, namely, in all systems where the afore-mentioned conditions particularly warrant its application.

In order to be prepared for future developments it was considered necessary to modify the high-speed distance relay protective gear to permit of its use for long distance three-phase extra-high-voltage lines. A difficulty encountered here, however, is that, even at 220 kV, the impedance starting principle employed hitherto does not suffice for a power of 150 MW and distances up to 480 km. In consequence new designs have been developed and constructed, which permit of clear differentiation between service and short-circuit conditions, while retaining all the advantages of impedance starting. This protective gear is also designed for the automatic high-speed reclosing of circuit-breakers, on one or three poles as desired. It effects simultaneous operation of the circuit-breakers at both ends of the protected section without any auxiliary coupling channel whatsoever. The relays are also designed to take account of the unfavourable stability conditions inherent in such large transmission systems.

It is common knowledge that the single-phase loading of three-phase systems invariably leads to asymmetrical currents and in consequence also to asymmetrical voltages, which in certain cases are required to be measured. For this reason equipment was developed in the course of the year to *measure the degree of asymmetry of the currents of three-phase systems,* which is based on the following principle:—

The system currents required to be measured are supplied to the stator of a small three-phase motor and produce in its air-gap opposing rotating fields (neglecting the higher harmonic fields) the strength of which is proportional to the corresponding current components (assuming no saturation). If the wound rotor is now allowed to run in synchronism with one of the two rotating fields an e. m. f. proportional to the strength of the other rotating field and therefore also to the corresponding current component, appears at its terminals. By inverting two phases of the stator the other current components and then the degree of asymmetry of the load on the system under test can be determined in a similar manner. Since the result can be affected by the higher harmonic fields caused by the motor itself as well as by the system current, the stator and rotor slots are closed with iron wedges, and the stator winding is arranged with partially overlapped phases, while the air gap is made comparatively large, in order to exclude these disturbing fields. The effect of the system higher harmonic currents is greatly reduced, but not entirely suppressed by the provision of a band pass filter in the rotor circuit, so that care is necessary when measuring systems which are not greatly out of balance. The asymmetry meter is rated 5 A and can be simply connected to the system through current transformers. The smallest degree of asymmetry which can be measured is 0·4 %.

D. CIRCUIT-BREAKERS.

Under this heading it is first of all worthy of mention that the *high-power testing station,* which is chiefly employed for the testing of circuit-breakers, was modernized simultaneously with the erection of the new high-voltage laboratory. Hitherto, the transformer connected after the testing generator would only allow of testing circuit-breakers of up to 150 kV or at the very most 180 kV rating. In order to be prepared also here for coming developments the high-power testing plant has been extended by a transformer for a high voltage of 400 kV (Fig. 37). Fig. 38 shows a short-circuit arc at this voltage and at a short-circuit power of about 300,000 kVA, which circuit-breakers for the coming extra-high voltages will have to be designed to rupture.

The summer of 1942 with its numerous thunderstorms put the obsolete oil circuit-breakers, with their inadequate rupturing capacity, to a hard test. The ensuing breakdowns and the serious consequences they involved induced several power supply undertakings to install circuit-breakers in their systems which meet not only present conditions, but also those to be anticipated in the immediate future. Apart from the mechanical and electrical properties, installation possibilities had to be studied when planning such equipment, for the change-over frequently had to be effected without interruption to service and under the most unfavourable conditions conceivable. For the modernization of various large and small indoor installations carried out during the year air-blast high-speed circuit-breakers were universally selected. Due to its unique design such switchgear can be installed in any desired position and greatly facilitates the removal of the oil circuit-breakers. The change-over of a switch panel can frequently be effected in one to two days.

A large number of outdoor-type multiple-break air-blast high-speed circuit-breakers for service voltages of 100 to 220 kV were supplied and taken

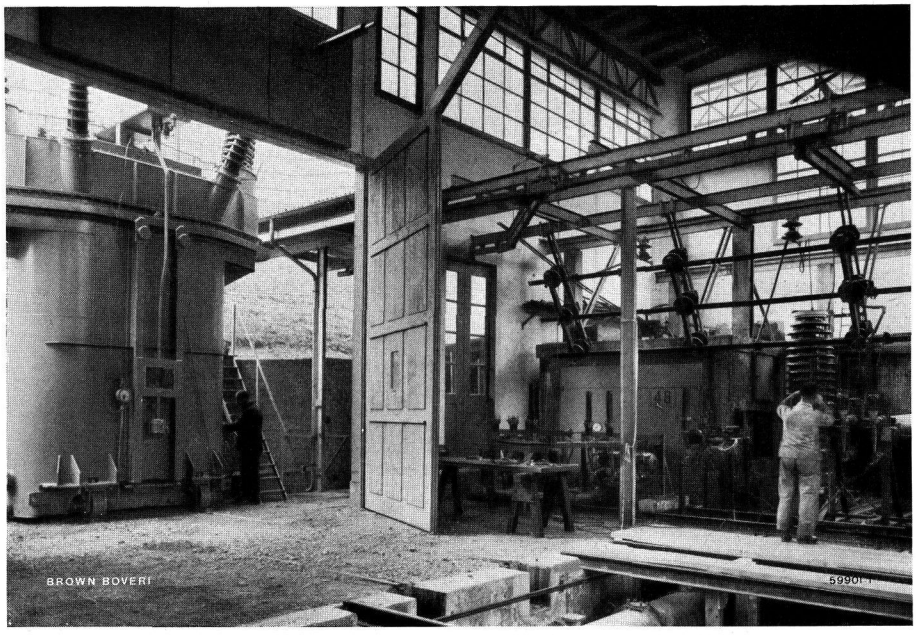


Fig. 37. — Partial view of high-power testing station for high-voltage circuit-breakers with a number of test platforms on the right and the new short-circuit transformer for 400 kV on the left out-of-doors.

The 400 kV cables are taken over the roof of the building to the outdoor testing station on the opposite side. The new transformer is of the same rating as the short-circuit generator and is employed for testing circuit-breakers for service voltages up to 400 kV.



Fig. 38. — Arc at 400,000 V and 300,000 kVA short-circuit power, supplied by new short-circuit transformer in Fig. 37.

Such short-circuit powers will have to be coped with by the circuit-breakers for the coming high voltages.

into commission, the voltage across the individual breaks being controlled (Fig. 39). High-speed reclosing of circuit-breakers is now recognized and specified in many countries as a valuable adjunct to system protective gear. Most of the extra-high-voltage air-blast high-speed circuit-breakers, therefore, were supplied with the reclosing feature. As far as Switzerland is concerned such switchgear was put into service during the past year in the Verbois, Klingnau, Laufenburg, and Ryburg-Schwörstadt power stations.

Not satisfied with this success, however, the Company has developed a new series of *indoor-type air-blast high-speed circuit-breakers* which with the addition of an auxiliary air receiver can also be provided with the high-speed reclosing feature (Fig. 40). The new switchgear which was demonstrated to a wide circle of interested parties under service conditions last autumn will be ready for the market by the spring.

Distribution systems with single switching points are generally only of low power and, apart from special cases, require no attendants. The power circuit-breakers for such plants should therefore not be too costly, while maximum reliability and simplicity of attendance are essential. In the course of the present year air-blast high-speed circuit-breakers for 10 and 20 kV with rupturing capacities of 120 and 200 MVA, respectively, designed specially for the conditions ob-

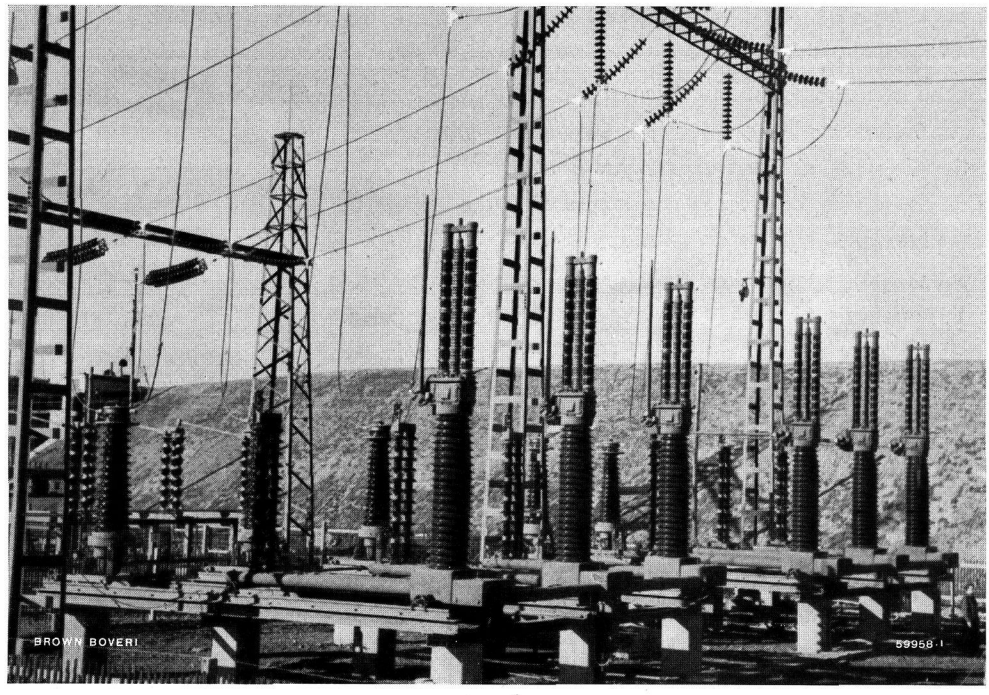


Fig. 39. — Banks of three-pole air-blast high-speed circuit-breakers for 220 kV service voltage with 2500 MVA rupturing capacity.

This switchgear connects the large power stations in the north of Sweden with the industrial centres in central and southern Sweden. Transmission lines over 300 km in length have been successfully disconnected with these circuit-breakers under no-load earth-fault conditions.

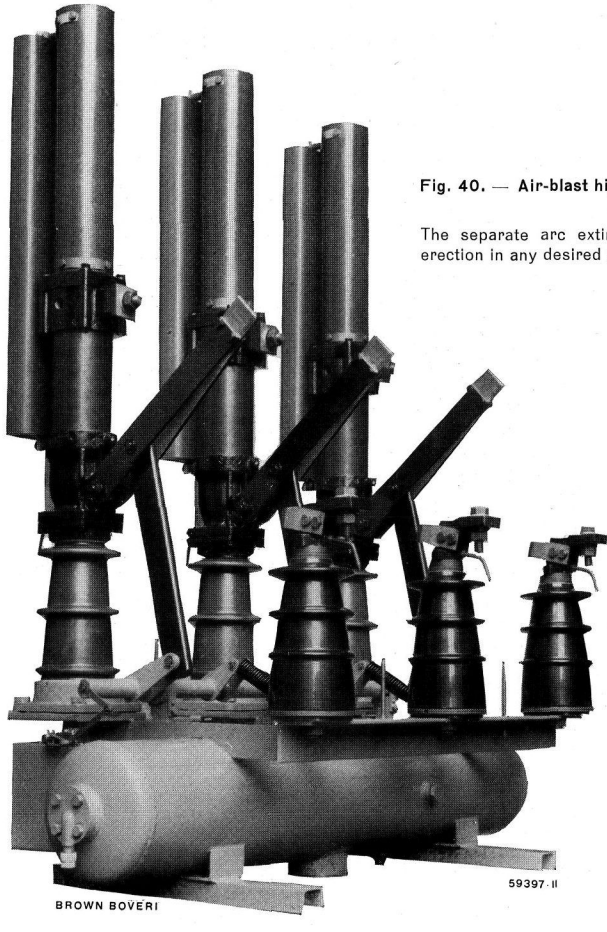


Fig. 40. — Air-blast high-speed circuit-breakers with a rating of 1000 A at 30 kV and a rupturing capacity of 600 MVA.

The separate arc extinction and isolating switches with air-break contacts and the possibility of erection in any desired position are features which pave the way for the introduction of the air-blast high-speed circuit-breaker into all systems.

taining in small systems will, be put on the market. The necessary compressed air can be provided in a simple and inexpensive manner. In the case of small systems operations are not an everyday occurrence and the amount of air required by the circuit-breakers is very small and can be supplied from a compressed-air cylinder. The way is therefore now clear for the general introduction of air-blast high-speed circuit-breakers in small systems.

Short-circuit tests were carried out in the systems of two large Swiss power supply undertakings with a view to studying the stability conditions for interconnection with other power supplies. These tests have again confirmed the vital importance of short rupturing times for the reliable localization of faults and the possibility of more or less completely avoiding service interruptions by the application of the high-speed reclosing feature.

E. RELAYS.

With the evolution of network protecting equipment for the safe-guarding of electrical plant, e. g., machines, transformers, cables, etc., against dangerous fault conditions, enhanced plant economy was also called for. This could only be achieved by lengthening the life of the plant and utilizing it to the full without impairment of the winding and conductor insulation. As a result, apparatus for checking and controlling the thermal load capacity has been developed, the first of this type being the *thermal series relay*[1] put on the market in 1936/37.

With this relay the conductor temperature of the protected object is imitated on a model and measured by means of robust thermometers. The relay picks up when a definite adjusted temperature is exceeded and operates either a circuit-breaker directly or a signal. Like the series relay the thermal series relay can take over a secondary function, i. e., instantaneous tripping upon an adjustable multiple of the service current being exceeded, due to the provision of a so-called limiting-current instantaneous release.

This apparatus was the first to provide an entirely satisfactory solution of the problem of protection of electrical plant against harmful overloads and quickly found application in plants where series relays were already employed or could be installed.

In operating circles, however, there proved to be a need for a secondary relay of the same type, due to the fact that in large stations supervision and control is concentrated at one central point, i. e., in a control room, in which only secondary apparatus can be fitted. After exhaustive investigations and extensive practical tests, based partly on working experience with the thermal series relay, a *thermal secondary relay* was finally developed and put on the market. The fundamental construction of this new protective apparatus is virtually the same as that of the thermal series relay, although there are two other features which are worthy of special mention. An apparatus for connection to an instrument transformer should have the lowest possible power consumption and, in order to obtain a faithful thermal image of the different plant components to be protected, at the same time permit of *adaptation of the time constants to actual conditions within wide limits.* Both these requirements have been extensively met in the thermal secondary relay.

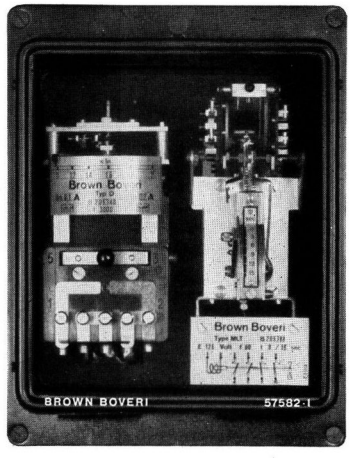


Fig. 41. — Combination of an over-current and time relay in a common case.

Model for 3000 cycles. Since the individual relays are specially designed for their particular function great accuracy can be obtained with this combination, even when there are several independent possibilities of adjustment.

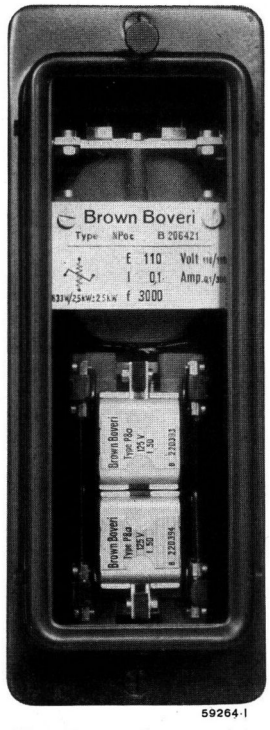


Fig. 42. — Dynamometric power relay for maintaining constant a power value adjustable on the relay.

Special design for 3000 cycles, intended for metallurgical applications (annealing, case-hardening).

The relay has separate signals for temperature and limit-current tripping. The limit-current instantaneous release is adjustable between 3 and 10 times I 60°, but can also be blocked. For reasons of cooling this apparatus is only available in a single-pole casing.

The thermal secondary relay was already referred to in last year's review of progress and work, but inasmuch as it has only been manufactured on mass production lines since August, 1943, and moreover, is thought to fill a long-felt want in operating circles, attention has again been drawn to it and more particularly to the history of its development, this year.

[1] The Brown Boveri Review, 1937, p. 323.

The increasing use of frequencies up to 10,000 cycles for heating applications has involved the development of special over-current, voltage, and power relays for protection purposes. These relays are similar in external appearance to the corresponding apparatus marketed for industrial frequencies. Fig. 41 shows an over-current relay with a range of adjustment of 1...4 times the rated current combined with a time relay in the same case. Fig. 42 depicts a dynamometric power relay with two auxiliary contactors. The maximum and minimum power above and below which the relay contact closes is adjustable.

F. SWITCHGEAR.

Of the numerous switchgear orders completed during the year only one or two will be touched upon here. The most important was undoubtedly that for the *ore-reducing furnace* at *Choindez* which is referred to elsewhere in the present number of this journal. An outstanding feature of the installation is the very high current (up to 25,000 A) which involved very careful running, i. e., transposing, of the aluminium bus and conductor bars to avoid additional losses.

Switchgear of quite another character was employed for the modernization of the *Martigny-Bourg* power station already alluded to. Fig. 43 shows the control board with the position indicating diagram. Two different colours are employed for the first time to illuminate the symbols of the circuit-breakers and isolating switches according to their position.

Very comprehensive switchgear was built for the Company's new *high-voltage laboratory* (Fig. 44). Since this was described in detail in a special number of this journal a short time ago[1] it will not be gone into here. A noteworthy feature, however, is the new type of line selectors which permit of a hitherto unattained number of combinations of the incoming and outgoing lines. The experience obtained here is available for the installation of similar plant in research laboratories and polytechnical institutes.

[1] The Brown Boveri Review, Nos. 9/10, 1943, p. 212.

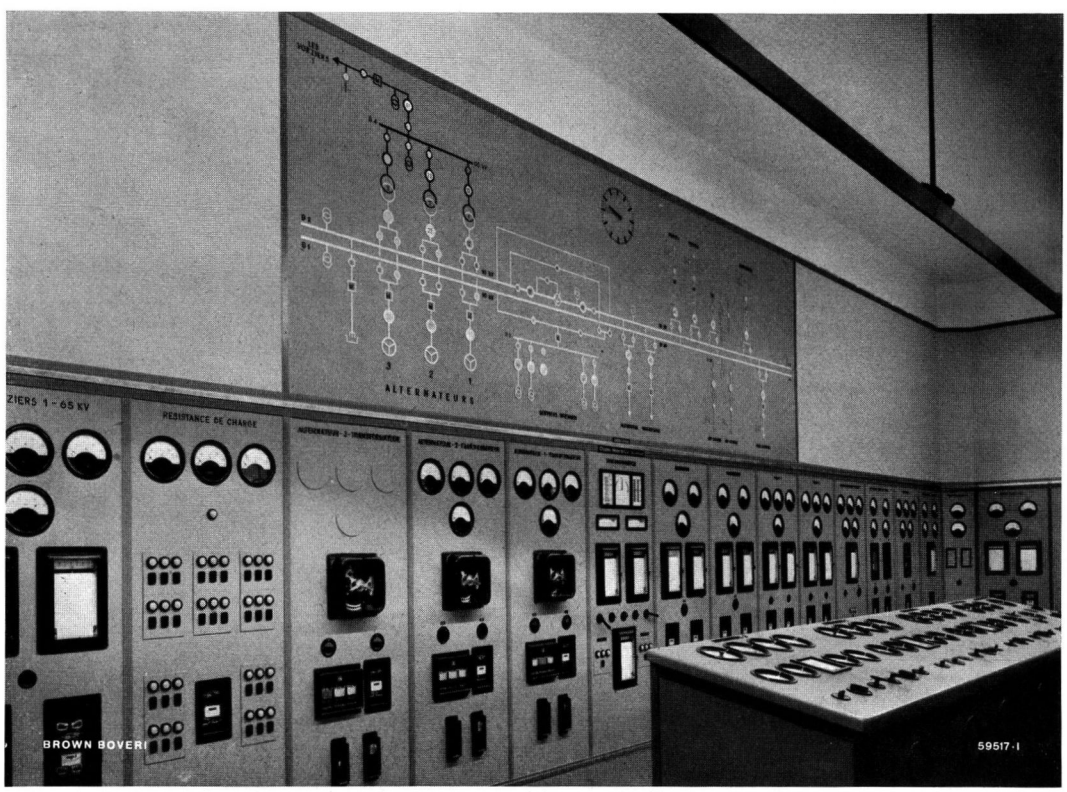


Fig. 43. — Control room at Martigny-Bourg power station with position indicating diagram having luminous symbols.

The connections of the plant are represented by aluminium strip of different colours, according to the voltage, on the front of the panel. Circuit-breakers and isolating switches have luminous symbols each of which is illuminated by lamps capable of being fitted from behind. The symbols are illuminated red or white according to whether the circuit-breakers or isolating switches are closed or open, respectively.

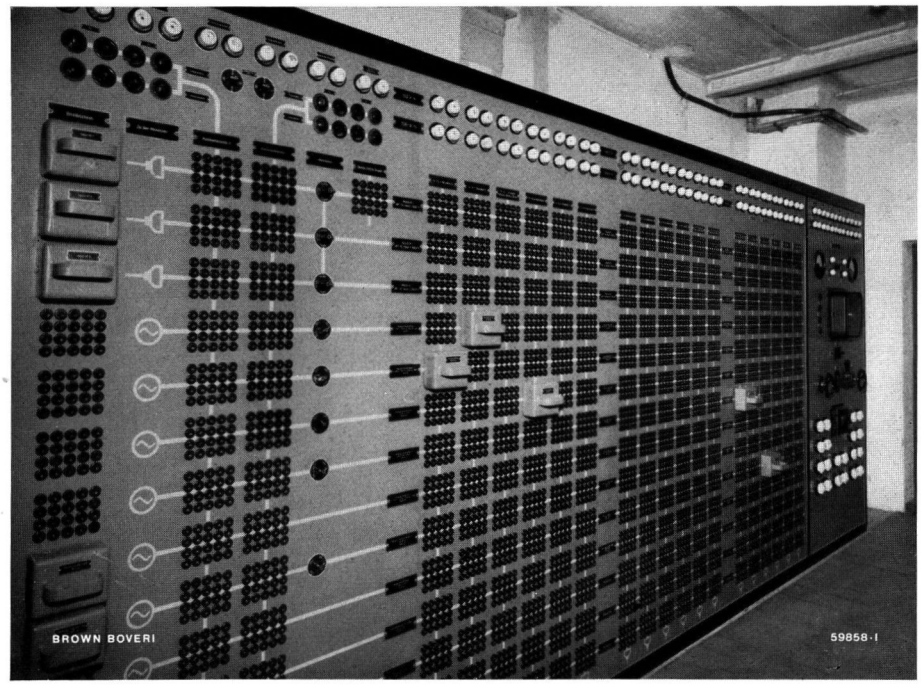


Fig 44. — An interesting section of the switchgear in the firm's new high-voltage laboratory: The excitation line selectors.

The excitation, as well as the control and position indicating gear (each ten lines) of fourteen power supplies can thus be switched over to eighteen different working points.

G. MUTATORS.

As in the case of the investigations in connection with the problem of the transmission of power over long distances by means of extra-high-voltage alternating current (alluded to elsewhere in this issue [1], the study of *direct-current high-voltage transmission* has been continued in accordance with the principles adopted for the Wettingen-Zurich line erected on the occasion of the Swiss National Exhibition in 1939. Two single-phase mutator sets, each for a d. c. voltage of 33 kV, with the necessary ripple smoothing equipment (Figs. 45 and 46) and coupled so as to act as sending and receiving stations of a supposed d. c. transmission line with the sending and receiving systems connected to the a. c. system, have now been installed at the Biaschina power station, thanks to the courtesy of the Aare-Tessin A.-G. These single-phase sets form the elements of three-phase sets for 100 kV, 400 A d. c., i. e., 40,000 kW. The results of the tests, which were begun last autumn, will be communicated later.

The development of *pumpless mutators* was pushed forward. During the year under review a mutator of this type was built for 1500 A, 600 V. This unit was installed in the *"Drahtzug" Substation of the Zurich Municipal Electricity Supply* (Fig. 47) and has given entire satisfaction in very arduous continuous service with heavy load fluctuations (Fig. 48). The new model

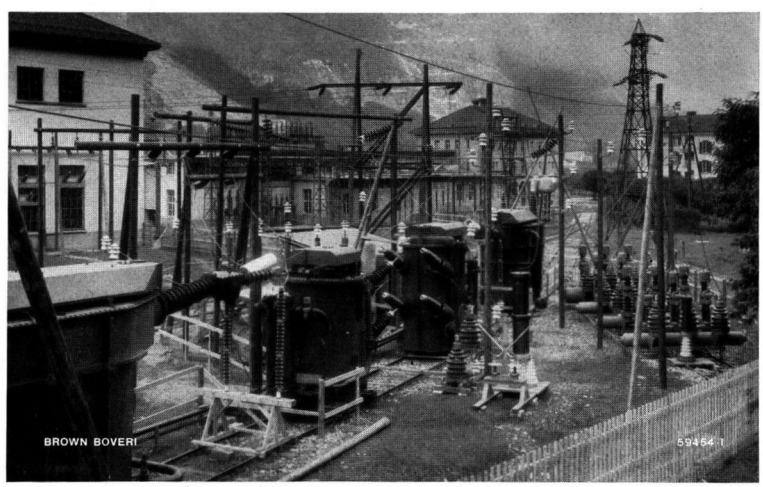


Fig. 45. — Trial plant with two high-voltage mutator sets, each rated 33 kV, 400 A, for the conversion of a. c. to d. c. and vice versa.

Direct-current power transmission plant in the Biaschina power station of the Aare-Tessin A.-G. Transformers, smoothing choke coils, and air-blast circuit-breakers are of the outdoor type. The conductors to the anodes and cathodes of the mutators are taken through the windows of the building on the left, into the mutator room, by means of bushing insulators.

[1] See p. 25.

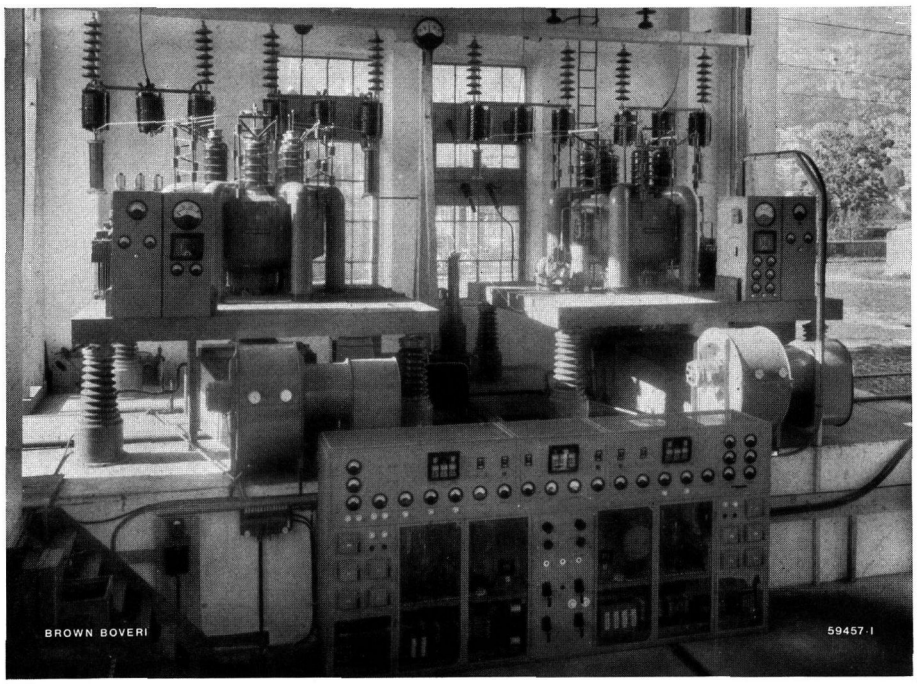


Fig. 46. — Trial plant with two high-voltage mutator sets, each rated 33 kV, 400 A, for the conversion of a.c. to d.c. and vice versa.

Direct-current power transmission gear in the Biaschina Power Station of the Aare-Tessin A.-G.

At top: Air-cooled mutator sets. On left: Sending set.
At bottom: Switchboard with control gear. On right: Receiving set.

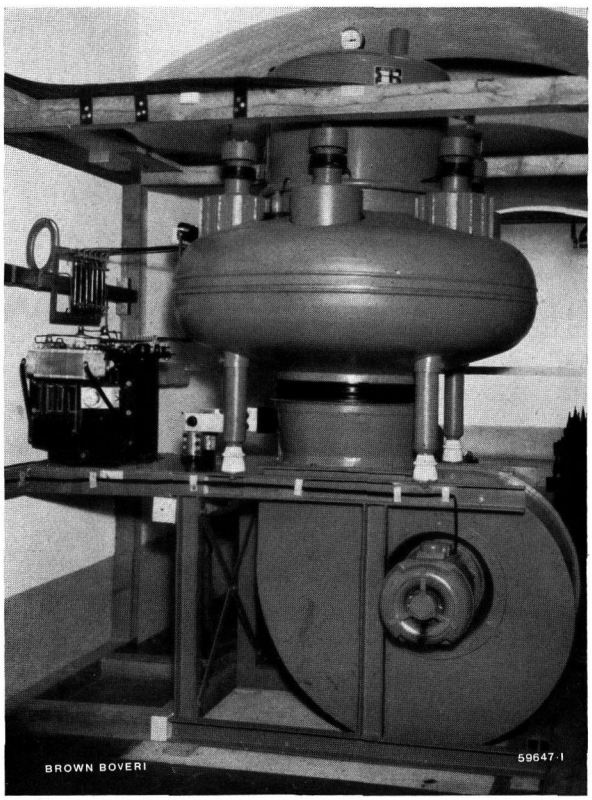


Fig. 47. — Pumpless mutator in "Drahtzug" Substation of Zurich Municipal Electricity Supply.

The first trial plant with a Brown Boveri pumpless, air-cooled mutator for 1500 A, 600 V.

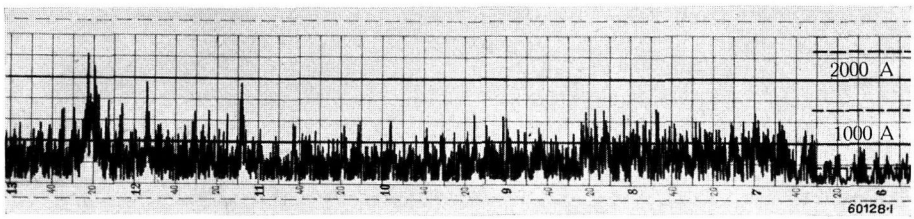


Fig. 48. — Load chart of pumpless, air-cooled mutator in the "Drahtzug" Substation of the Zurich Municipal Electricity Supply.

Note the heavy load fluctuations involved by tramway operation.

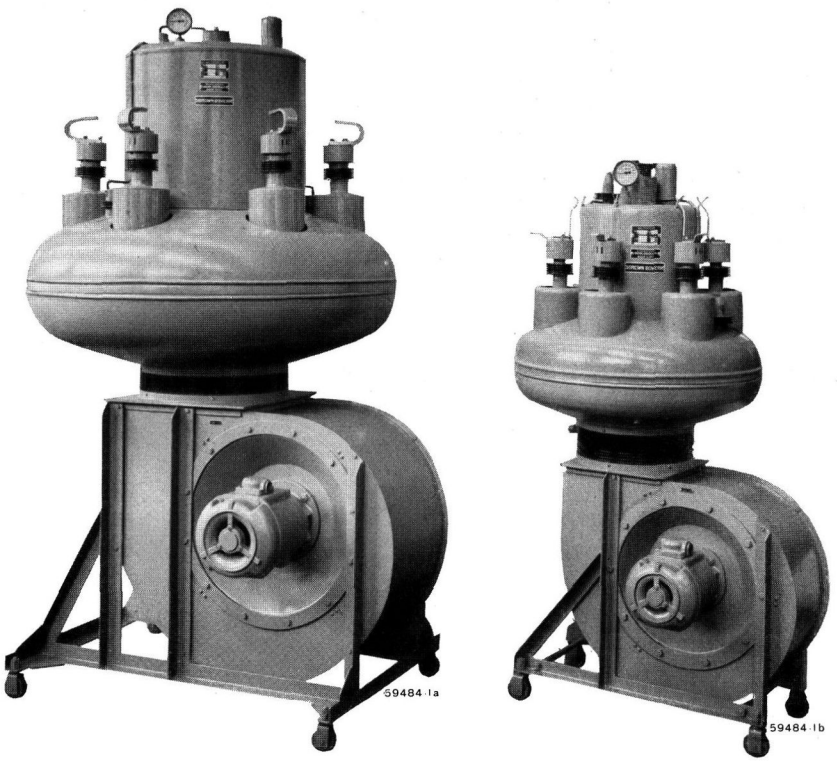


Fig. 49. — Pumpless, air-cooled mutators manufactured on mass production lines. The two standard types L 36 (on left) and L 06.

Mutator type L 36	Mutator type L 06
900 kW at 600 V	360 kW at 600 V
1500 kW at 1650 V	600 kW at 1650 V

is shown together with the 600 A set in Fig. 49. This engraving gives a good idea of the relative size of the two sets.

Work on the *single-anode mutators* referred to in this number of the Review last year was also continued. Compared to the plants supplied in the past year the output of these mutators (or rather mutator elements) has been quite substantially increased. Investigations are in progress with a view to dispensing with the pump of these units.

The development of such mutator units has been taken up because the arc drop is inherently smaller than with the conventional multi-anode design. The improvement in efficiency achieved in this way is of particular importance in the case of high-current types for the electrochemical industry where the cost of energy represents up to 80 % of the total working costs. A step forward in this direction, i. e., in the

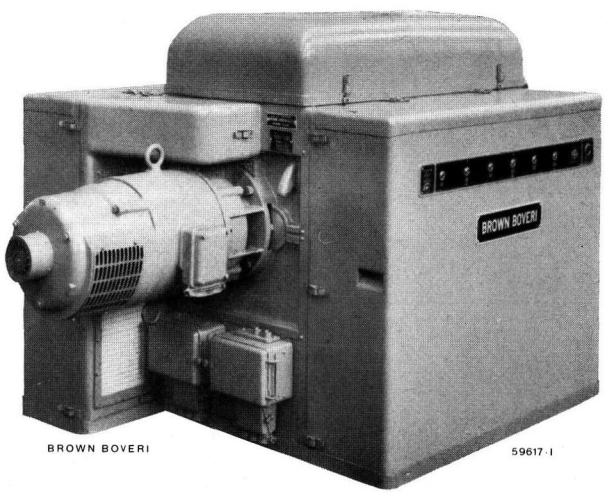


Fig. 50. — Mechanical rectifier for an aluminium works.

3400 kW, 150—400 V, 8500 A. This unit operates without windings or arcs and therefore has a correspondingly high efficiency.

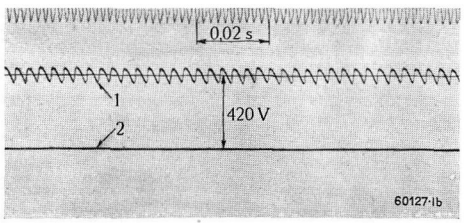


Fig. 51. — Oscillogram of unsmoothed direct current of mechancal rectifier in Fig. 50.
1. Voltage. 2. Zero line.

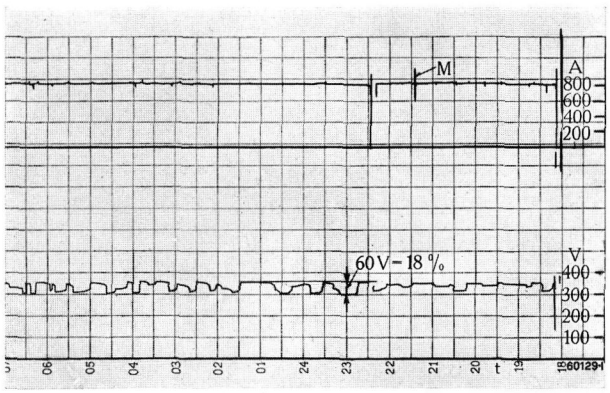


Fig. 52. — Constant current regulation of a mutator with grid-control induction regulator operated by our new servo-motor regulating gear.
Notwithstanding voltage fluctuations of 30 % the current variations are no greater than ± 6 %.
M. Manipulation. At top: Direct current.
t. Time in seconds. At bottom: D.C. voltage.

improvement of the efficiency of a. c. – d. c. conversion at low voltages with very high currents, has been made through the development of a *mechanical rectifier*. Fig. 50 shows the firm's first rectifier of this type, rated 8500 A at 400 V, in a noise-proof casing, which was completed during the year.

Work was also systematically continued on the development of the mutator accessories. Particularly in the case of high-current mutators the grid control gear was found to need improvement, or rather, refinement. This was achieved by completely separating the control and regulating functions. With the new arrangement the motion of the electrical regulating gear is transmitted to the induction regulator—provided to vary the phase displacement of the grid voltage—by means of a torque amplifier operating with oil under pressure. The whole equipment forms a compact self-contained unit of pleasing appearance. The multifareous requirements of such regulating sets have been taken into consideration in the new equipment. The chief of these requirements are:

1. Adaptation to various regulating duties, such as adjustment of voltage, current, power, power factor, etc.
2. Adjustment of the range of regulation, e. g., to 5, 10, or x % of the regulated quantity.
3. Damping of regulating process to obviate hunting.
4. Adjustment of desired characteristic.
5. Ready change-over from automatic to hand regulation or remote operation.
6. Adjustable contacts for the operation of other regulating units as a function of the induction regulator position.
7. Ready adaptability and adjustment for setting to work.
8. Rapid automatic downward regulation with subsequent slow upward regulation upon the grid protecting gear operating.
9. Automatic downward regulation of voltage in case of breakdown of pressure-oil control gear.

The diagram in Fig. 52 gives an example of the method of operation of the new regulator.

III. BROWN BOVERI MANUFACTURES IN INDUSTRY, TRADE, AND AGRICULTURE.

A. MOTOR DRIVES AND ASSOCIATED CONTROL GEAR.

Introduction.

The development of motors for all systems of supply and all types of drives was continued. Such work, although as a rule only affecting design details, has to be carried out unceasingly, partly to meet customers' requirements, but also to achieve definite improvements which from the firm's experience in the field in question appear to be advisable and will lead to more convenient operation or at least increased production of the driven machine. Apart from such, in itself, insignificant work, but which throughout the years represents a considerable overall advance, a certain amount of specific development work was carried out in the motor field during the year under review, as exemplified hereafter.



Fig. 53. — Double-slot rotor of a three-phase motor rated 870 kW, 6000 V, 50 cycles, 2975 r. p. m.
Such high-speed squirrel-cage motors are intended for the drive of blowers with large gyrating masses, i. e., arduous starting conditions with long starting periods.

For instance, we had occasion to build a number of large high-speed *squirrel-cage motors* for the drive of blowers with large gyrating masses, i.e., for arduous starting conditions with long starting periods. The motors in question are of the drip-proof or pipe-ventilated type, incorporating a double-slot rotor and special design features to reduce the mechanical and thermal stresses. Fig. 53 depicts the rotor of such a motor and Fig. 54 a complete machine of this type.

Apart from these special cases large squirrel-cage motors appear to be finding greater application for drives involving onerous operating conditions, such as in the heavy and chemical industries, etc., due to the more liberal attitude increasingly adopted by power supply undertakings with regard to their connection.

Fig. 55 shows a large squirrel-cage vertical-shaft motor for the drive of a bore-hole pump of which maximum reliability is demanded in strenuous day and night service. Notwithstanding the robust design a very effective self-ventilating system has enabled the motor dimensions to be kept small. Due to the automatic oil lubrication of the bearings attendance is only necessary at long intervals, notwithstanding the fact that the motor is in uninterrupted service.

Fig. 56 depicts a large squirrel-cage motor for the drive of a slow-speed, high-pressure, reciprocating compressor in the chemical industry, which can be run up with favourable starting currents by means of a starting transformer. By reason of the design of the motor, which is specially adapted to the arduous working conditions, together with the common bearing for the driving and driven machine shafts, a compact assembly with small space requirements has been achieved. A similar drive has been in continuous operation in the same works for the past four years.

For a long time it was thought that everything was known about the peculiarities of the induction motor. Occasionally, however, phenomena are still encountered which require elucidation. For instance, the starting switches of lift motors may be damaged through an over-voltage phenomenon which hitherto had been given little attention and never satisfactorily cleared up. This problem was exhaustively investigated on an asynchronous motor during the year and the over-voltages found to occur at the moment of disconnection from the supply. They are not caused by the cascade connection of the motor as originally presumed, but by abnormal conditions in the rotor circuit. If one phase of the stator of an asynchronous motor is interrupted and unsymmetrical conditions exist in the rotor circuit, an over-voltage with a heavily

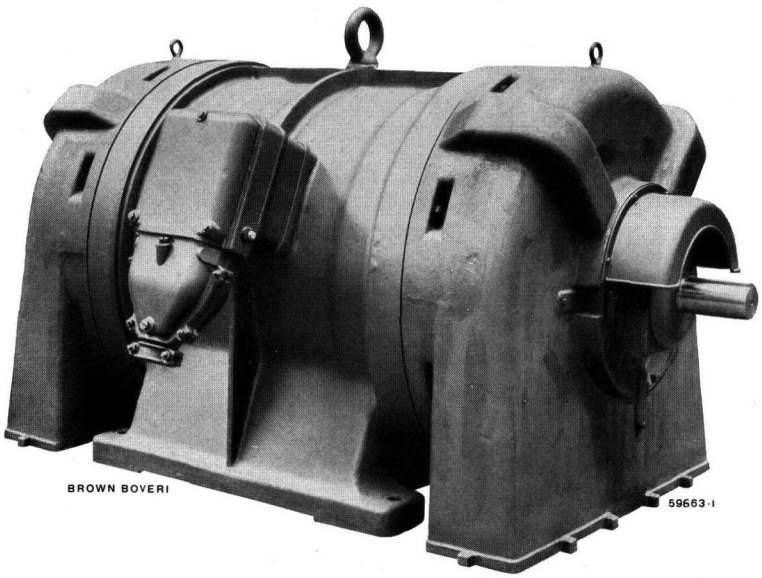


Fig. 54. — Three-phase pipe-ventilated motor rated 1000 kW, 6000 V, 3000 r. p. m., 50 cycles, with oil-lubricated plain bearings, for a hydration plant.

distorted curve form occurs across this phase; the amplitude of the wave can attain six times the supply voltage according to the degree of unsymmetry, the extreme case being provided by an open-circuited rotor phase. The following theory is advanced for the occurrence of these over-voltages in lift service:—

The three contacts of the switch never open absolutely simultaneously when the motor is disconnected from the supply, so that an over-voltage occurs across the phase opening first and an arc re-bridges the open contact. The same process is repeated on the two other phases until the open contacts are bridged by an arc across each of the three phases. If the motor is then kept turning by the descending cabin during the disconnection process, the over-voltage may persist for some time and attain a value capable of damaging even a switch adequately dimensioned for normal conditions. An additional proviso, however, is the existence of unsymmetrical conditions in the rotor circuit. The only part played by the cascade connection in this sequence of phenomena is that its more or less complicated automatic cycle of operations may favour the setting up of unsymmetrical conditions in the rotor circuit.

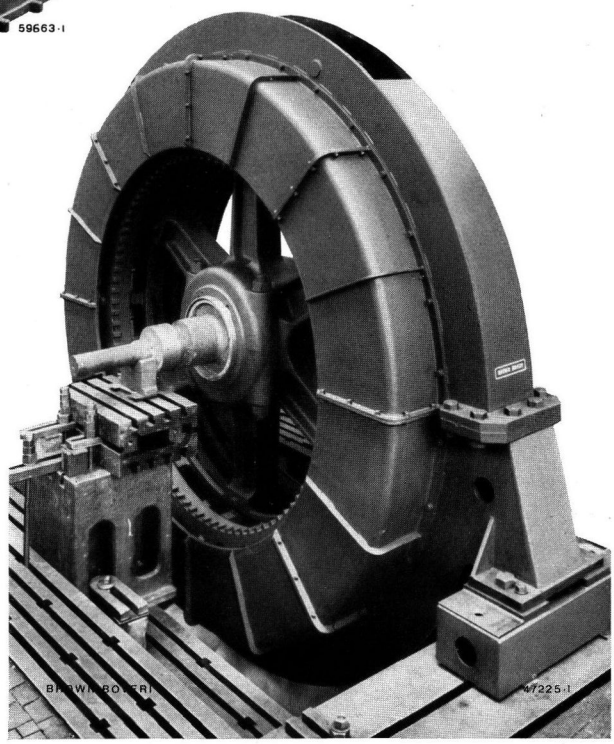


Fig. 56. — Three-phase motor rated 900 kW, 3000 V, 146 r. p. m., 50 cycles.

The motor drives a double-crank compressor.



Fig. 55. — Three-phase drip-proof squirrel-cage motor rated 180 kW, 730 r. p. m., 380 V, 50 cycles.

Apart from the weight of the rotor the upper journal bearing has to take up an external thrust of 1800 kg. The patented automatic bearing lubrication system enables the ball or roller bearings to be effectively lubricated and even with continuous service makes attendance unnecessary for long periods.

A fault intentionally produced in a plant on the basis of these tests resulted in a persistent arc when the motor was disconnected from the supply, although in this case the contact parts were not completely burnt. Nevertheless, it is highly probable that occasional trouble encountered with lift motor switches may be connected with this phenomenon.

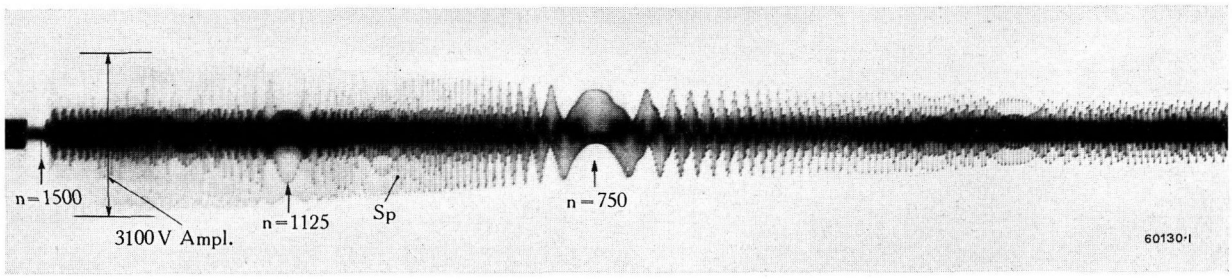


Fig. 57. — Oscillogram of over-voltage occurring when three-phase motor disconnected from supply (one rotor phase open-circuited).
n = r. p. m. Sp = Voltage in open stator phase.

An oscillographic investigation of the conditions obtaining with one of the three contacts of the rotor short-circuiting switch making poor contact, i. e., interrupted, gave an over-voltage of 1850 V amplitude equal to 2·6 times the supply voltage. With one rotor phase completely open-circuited the maximum amplitude of the over-voltage was 2960 V, i. e., 4·2 times the supply voltage. Amongst other things, however, the over-voltage also depends on the saturation of the motor; when this is slight the absolute and relative over-voltage is greater. The oscillogram in Fig. 57 shows the over-voltage during the test with a 380 V supply voltage, corresponding to the normal field. Here the maximum amplitude of the over-voltage is 3100 V, i. e., approximately 5·8 times the supply voltage.

In the case of small three-phase motors it may be stated in passing that the shaft extensions have been standardized to conform to I. S. A. recommendations.

The existing proved design of *three-phase shunt commutator motors* has been extended by a new series of machines of low rating, thus meeting the present tendency increasingly to employ variable-speed motors and furthering the development of driving technique, in which the firm has invariably played a leading part.

The sphere of application of this type of motor has therefore been considerably extended.

In point of fact, motors which can be conveniently regulated entirely electrically are in great demand for the countless small low-power machines in various industries. Examples of new and interesting applications are: Warping machines for weaving mills, dye-works

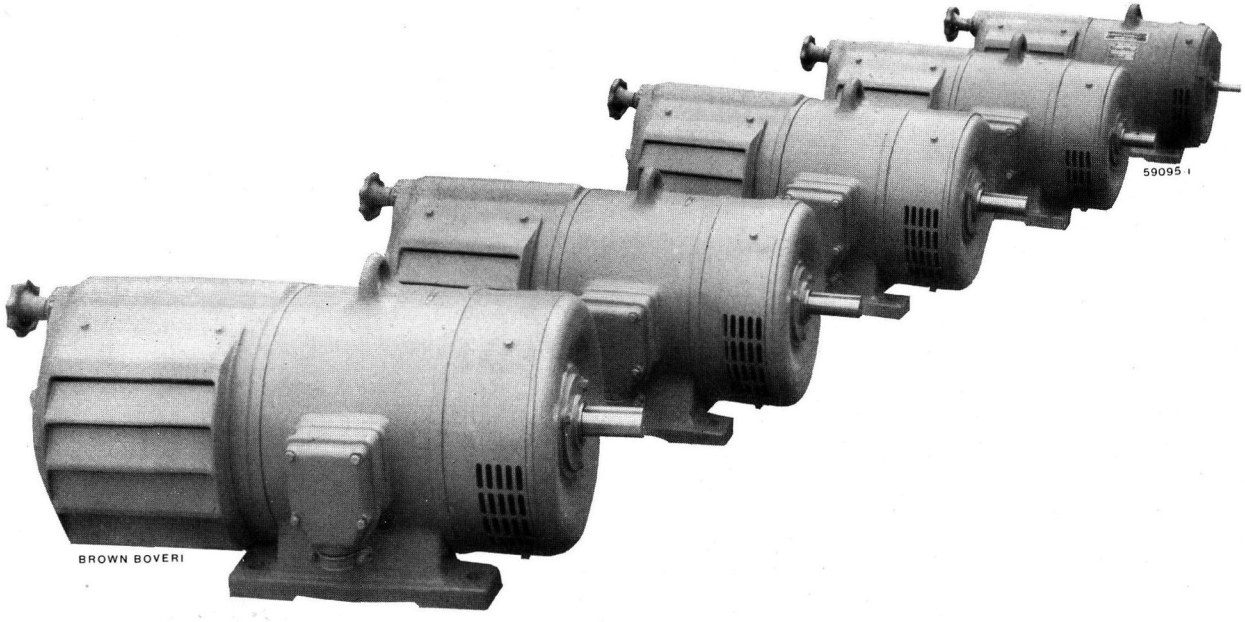


Fig. 58. — A series of small three-phase variable-speed drip-proof shunt commutator motors.
These have proved to be the ideal variable-speed motor for machines of all kinds in different industries.

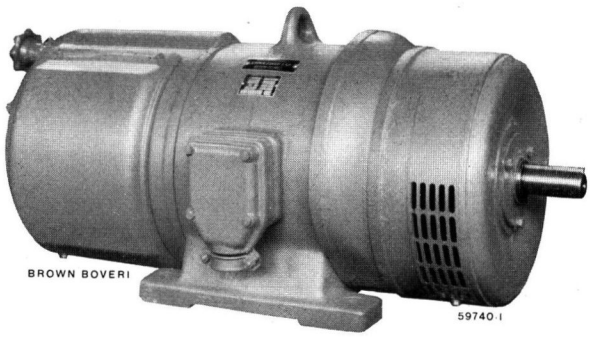


Fig. 59. — Three-phase shunt commutator motor.

Rating 3·7 kW at 2150 r. p. m., speed variable in fine steps between 2150 and 550 r. p. m. with constant torque; totally-enclosed surface-cooled pattern, specially suited to dusty and damp operating rooms.

and cloth finishing machines of all kinds, machine-tools, printing presses, transverse cutters, machines in the rubber industry, etc.

The new motors are available for speed ratios up to 1 : 12. In order to be able to meet the various industrial requirements, both drip-proof (Fig. 58) and totally-enclosed surface-cooled types (Fig. 59) are built. Excellent regulating properties, convenient operation, and economical energy consumption make these new three-phase shunt commutator motors the ideal variable-speed motor. They can be directly connected to any three-phase supply system and their speed varied over a wide range without loss of efficiency and practically independently of the load, without any auxiliary gear whatsoever.

New electrical brush control gear of small dimensions (Fig. 60) has also been devised for the foregoing three-phase shunt commutator motors. The motors are started, regulated, and stopped by means of a few push-buttons, thus making for simple operation.

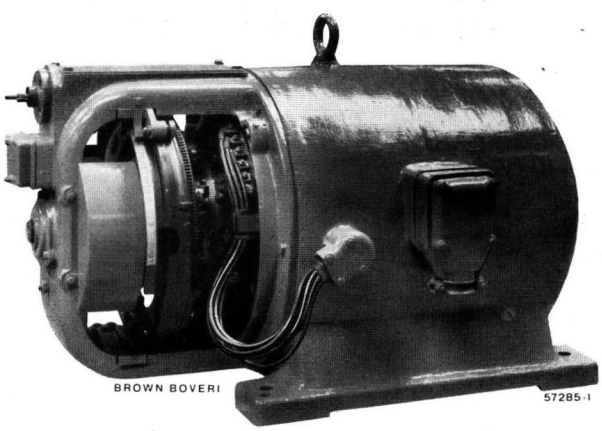


Fig. 61. — Three-phase high-speed shunt commutator motor with patented rotor winding.

Rating 53 kW at 2000 r. p. m., speed progressively variable down to 875 r. p. m. without loss of efficiency, for the drive of a centrifugal pump.

In the case of large commutator motors the output per pole must not be allowed to exceed a definite value on account of the commutation. New types of commutator windings[1] patented by Brown Boveri now enable outputs and speeds to be substantially increased without impairing commutation. This not only permits the material to be better utilized with the resultant relative reduction in the price of the motors, but the latter can be directly coupled to high-speed machines such as centrifugal pumps, blowers, fans, etc., thus enabling gearing to be dispensed with. These motors are built for outputs up to about 350 kW. Whereas without the special windings referred to at the beginning of this paragraph a 75 kW shunt commutator motor could only be built for about 1000 r. p. m., it can now be designed with a speed of up to 2000 r. p. m. Fig. 61 shows one of the new motors.

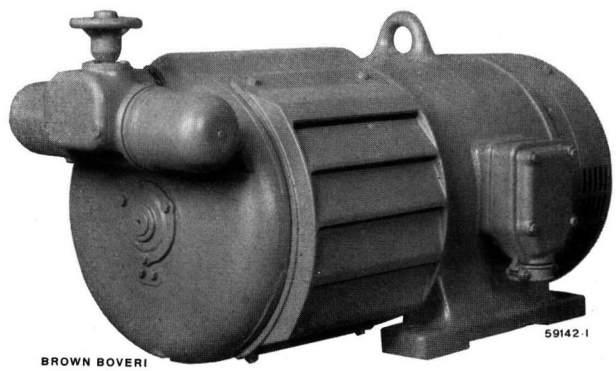


Fig. 60. — Three-phase variable-speed drip-proof shunt commutator motor.

Rating 7·5 kW, 2150—550 r. p. m., 380 V, 50 cycles, with remote-operated electrical brush control gear. The motor can be conveniently started, regulated, and stopped from one or more push-button stations.

1. *Drives in the Textile Industry.*

The equipment for smoothly starting modern heavy speed frames referred to in the review of progress last year, has been improved upon during the interim. It permits of smooth starting without involving the use of a starting resistor. A special rotor combined with automatic changing-over of the stator connections enables the starting torque of the motor to be well adapted to the moment of resistance of the machine during the starting period. In this respect the equipment is far superior to similar contrivances available hitherto. Its operation can be adapted within wide

[1] See H. K. Schrage, Bull. Schweiz. Elektrotechn. Ver. 1943, p. 138.

limits to the prevailing working conditions by means of readily accessible relays provided with scales for adjustment purposes.

The device has proved very satisfactory in the case of a large order for two-speed pole-changing motors. The change-over from the lower to the upper working speed is also effected smoothly. The machine is operated with the existing control rod running along the whole length of the machine, as in the case of the former lineshaft drive, with the addition of a special control switch. The same equipment is also suitable for single-speed drives (Fig. 62).

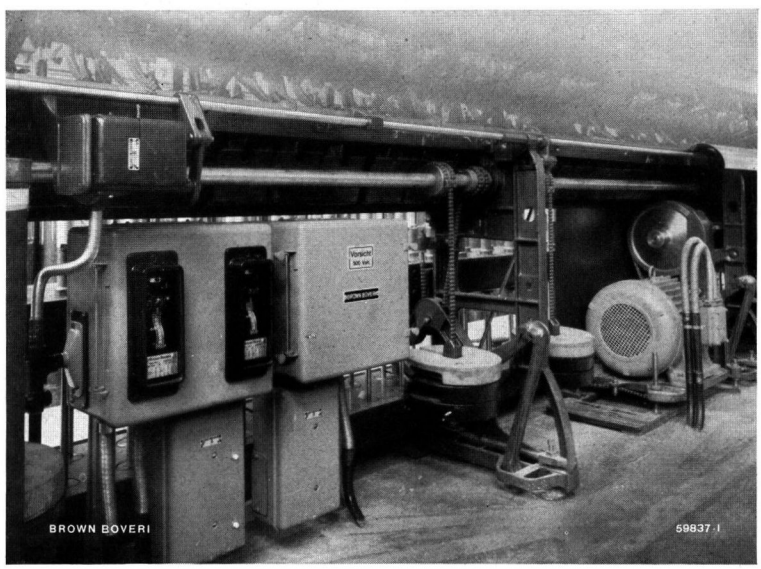


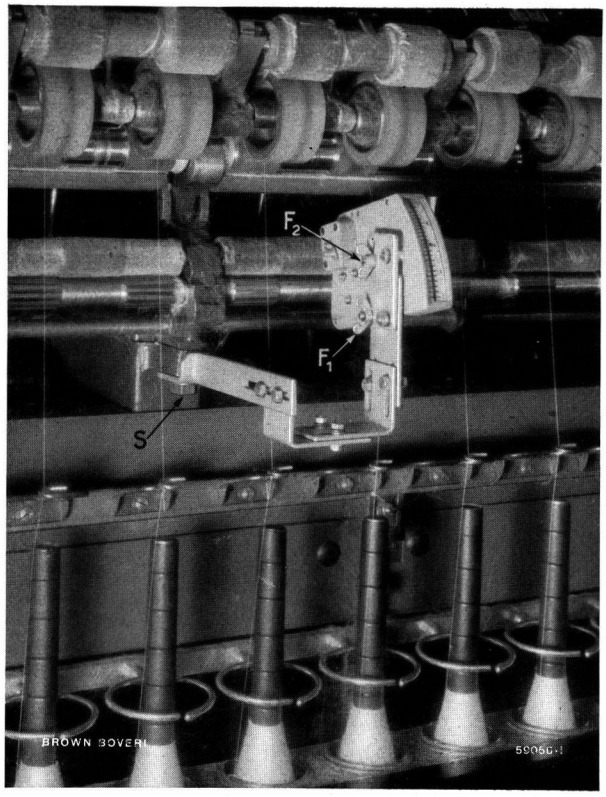
Fig. 62. — Flyer drive with two speeds and smooth starting gear.

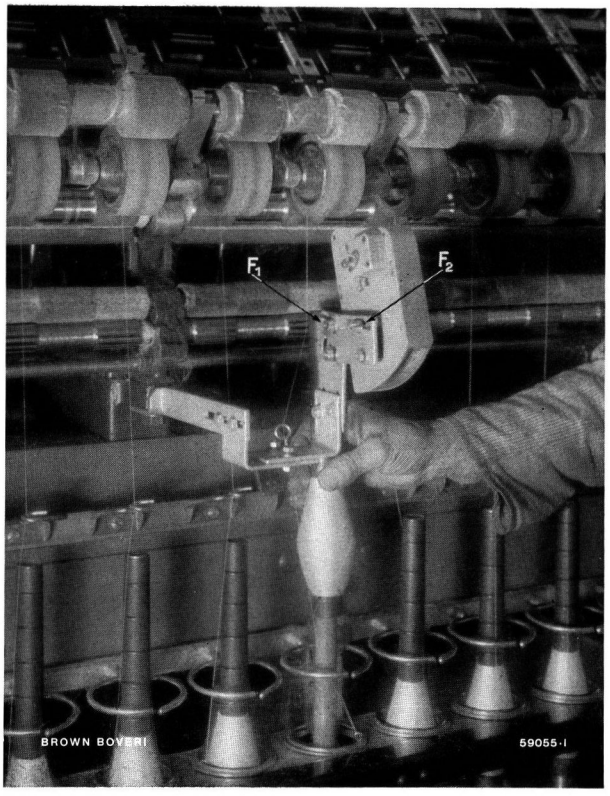
Advantages: smooth starting without starting resistors; starting time conveniently adjustable on two scales; two motor operating speeds, therefore few pulleys; simple operation; the mill hand has simply to displace the control rod in the usual manner whereupon the machine runs up automatically and smoothly.

The field of application of the *thread tension indicator* developed the year before last has been extended by increasing the measuring range to include fine and coarse yarn numbers. The indicator can be supplied with a scale having a range of only a few grams for fine cotton yarns, as well as with scales for the considerably higher thread tensions occurring in carded-wool spinning mills. For certain types of spinning frames in worsted and carded-wool spinning mills special mounting brackets adapted to the construction of the frame were also devised. Through these improvements, the thread tension indicator has found increased application in the cotton industry and, moreover, been introduced in the wool industry (Figs. 63 and 64).

In the case of *sizing machines* it is possible to vary the speed of the warp threads by regulation of the driving motors instead of by a differential and conical pulleys. A separate motor is allotted to each individual part of the machine—squeezing rollers, drying cylinders, weaver's beam—and the speed of all of the motors varied in concert as in the case of cloth finishing machines. The beaming motor in particular requires additional speed regulation to ensure constant warp thread tension with the increasing beam diameter. For this purpose an already proved, patented equipment for the control of electrically-driven reeling devices is employed, this having been used in particular for reelers of paper-making machines, but being just as easily capable of application to the beaming of warp threads and similar processes.

Numerous three-phase shunt commutator motors were again supplied for interesting applications in connection with the variable-speed and remote-controlled drive of machines of all kinds in the *cloth finishing industry*. In the case of Duplex stentering frames (Fig. 65) 6 and 4·5 kW commutator motors drive the needle chain and wringer, respectively. The





Figs. 63 and 64. — Thread tension indicator on worsted-wool ring spinning frame.

Apparatus in measuring position.

Apparatus in position for doffing (exchanging of full cops for fresh bobbin tubes)

Wing nut F_2 serves for adjusting the indicator in the correct measuring position, F_1 for conveniently swinging up the instrument when removing full cops and fitting empty bobbin tubes.

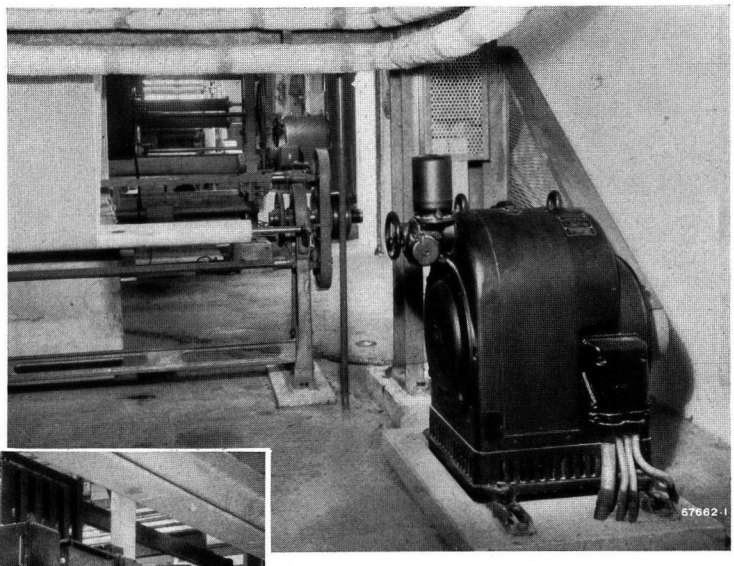


Fig. 65. — Variable-speed drive of Duplex stentering frame with two three-phase shunt commutator motors.

The cloth speed can be conveniently varied within wide limits by push-button control gear.



Fig. 66. — Bank of control and distribution gear for the main and auxiliary drives of a Duplex stentering frame.

Clear layout and simple installation on site are the salient features of this equipment.

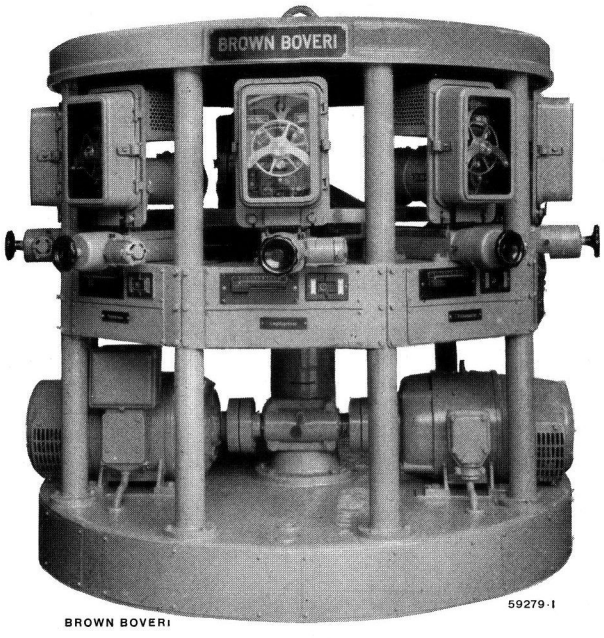


Fig. 67. — Regulating equipment for the sectional drive of a paper-making machine.

The apparatus necessary for adjusting and automatically maintaining the paper draw constant is concentrated in a common stand which is completely dust-, dirt-, and splash-proof and erected away from the paper-making machine. The paper draw is adjusted from the operator's side of the paper-making machine by remote control gear, while completion of the adjusting operation is electrically indicated.

speeds of these motors are automatically controlled within the range of speeds between 1500 and 300 r. p. m., corresponding to a cloth speed ratio of 1:5, in such a manner that the correct draw in the cloth is maintained. In addition, a reversible motor for the adjustment of the cloth width and ten fan motors are provided. These auxiliary drives, like the two main variable-speed motors, are remote-controlled by means of push-buttons. All control and distribution gear is concentrated in a clearly arranged bank (Fig. 66) which considerably simplifies and facilitates installation on site. The advantage of such sectional drives, with which a motor is provided for each separate function, consists in the simpler mechanical construction and much easier operation of the machine due to the omission of numerous wasteful power transmission components.

In spinning and weaving mills there is an increased trend towards the *air conditioning of the work-rooms* to obtain uniformly good working conditions independent of the weather and time of the year. Large numbers of commutator motors have been supplied for the variable-speed drive of the fans which force the humidified air, already brought up to the desired temperature, into the work-rooms. The speed of these motors is automatically regulated in relation to the air velocity and temperature in the work-rooms.

2. *Drives in the Paper Industry and Printing Works.*

In the review of progress in 1940[1] reference was made to a new regulating system for sectional drives of paper-making machines which in the interim has proved entirely satisfactory in a number of mills, some of which overseas. The system comes into consideration chiefly when gearing mounted on the driving shaft extension is employed for the driving sets or when space conditions on the driving side of the machine are so restricted that all equipment required for adjusting and maintaining the paper draw has to be arranged away from the machine. This equipment is mounted in a common stand which has recently been so re-designed that with unimportant modifications it is suitable for nine or eighteen regulated driving sets.

Fig. 67 shows such a stand for a maximum of nine regulated sets. For twice this number of sets the stand is extended upwards and the regulating apparatus arranged on two levels. Each driving set of the paper-making machine is allotted a regulating unit (as shown in Fig. 68) which comprises the equipment for adjusting and maintaining the draw constant, as well as

[1] See The Brown Boveri Review 1941, p. 27.

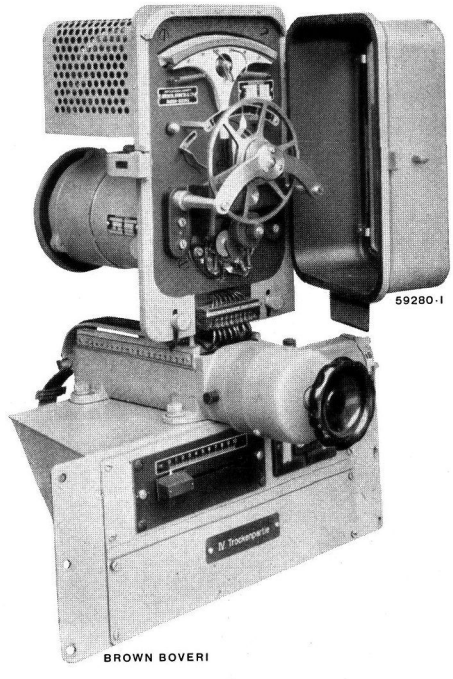


Fig. 68. — Regulating unit for the sectional drive of a paper-making machine.

The apparatus necessary for remote adjustment and automatic control of the paper draw, including all internal wiring, is concentrated in one single unit which can be fixed on the stand in a simple and convenient manner.

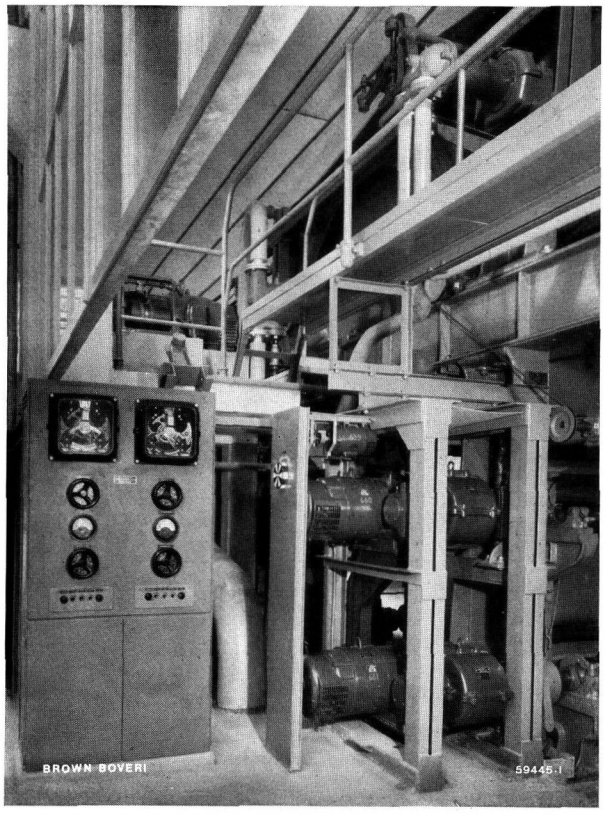


Fig. 69. — Centre-driven reeler with two driving sets, for paper speeds from 18 to 200 m/min.

On the left of the reeler is the control switch cubicle and in between them the equipment for reliably transferring the paper from a full to an empty reel without waste of paper. Firmly wound reels, reduction of scrap, big saving in power consumption, and simple control are salient features of the Brown Boveri centre-driver reeler.

the internal wiring. Such a unit is fixed to the pillars of the stand by means of a few bolts and connected to the leads run inside the pillars. This makes for simple and convenient installation and permits of rapidly changing a complete unit in case of need.

During the year, progress in the design of centre-driven reelers for paper-making machines was also made. A special arrangement, for which a patent application has been filed, enables such equipments to be supplied for large speed ranges and roll diameters. Fig. 69 shows an equipment of this kind for paper speeds from 18 to 200 m/min.

For the drive of rotary presses it has hitherto been standard practice to provide a main motor with a speed range of 1:3 for the printing process proper and a special auxiliary motor for the threading in of the paper at about one-fiftieth of the maximum printing speed, which drove the main motor, or rotary press through reduction gearing and an over-running clutch. This auxiliary drive, however, had various drawbacks, i. e., it complicated the whole drive, increased the cost of the machine, and was a source of trouble in service, which naturally became accentuated in the case of multiple presses inasmuch as each section of the press has its own drive. For this reason it was long desired to eliminate the auxiliary drive by employing a main motor with a correspondingly larger speed range.

Brown Boveri are now in a position to supply three-phase shunt commutator motors — which practically invariably come into consideration for such drives — with a speed range of 1:50, the necessary high starting torque and stable operation of the motor at the lowest speed being achieved by means of a special connection.

A rotary press drive of this type without auxiliary motor was supplied and successfully put into operation for the first time during the past year (Fig. 70).

3. *Industrial and Agricultural Drives and Switchgear.*

The advantages accruing to the user from standardization of machines manufactured on mass production lines are well known and will not be repeated here.

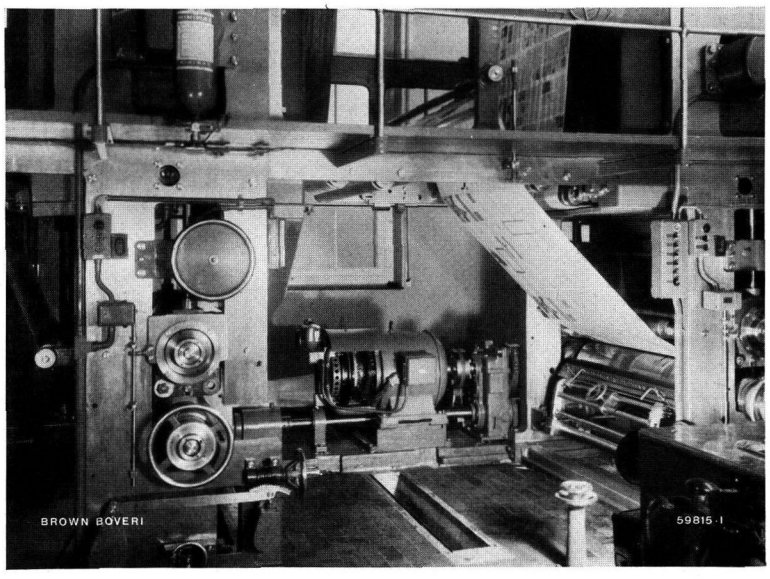


Fig. 70. — Drive of a non-relief rotary press without auxiliary motor.

The three-phase shunt commutator motor has a rating of 16 kW at 1650 r. p. m. Its speed can be continuously regulated down to 550 r. p. m. or temporarily down to 33 r. p. m. for threading-in the paper. Advantages: Simple, reliable layout, smooth starting free from shock, gradual change-over to desired printing speed, no tearing of paper.

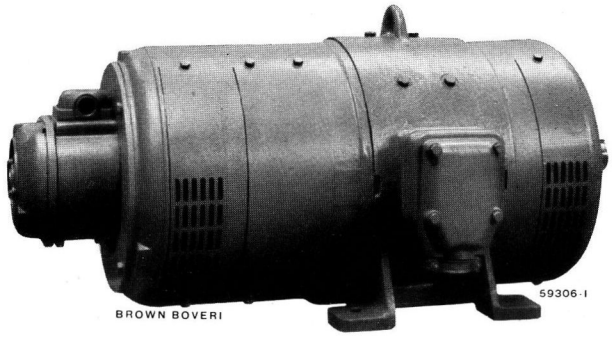


Fig. 71. — Direct-current motor type GJBa 104s + NGe 22, torque 20 mkg in continuous intermittent service, 110—550 r. p. m. (entire speed range up to 1100 r. p. m.), for rapid-reversing planing machine drives.

These motors are built with a particularly low flywheel effect to make them as readily reversible as possible. Moreover, a relatively small type of motor can be employed because the fan built on one of its ends and driven by a separate motor always cools it at the full rate independent of the speed of the main motor.

In this connection, however, another, no less important consequence is worthy of mention, namely, the monobloc design, employed instead of simply coupling two or more machines together to form the motor or convertor sets of all kinds required for the solution of many driving problems. Figs. 71—73 give a number of examples of this design.

The compact and harmonious form of such monobloc machines gives them a pleasing appearance. A further advantage is the shorter overall length compared with the sets of coupled machines employed earlier (Fig. 74). Monobloc convertors can be built up from two, three, or even four machines, are extremely easy to erect, and can be installed in any desired position, even with the shaft vertical. Apart from the economy in material the amount of space saved is valuable both when installing in workshops and particularly when incorporating in machines. The quiet, vibrationless operation enables high-speed machines to be employed, with the result that further material, space, and expense is saved.

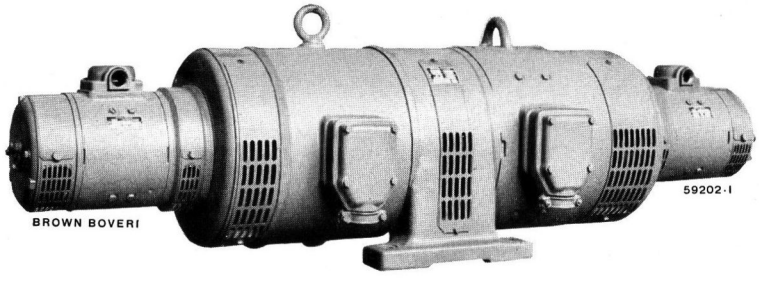


Fig. 73. — Ward-Leonard monobloc convertor, generator rating 20·5 kW, load factor 70%, for rapid-reversing planing machine drives.

This convertor comprises a three-phase motor and a Ward-Leonard generator with main and auxiliary exciters, and is mounted either beside the machine or vertically on a wall.

The range of mass-produced *industrial switchgear* has been extended by a series of new designs. *Reinforced contact gear* has been added to the *small contactor* hitherto rated 15 A, and an alternative with a 25 A rating thus created. The reinforced contactor has the same dimensions as the basic design and can therefore be supplied in the same casing. It is available in a variety of designs — with or without thermal releases, with built-in push-puttons — as single and double contactor, etc. (Figs. 75 — 78). Notwithstanding the greatly increased rated current the reinforced design conforms to the severe motor protecting switch specifications of the Swiss Association of Electrical Engineers (SEV) on the score of switching power and

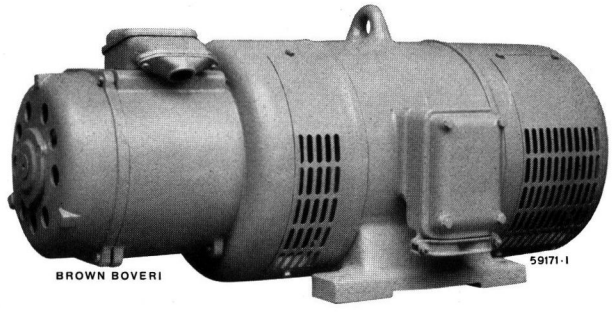


Fig. 72. — Frequency changer set comprising an asynchronous frequency changer driven by squirrel-cage motor.

Such sets are available with all the necessary outputs and frequencies for the drive of high frequency tools.

contact welding. Moreover, it also meets the severest demands as regards operating frequency and life so that it can be employed for the most arduous working conditions.

A special star contact which can be built on to both the 15 and 25 A contactors has increased the power of combination of these contactors still further. With this contact the star connection of star-delta switches and pole-changing switches of motors in Dahlander connection can be established without the necessity of a further contactor, so that such apparatus is not only of small dimensions, but also inexpensive. The numerous design alternatives obtainable with this innovation cannot be gone into here (Figs. 79 — 81). The uniform construction of the cases of the industrial switchgear, which enables it to be concentrated into banks of any desired form, proves particularly advant-

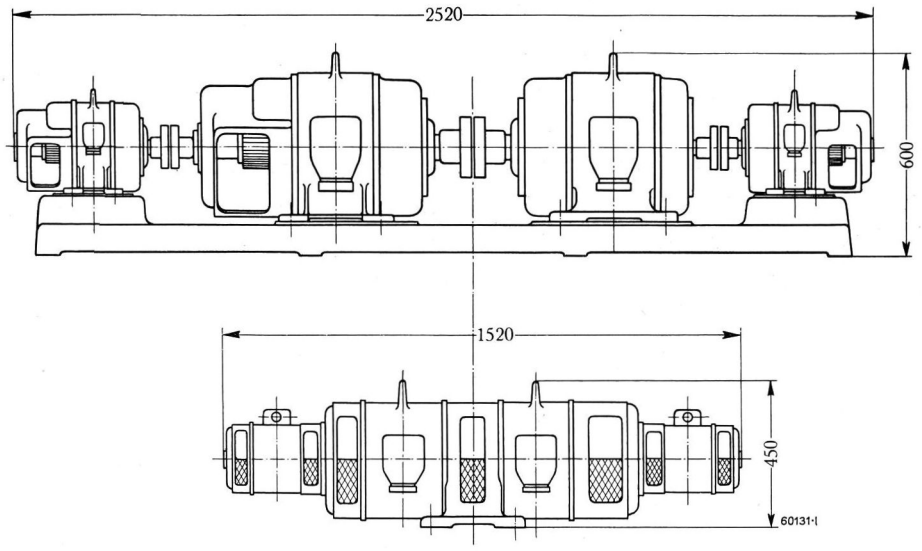


Fig. 74. — Comparison between a convertor with four coupled standard machines and a monobloc convertor of the same size; generator rating 20·5 kW with 70% load factor.

The comparison clearly shows the large amount of space saved by employing monobloc convertors. To obtain satisfactory running conditions a speed of about 1500 r.p.m. was assumed for the four coupled machines and 3000 r.p.m. for the monobloc set.

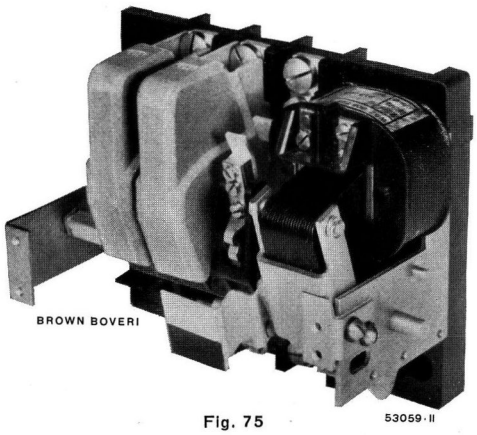


Fig. 75



Fig. 76



Fig. 77

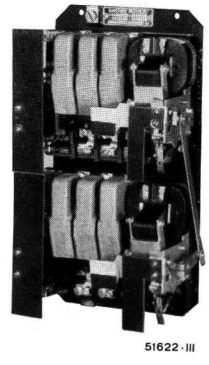


Fig. 78

Figs. 75—78. — Examples of different models of 15 and 25 A contactors available.

The numerous design alternatives and their extremely long life (up to 10 million operations) make these contactors an all-purpose apparatus.

ageous where the combination of such apparatus is concerned.

The range of *d. c. and a. c. contactors* (Figs. 82 and 83) has been extended upwards so that a complete series of one, two, three and four-pole contactors rated 40, 80, 150, 250, and 400 A, with and without magnetic blow-out, is now available. Great care has been taken to make these contactors suitable for the most arduous working conditions, and various improvements have been introduced to this end. By employing the current and time relays referred to earlier automatic contactor control gear of all kinds can be built up.

In order to fulfil motor protection requirements in connection with contactor control gear a new range of *thermal over-current relays* has heen developed. These are built in one, two, and three-pole models for the 0·5 — 400 A current range, like the contactors. For protection purposes directly-heated thermal releases, which have proved their worth in the motor protecting switches marketed for the last two decades,

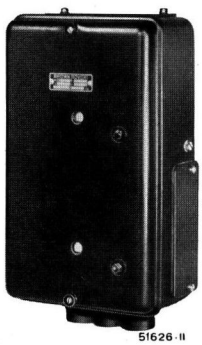


Fig. 79



Fig. 80



Fig. 81

Figs. 79–81. — Examples of 15–25 A star/delta contactors and remote-controlled single and multiple pole-changing switches available.
Fuses can also be built into, and isolating switches combined with, the apparatus.

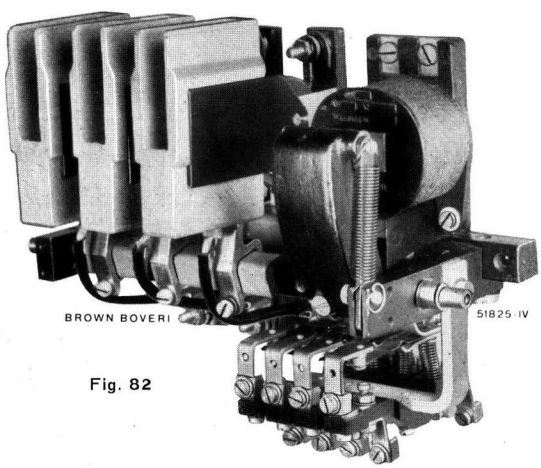


Fig. 82

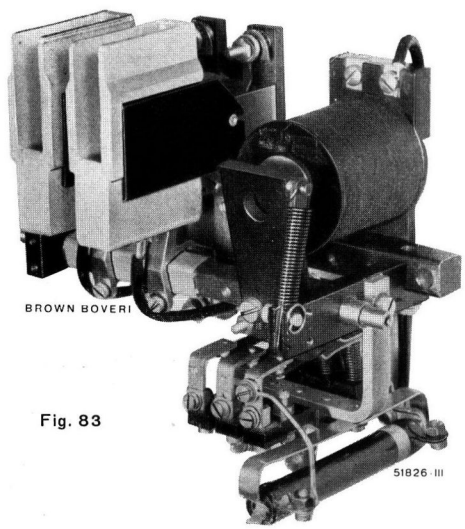


Fig. 83

Figs. 82 and 83. — Three-pole a.c. contactor (on left) and two-pole d.c. contactor.
The contactors have no base-plate, being mounted on a stiff square steel bar, thus making all parts readily visible and accessible.

are employed. A temperature compensating device renders the operation of the releases independent of the ambient temperature.

Apart from the relay element without casing for fitting in switch frameworks and the design with casings of different sizes (Fig. 84), the alternative for directly mounting on the a. c. and d. c. contactors shown in Figs. 82 and 83 deserves special mention (Fig. 85). The relays are bolted on to the square supporting bar of the contactor by means of a special frame, so that the contactor and protective gear form a self-contained unit.

Fitted in *steel cases* these contactors find universal application as industrial switches. In this design the apparatus is available both with and without thermal over-current relay. The accessories of the comprehensive standard industrial switchgear, e.g., ammeters, connection parts, etc., can also be applied here. In this way the apparatus can be well adapted to operating and installation requirements (Fig. 86).

According to the application in question contactors involve control switches which must be just as reliable as the contactors themselves. The severe requirements in this respect, entailed in particular by automatically controlled machine-tools and applications in the heavy engineering industry, are met by new cam-operated control switches (Figs. 87—89). These are available in

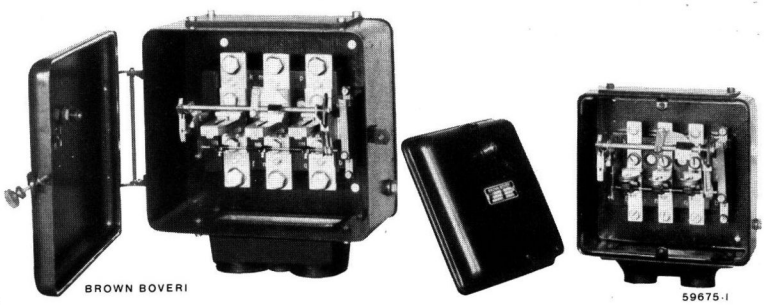


Fig. 84. — Relays type E, in boxes of different sizes.

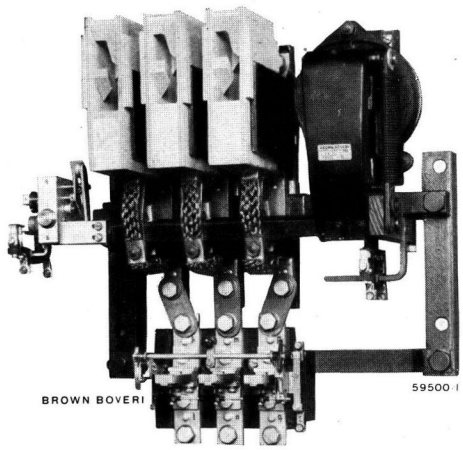


Fig. 85. — Contactor type R with built-on type E relay.

The thermal releases operate a contact lying in the coil circuit of the contactor to be controlled, through a common tripping rod with spring operator and a temperature compensating device.

two sizes, i.e., with up to four or eight switch units of 5 A rating, respectively, which are enclosed in a robust, two-part, dust-tight, cast-iron casing. For operating purposes single or double roller levers, three-pronged forks actuated by stops on the moving part of the machine, or a hand-operated ball-headed lever can be employed. In the end positions there is a play of a few degrees so that the controlled machine part can run on a little after operation of the contacts. Greater flexibility can be achieved by employing a sprung roller lever.

This apparatus is designed for up to 3000 operations per hour and a total number of operations of about 10,000,000. Given uninterrupted day and night service and 400—500 operations per hour this represents a useful life of approximately $2\,^1/_2$ years.

Widest application was also aimed at in the design of these switches. In consequence, they can be supplied with or without automatic return to the neutral position, for operation in one or both directions, with two or more notched positions, with end stops, or for unrestricted switching motion with up to twelve notched positions. By adjusting the cams the cycle of operations can be varied practically indefinitely.

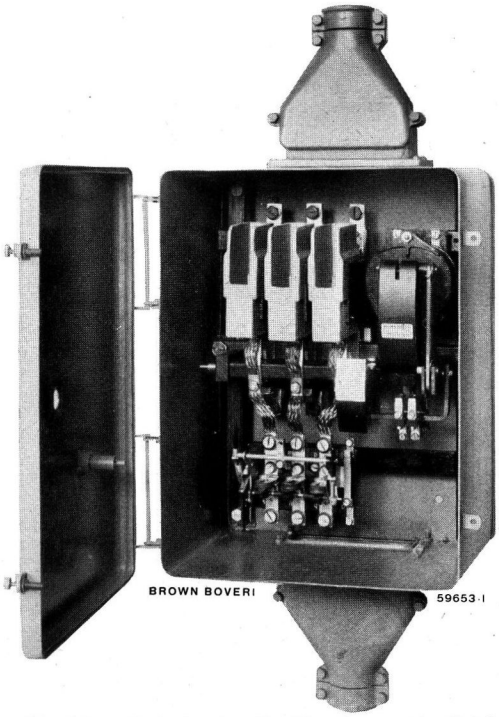


Fig. 86. — Contactor type R with ratings up to 320 A and built-on over-current relay type E in dust and splash-proof steel casing.



Fig. 87

Figs. 87 and 88. — Cam-operated control switch; on left, closed; on right, open.

This control switch is characterized by its great adaptability and its suitability for the most arduous operating conditions.

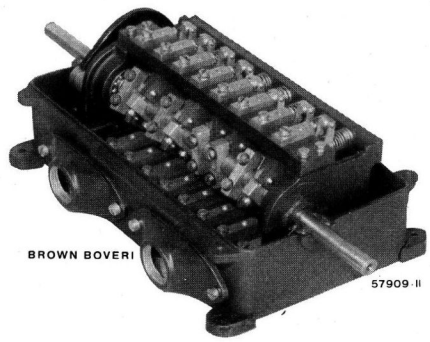
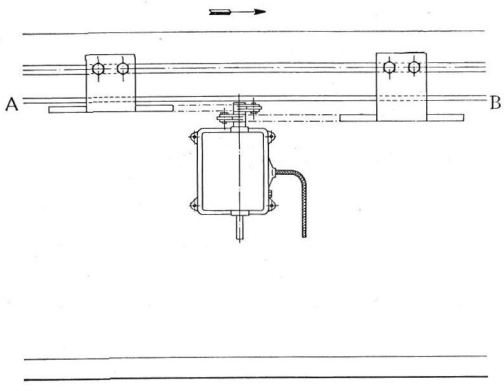


Fig. 88



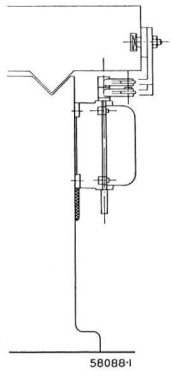
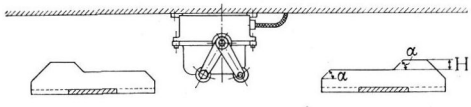


Fig. 89. — Cam-operated switch mounted on bed of planing machine and controlled through a double lever by means of two adjustable stops fixed to the slide.



Furthermore a new range of *high-power low-voltage industrial switches* has been evolved (Figs. 90—92). These are available for a.c. and d.c. in one, two, three, and four-pole models with current ratings of 100—2500 A. A larger switch is in course of development. The types with ratings lower than 600 A are mounted on a base-plate of insulating material, above this rating on robust frames of rolled section iron. The contact gear comprises partly rolling contacts, partly butt contacts with or without silver plating. An effective blow-out device, together with arc chutes and if necessary special phase barriers, enables the switches to cope with high breaking currents. Rapid break, entailing only 0·01—0·02 second from the imparting of the impulse to the tripping pawl, favours the interrupting process.

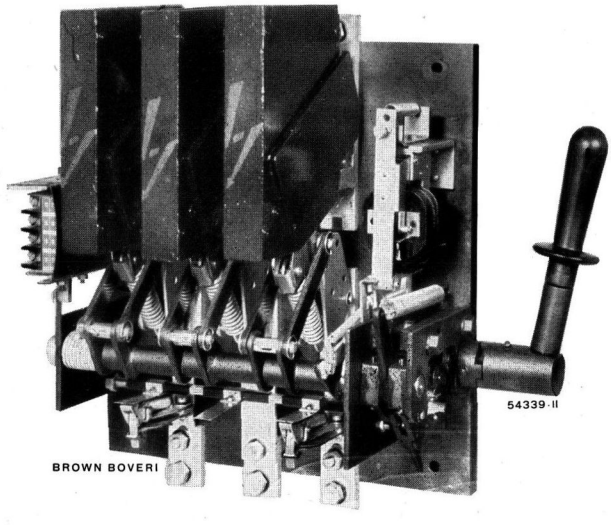


Fig. 90. — Automatic circuit-breaker rated 100 A with thermal releases in two phases and low-voltage release.

Switch mechanism on strong insulated base-plate, contacts enclosed in large arc chutes, convenient wiring top and bottom.

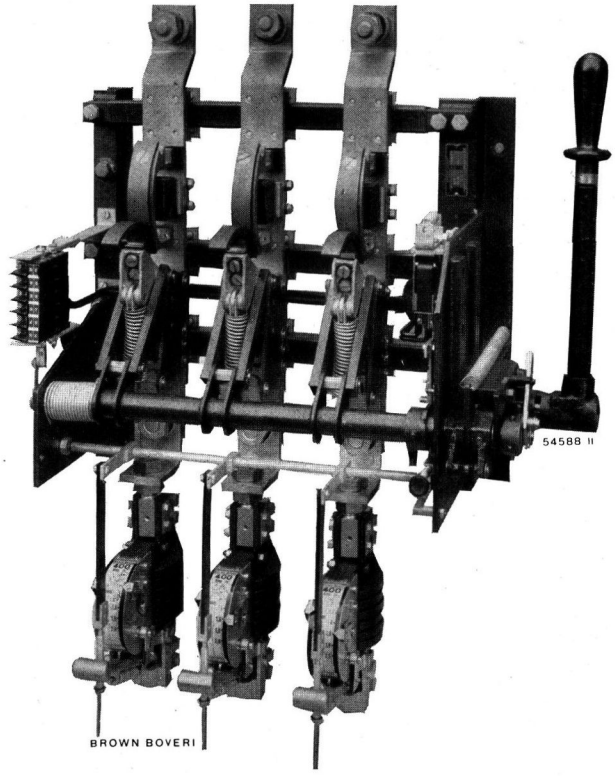


Fig. 91. — Automatic circuit-breaker rated 1000 A.

Three electromagnetic over-current relays and a tripping coil for remote release are provided. The switch mechanism is mounted on a strong rolled section iron frame. The illustration shows the circuit-breaker closed, arc chutes removed.

Automatic circuit-breakers are employed in both public and industrial low-voltage systems for important duties. They are indispensable as switches for generators, transformers, and motors, as cathode switches

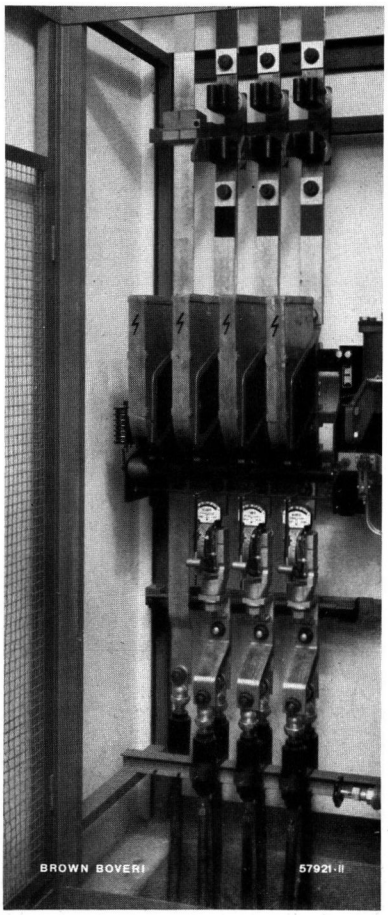


Fig. 92. — Automatic circuit-breaker rated 1000 A.

This apparatus, built in a switch cell in a transformer station, has a pneumatic operating mechanism and three electromagnetic overcurrent relays with adjustable time-lag.

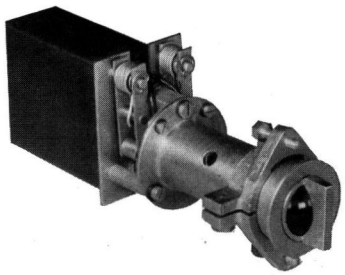


Fig. 93. — Control switch rated 10 A, 500 V, with built-in pilot lamp.

This switch is intended for building in switchboards and can be employed for the electrical remote control of switches of all kinds with position indication.

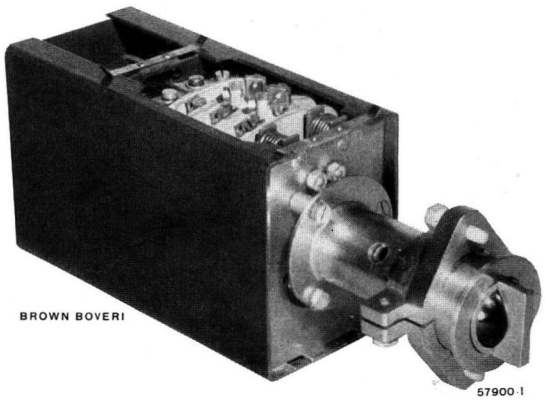


Fig. 94. — Control switch rated 15 A, 500 V, with pilot lamp and holding coil.

This switch only needs a momentary control impulse, being kept in the order position by the holding coil until the order has been carried out. The lamp indicates the position of the controlled switch.

for mutators, as busbar supply switches in distribution plants, and as branch-line switches. Reliability and adaptability to the conditions imposed by the application and method of installation and operation are therefore extremely important requirements and, in consequence were given particularly careful attention in the design of the new automatic circuit-breaker. For operating purposes a simple handle, handwheel with chain transmission, lever drive with rodding, solenoid control, and in the case of large circuit-breakers motor and pneumatic operating mechanisms can be provided. According to the application in question they can be equipped with overload or short-circuit protective gear. For overload protection purposes directly-heated thermal releases (for rated currents up to 600 A), thermal relays, or electro-magnetic ralays with adjustable time-lag can be employed; for protection against short-circuits electromagnetic instantaneous releases, the high-speed releases of the afore-mentioned relays, or in the case of direct current also reverse-current relays, are available. Electrical tripping gear in the form of trip-coils or low-voltage releases can be applied.

Contact gear for control circuits, mechanical position indicators, etc., complete this apparatus so that all conceivable control and signalling equipments can be combined with it. Up to 600 A rating the new circuit-breakers can also be supplied in tightly closing sheet-steel cases or cubicles for individual installation or assembly with metalclad switchgear.

New control switches have also been developed for the electrical remote operation of this and other apparatus. These are of the multiple-unit type with cam-operated elements of 10 or 15 A rating which enable any desired cycle of operations to be carried

out. With the simplest model the handle can be supplied fixed or removable. The position of the switch is given either by the handle or the cam behind it or a pilot lamp which is incorporated in the handle and lights up when the position of the control switch is in opposition to that of the controlled switch itself (Fig. 93). Apart from the pilot lamp a holding magnet is also provided (Fig. 94) which upon a brief impulse being imparted holds the control switch in the "order" position until the order has been carried out, i. e., until the controlled switch has reached the position corresponding to the order. All of these control switches can also be used in conjunction with luminous and mimic diagrams.

The trend in electric driving practice more and more intimately to combine the drive with the driven machine and to split up the driving equipment between the individual driven shafts is extending to all fields of application. The change-over is being effected at an extraordinary high rate, chiefly taking the form of the adaptation of already known elements to new purposes, although progress in the light of new knowledge is otherwise not lacking. In point of fact, the electrical individual drive is passing through a popularization period, whereby all of its possibilities are being exploited to improve and increase the production of machines, while at the same time it is having a favourable iufluence on the design of the processing machines themselves.

Particularly good examples of this tendency are supplied by the electrical drive of machine-tools. They are all the more interesting, inasmuch as, for a definite requirement, e. g., speed variation, no standard system is employed, but according to the problem in question, the electrical engineer is continually proposing new, unconventional controls. Hereafter a number of typical equipments of the many supplied during the year under review are briefly touched upon.

The simplest electrical variable-speed drive is obtained with *pole-changing squirrel-cage motors*. This method is employed where electrical regulation in two to four coarse steps is sufficient. An interesting example of a such a case is the drive of large lathes for locomotive wheel-sets for which a number of equipments with motors rated 40/38/37/33 kW at 1500/1000/750/500 r. p. m. have been supplied. The motors are controlled by means of contactors lodged in a special cubicle. The control gear is so designed that upon the closing push-button being depressed the motor runs up to the lower speed and is changed over to the higher speeds step by step by depressing the same push-button. Speed is reduced in the same way by a further push-button. Special design features incorporated ensure the revolutions being varied as gradually as possible during transition from one step to the next. Notwithstanding the extremely simple means employed this is achieved very effectively as proved by the oscillogram in Fig. 95.

Ward-Leonard drives enable the severest regulating, reversing, and braking requirements, etc., to be met. A particularly interesting example is the rapid-reversing planing-machine drive the development and perfectioning of which have frequently been alluded to in the Review. Of the many other Ward-Leonard drives for machine-tools one for *precision drilling machines* is worthy of special mention (Fig. 96). In this case not only is a Ward-Leonard-controlled d. c. motor employed for the drilling spindle, but also for the table motion and displacement of the slide. These three motors, however, only require two Ward-Leonard generators,

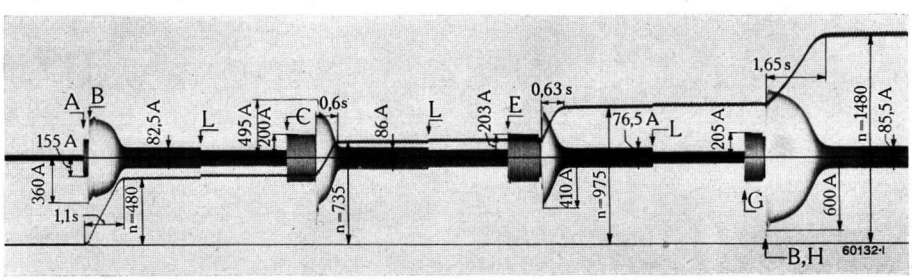


Fig. 95. — Oscillogram of the running up of a pole-changing motor when loaded with the rated torque.
40/38/37/33 kW, 1500/1000/750/500 r. p. m.

A—H = Change-over from one winding to the next, with intermediate steps.
L = Load variation (change-over to rated torque corresponding to next higher step).
n = Speed in r. p. m.

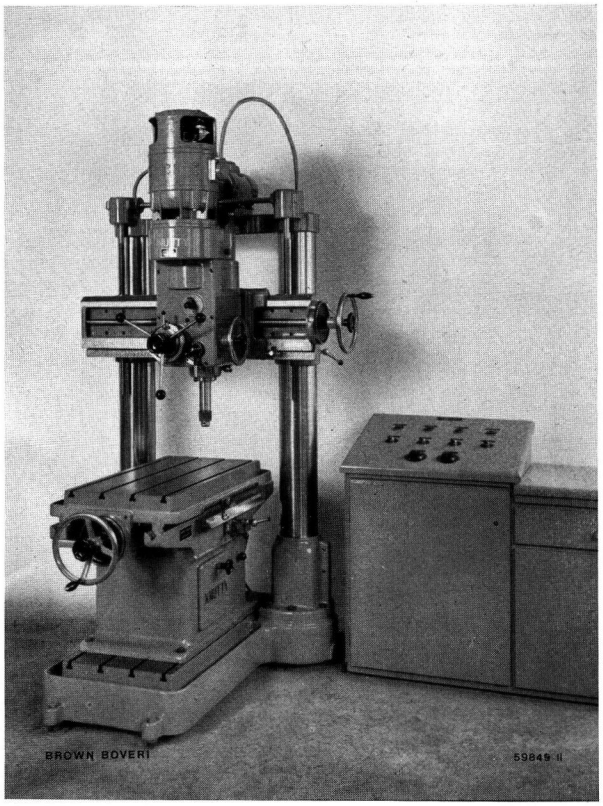


Fig. 96. — Precision drilling machine with drive by variable-speed d. c. motors for drilling spindle, table motion, and displacement of slide.

The control desk, combined with a work bench, contains all operating and control apparatus as well as the Ward-Leonard monobloc set for feeding the motors. All of the electrical control gear is within easy reach of the workman.

inasmuch as the two last-mentioned motors are in operation alternately and are therefore only coupled to the generator when required. The Ward-Leonard set together with the control, protective, and regulating apparatus is lodged in a combined switch desk and work bench arranged to one side of the drilling machine.

Shunt commutator motors are finding wider and wider application for the drive of machine-tools, due to their excellent regulating properties. A quite original drive of this kind was supplied for the *centreless grinding machine* shown in Fig. 97. A conventional induction motor is employed to drive the grinding wheel, whereas the back-pressure wheel is rotated as a result of the grinding process. In order to vary the speed of the back-pressure wheel it is braked by a shunt commutator motor operating as generator, the speed of which can be varied progressively within a range of 1:10. To facilitate operation automatic gear is provided which ensures the work being ground and re-ground exactly to dimensions. After completion of the grinding operation the back-pressure wheel runs back of its own accord and allows the next object to be ground to slip into place, thereupon being automatically pressed on to the work again. In this manner one grinding process succeeds the other without any special attendance being necessary.

The example of a *Starr milling machine* (Fig. 98) shows how perfect a variable-speed drive can be obtained with a squirrel-cage motor. The milling head is driven by a squirrel-cage motor progressively regulated between 4000 and 15,000 r. p. m. by variation of its frequency. The variable-speed drive of the frequency changer is provided by a shunt commutator motor. The big advantage of this method of speed variation is that the working motor proper is very small, inasmuch as the squirrel-cage motor itself is of very small dimensions and such a motor gives an approximately five times greater output at 15,000 r. p. m. than at the basic speed of 3000 r. p. m. On the other hand, the control set comprises a relatively large amount of equipment, although this is of no great importance owing to its being separately erected. A large number of these equipments have also already been supplied.

For the *foodstuffs industry* extensive electrical equipments have also been delivered. Here, the large banks

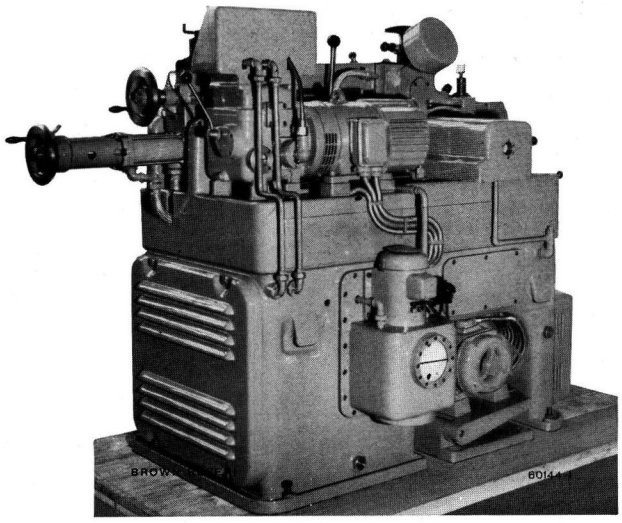


Fig. 97. — Centreless precision grinding machine (view from rear).

The grinding wheel is driven by an induction motor built in underneath the machine, while the counter-pressure wheel is braked by a shunt commutator motor mounted on top and operating as generator; the latter is variable in speed within a range of 1 : 10. This is an interesting example of the intimate assembly of electrical driving units with semi-hydraulically operated machine parts which results in a machine-tool of maximum precision and extraordinary production capacity.

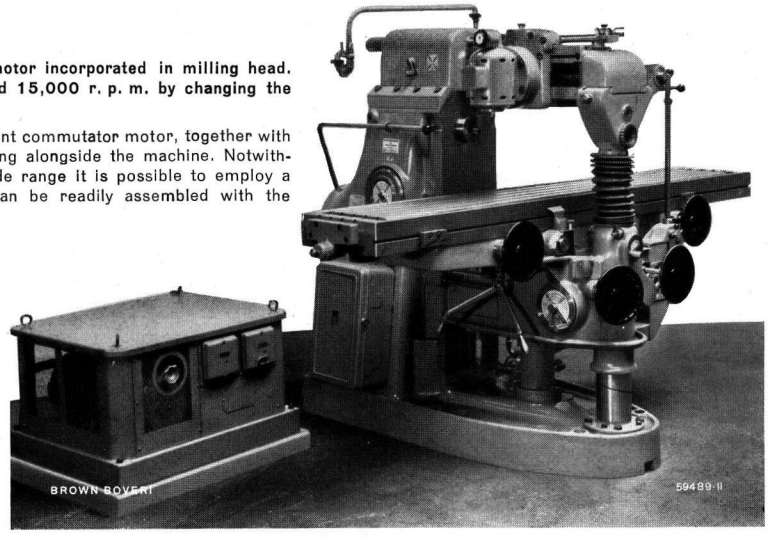


Fig. 98. — Starr milling machine with squirrel-cage motor incorporated in milling head. The speed of the motor is varied between 4000 and 15,000 r. p. m. by changing the frequency.

The variable-speed frequency changer with drive by shunt commutator motor, together with the associated control gear, is lodged in a special casing alongside the machine. Notwithstanding the progressive speed variation within a wide range it is possible to employ a motor of simple design and small dimensions which can be readily assembled with the machine.

of metalclad control and distribution gear are of particular interest (Fig. 99). This bank-wise centralization of the control and distribution gear not only facilitates supervision and operation, but enables special control requirements to be met. According to the manufacturing process groups of motors are operated through a common programme switch so that when setting to work all of the motors start up in the correct sequence. Should a motor break down interlock connections ensure that either all motors preceding it in the manufacturing process or all of the machines in the department in question are shut down. Optical and acoustical indicators inform the attendants immediately a motor has dropped out. Fig. 99 shows the imposing proportions to which banks of modern metalclad control and distribution gear can attain. In point of fact there is nothing more practical than such readily combined and well protected and supervised equipments for industrial plants of all kinds.

4. *Drives for Materials-handling and Rolling-mill Equipments.*

In this field the setting to work of a *high-capacity loading bridge* in the Rhine port of Basle, the electrical equipment of which was developed and manufactured by Brown Boveri, is of particular interest. The plant in question is one of the largest materials-handling installations in Switzerland and is chiefly employed for loading and unloading coal (Fig. 100).

Both the hoisting gear (which is designed for crab operation) and the high-speed crane travelling gear have electrical braking controls which not only permit of accurate manœuvring of the crab, but also reduce wear and tear on the mechanical parts. All of the

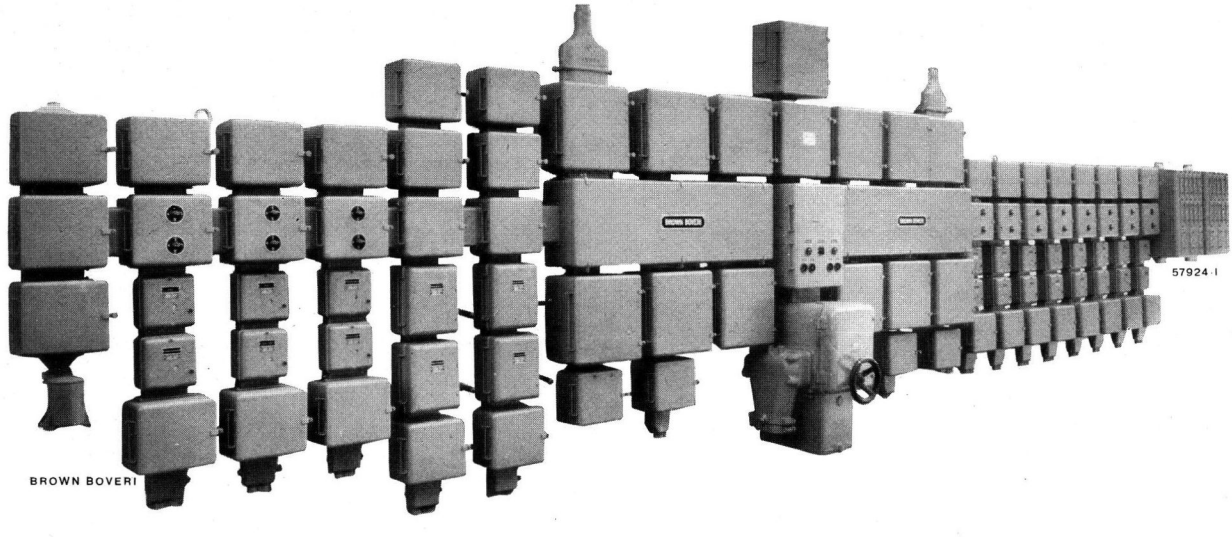


Fig. 99. — Example of a bank of metalclad control and distribution gear for the foodstuffs industry.

Such installations can be arranged in the work-rooms themselves and enable all electrical and space requirements to be met.



6031 B.R.B. 3. X. 39.

Fig. 100. — 6 t slewing travelling crane on a loading bridge.
With a hoisting motor rated 90 kW the hoisting speed is 1·25 m/s. Hoisting and travelling gear are rapidly and smoothly braked by electrical braking controls in conjunction with electrohydraulic thrustors. Under heavy-duty materials-handling conditions wear and tear on drives, material, and ship or wagon are greatly reduced.

drives are equipped with the firm's well-known cam-operated controllers with hammer contacts, which have proved extremely satisfactory under arduous materials-handling conditions. Electro-hydraulic thrustors complete the equipment which is based on the most modern design principles to give maximum reliability and materials-handling capacity, together with ease of control.

During the year a large number of electrohydraulic thrustors for a work per stroke of 250—2000 cmkg were supplied, chiefly for the operation of automatic mechanical brakes. The rapid, but completely shockless method of operation of this apparatus, compared to brake releasing magnets, meets with general appreciation.

Whereas electro-hydraulic thrustors are employed to brake different drives to a standstill *rapidly*, the so-termed *brake unit*, a derivation of the thrustor, enables the brake pressure to be regulated according to requirements. This unit was described in detail in the Brown Boveri Review 1943, Nos. 11/12, page 304.

Fig. 101 shows an interesting application of such a brake unit in the travelling crab of a large loading bridge, the travel of the unit being regulated by a pedal-operated anchored-post brake. Whereas earlier,

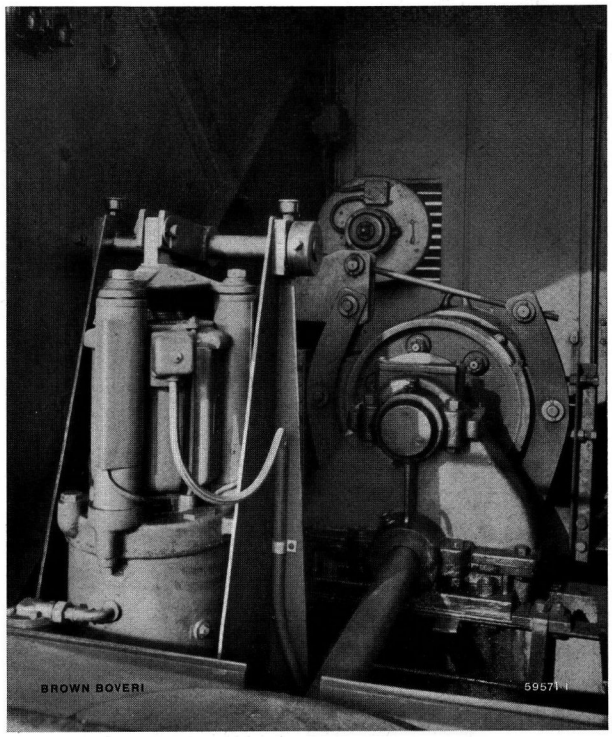


Fig. 101. — Brake unit as regulating brake in a high-speed crane travelling gear on a loading bridge.
Wherever pedal-actuated brakes are employed which demand great effort to operate and thus fatigue the crane driver, brake units can be advantageously applied. Only light pedal pressure is then necessary to obtain any braking power between zero and the maximum value and to readily stop the travelling gear at any desired point.

with the directly acting pedal-operated brake, great force had to be exerted on the pedal, the interposing of the brake unit has reduced the required effort to such an extent that the driver no longer becomes fatigued and, in consequence, a larger amount of material is handled.

In the electric winder control field a notable innovation is *decking equipment* which greatly accelerates the deck-changing of cages. The moving masses are made to follow so closely the retarding movement of the control that when the driving agent is cut out they also immediately come to a standstill. The beginning of each decking operation is controlled directly by the banksman and the end by the decked cage itself, it being impossible for the driver in the winder house to intervene in these manœuvres due to a special interlocking arrangement. The reader is also referred to an article entitled "Innovations in the Electric Winder Field" which appeared in the last number of this journal and in which the 1941 model of the *oil servo travel regulator*, first brought out in 1936, is described.

An order was received for the electrical equipment of a *furnace charging plant* for heavy, long steel plates. The material to be charged involved six separate charging platforms which, according to the length of the steel plates, operate alone or in synchronism and have to be controlled from six different points.

In order to satisfy these none too simple operating conditions synchronized control was chosen with which each of the six three-phase driving motors is allotted a so-termed three-phase synchronizing machine (Fig. 102). By appropriately selecting the machines and associated control gear, absolutely synchronous running can be achieved and working requirements thus fully met.

B. ELECTRIC WELDING.

The *spot and seam welding machines* discussed in detail in last year's review of progress have met with a ready demand due to the excellent operating results obtained. During the year an order was received from the Swiss Car and Elevator Corp., Schlieren, for the largest spot welding machine so far manufactured in Europe. The machine in question will be used for fabricating new lightweight express railway coaches.

For some years past the Swiss Federal Railways have been introducing trains composed of lightweight steel coaches. By reason of the shortage of sheet steel, however, these can no longer be built. In the new wagons, therefore, it is intended extensively to employ aluminium, the side walls and roof being made from one single aluminium sheet reinforced on the inside by rolled section aluminium, doors and windows being cut out of the side panels. The various components are joined together by spot welding, which entails welding machine arms 1500 mm long. It is the length of these arms which determines the output of the welding transformer, in this case 640 kVA. The maximum secondary current is 36,000 A so that aluminium sheets $3+3\cdot3+4$ and $2+6$ mm thick can be joined by spot welding. The design of this powerful machine is fundamentally the same as that of the 250 kVA machines built hitherto. The secondary current is continuously regulated by a sliding-coil regulator which also serves to step the primary voltage down from 8000/16,000 to 500 V. The machine is also equipped with control gear permitting all the usual welding cycles to be carried out. Inasmuch as a spot weld is completed in $^1/_{10} - ^1/_5$ sec. the fluctuation of the welding current and pressure during this short period presents very interesting control problems. The Brown Boveri welding

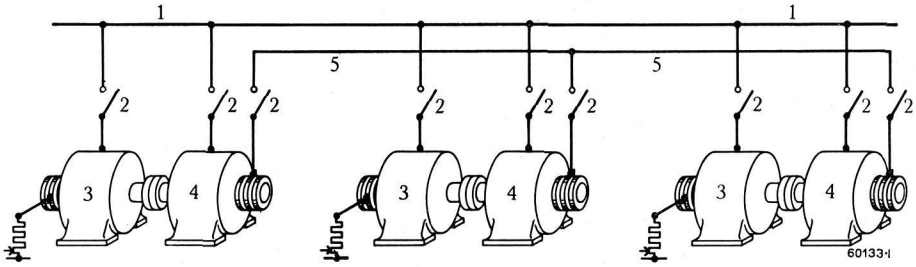
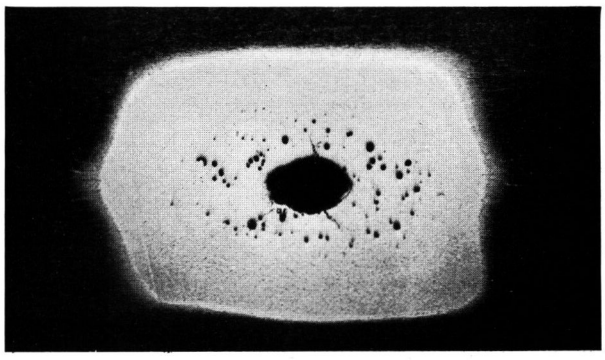
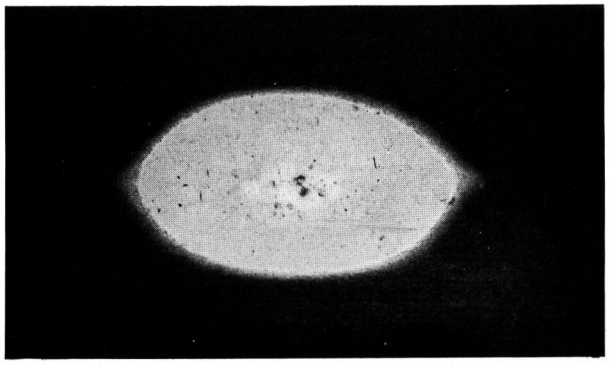


Fig. 102. — Three-phase induction motors operating in synchronism without mechanical connection.

When several drives are required to operate in synchronism, as frequently required for materials-handling equipment, the mechanical coupling shaft can be advantageously dispensed with and replaced by a special control formed by synchronizing machines and bars.

1. Three-phase system.
2. Switches.
3. Driving motors.
4. Synchronizing machines.
5. Synchronizing bar.
6. Starters.





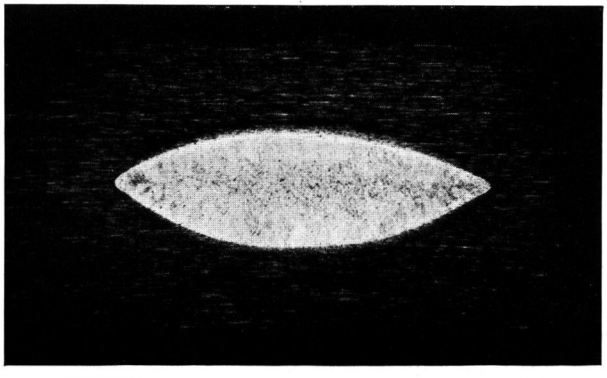


Fig. 103. — Ground sections of spot welds.

Top left-hand engraving: Spot weld with machine incorrectly adjusted. 2 mm anticorodal. Cracks and shrink-holes are impermissibly large.
Top right-hand engraving: Spot weld with machine not quite correctly adjusted. 2 mm anticorodal. Cracks and shrink-holes have disappeared, but the structure of the weld is not quite perfect, while the spot itself is still too large.
Lower engraving: Spot weld with machine correctly adjusted. 2 mm anticorodal. Structure and size of weld correct.

current-time regulator, however, solves this difficulty in a very satisfactory manner.

Welding tests on aluminium and aluminium alloys have been carried out with the machine referred to last year during the whole of the period under review. The results have by far exceeded expectations. The shearing strength of the individual spots is very high and surpasses the mean values published in technical literature. The ground sections shown in Fig. 103 prove the remarkably fine structure of each individual spot. Neither cracks nor pores are to be seen. The structure of the welded points is, if anything, of greater importance in the case of railway coaches than in aeroplane building, due to the joints being subjected to vibrations of a substantially higher frequency. All of these difficulties were successfully overcome as a result of the development work accomplished during the year.

Due to the current peaks occurring, the connection of welding machines to public supply systems sets a whole series of interesting problems. On the basis of extensive theoretical and practical investigations various arrangements have been devised which enable any machine to be connected to any supply system.

Firstly, there is the improved *synchronous switch* for seam welding machines which is so designed that the welding times and intervals can be adjusted for both iron and aluminium. The big advantage of this apparatus is that the switching in and out points can be selected. If the synchronous switch is correctly adjusted no current surges occur when switching in and no arcing when switching out. In this manner current surges are avoided in the supply system and burning of the contacts obviated, thus giving the latter a practically unlimited life. The adjustment of the synchronous switch is so simple that it can be carried out by any charge-hand or welding foreman. It is not necessary to make oscillographic tests, but simply to set a special metering instrument to zero.

In the case of spot welding machines, owing to their peculiar characteristics, other arrangements had

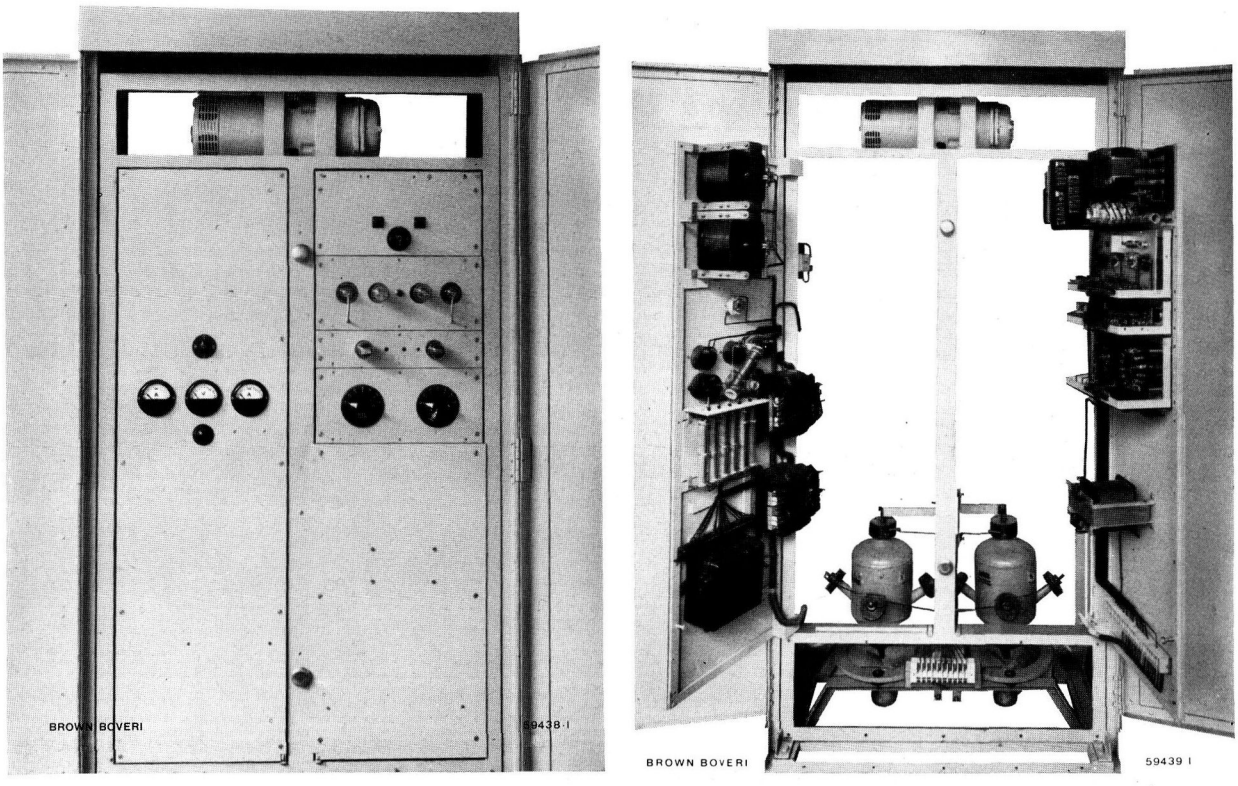


Fig. 104. — Current control equipment with grid-controlled pumpless mutators for spot and seam welding machines.
The grid control of the mutators with high-frequency valves permits of very accurate control of the welding current, as involved by metals which are difficult to weld in order to obtain satisfactory results.

to be sought. Of these, three are worthy of mention. One consists in a patented transformer control with switching-in and pre-magnetizing resistance and the two others controls with condensers. All three arrangements reduce the switching-in current surge — which may otherwise attain twenty times the rated current — to approximately twice the rated current. The question of which of the three controls results in the smallest voltage drop depends on the liability of the supply system to voltage fluctuations. Since it is difficult to elucidate this matter by computation a measuring device has been devised which enables the short-circuit impedance of the system to be determined in a simple manner. Thereupon, it is easy to select the most suitable control.

There are certain welding problems which involve such accurate control of the current that mechanical gear no longer suffices and current control equipment has to be resorted to. This comprises essentially mutators of which the grids are controlled by high-frequency valves. If sources of supply at higher frequences are then employed welding times of the order of $^1/_{1000}$ sec. can be obtained. Such a current control equipment (Fig. 104) was supplied to the Metallschlauchfabrik A. G., Lucerne, during the period under review, for use in connection with the seam welding of flexible tubes of rustless steel. Results to date are very gratifying. The illustration shows the small convertors as well as the mutators and the high-frequency valves.

This current control equipment doubtless has an interesting development stage before it and may ultimately also be employed for ordinary welding machines, since it enables all supply system connection problems to be solved in an ideal manner.

C. ELECTRIC FURNACES.

On the 1st August, 1943, the first iron to be smelted from pure Swiss ores was poured out of the *ore-reducing furnace at Choindez*, briefly alluded to in the review of progress last year[1]. Prior to publication of a detailed description the following particulars of the electrical part of the plant will be of interest.

[1] The Brown Boveri Review 1943, p.44.

The entire plant was built to the plans of "Det Norske Aktielselskab for Elektrokemisk Industri Oslo". In lieu of the proposed motor-operated regulating gear the Gesellschaft der Ludwig von Roll'schen Eisenwerke selected the Brown Boveri electrohydraulic system with which they had made excellent experience. This enabled the arrangement of both the whole electrode equipment and the building to be altered to advantage, compared with the plans. Apart from the electrohydraulic regulating gear, Brown Boveri supplied the entire electrical equipment from the high-voltage cable to the furnace electrode holders.

This ore-reducing furnace is rated 7500 kVA and given high-quality ore is capable of producing up to 50 t of iron daily. With a favourable burden mixture this figure could probably be pushed up to 60 t. The Söderberg electrodes which are progressively replaced as they burn down in the furnace through the setting of a plastic electrode compound continuously fed into the welded electrode sleeves, have a diameter of 800 mm. The three electrodes are arranged in triangular formation for the first time in a furnace of the present size. This arrangement enables an open connection to be employed for the transformer, thus resulting in low-impedance secondary leads. The power factor at full-load has proved to lie between 0·85 and 0·92, according to the electrode voltage, which in itself depends upon the quality of the ore to be smelted.

The range of products smelted at Choindez is extraordinarily large, inasmuch as, apart from the three Swiss ores from the Fricktal, the Delsberger Becken, and the Valais (Mont-Chemin), industrial scrap, such as pyrite residues, welding slag, rolling mill sinter and the like, has to be melted down. In consequence, the electrical equipment had to be made adaptable within wide limits from the point of view of voltage and

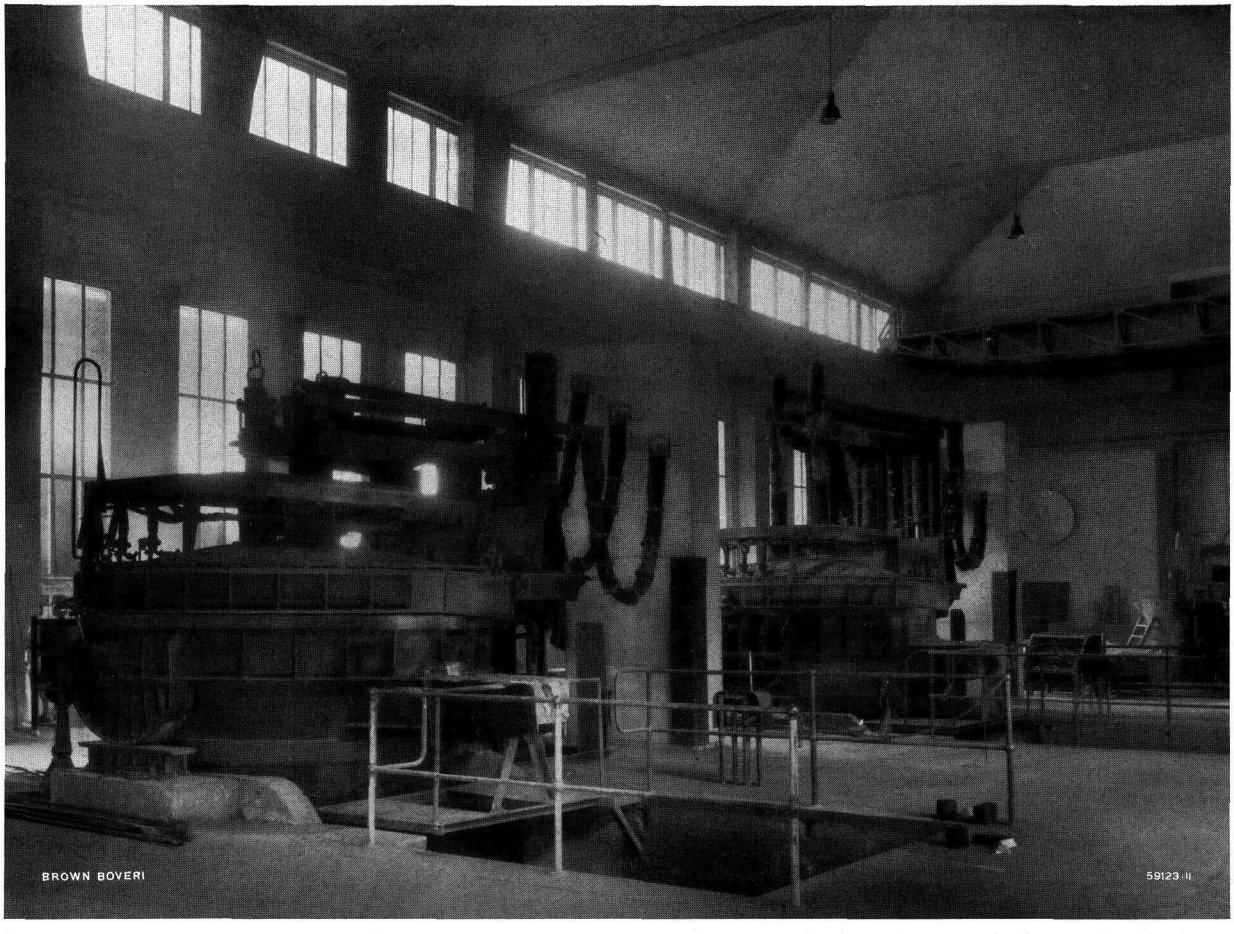


Fig. 105. — Electric steel melting furnaces.

On left, 3 t type with conical hearth, on right 5 t furnace with cylindrical hearth. View from pouring side of furnaces. Due to the lodging of the transformers and high-voltage switchgear in the basement a very neat layout is obtained and the whole equipment takes up a minimum amount of space.

current regulation. The on-load tap-changing switch incorporated in the furnace transformer enables the secondary voltage to be varied in thirty-one steps between 63 and 185 V. The maximum secondary phase current is 22,000 A with 38,000 A in the electrodes. The supply of this current to the electrodes with aluminium conductors involved very interesting designs, the success of which, together with the triangular arrangement of the electrodes, is proved by the high power factor.

The automatic regulating equipment is provided with a pressure-oil servomotor for the control of the main control valves, and results in a regulating accuracy of $\pm 0{\cdot}3\,\%$. The load curve thus approaches a straight line.

In the electrical part of the plant, and particularly in the electrohydraulic regulating gear, many new design features were incorporated for the first time. The fact that no trouble was encountered with the electrical and mechanical equipment when setting the plant to work proves that practical requirements were met in every respect. The article referred to at the beginning of this section, which will deal with the method of operation of the plant both from a metallurgical and an electrical point of view, will be published in the "von Roll Mitteilungen" around the middle of the year.

During the period under review the *electric steel melting furnaces* with pivoted cover, likewise mentioned in the corresponding number of this journal last year[1], were taken into service in the new steel works of the *A. G. der Eisen- und Stahlwerke vorm. Georg Fischer in Schaffhausen* (Figs. 105 and 106). The two furnaces, with a capacity of 3 and 5 t, respectively, have come up to expectations, both from an operating and metallurgical point of view, in every respect. The greater accessibility of the hearth for maintenance purposes, in particular, gives it a substantially longer life. With the new design the covers last for a greatly increased number of charges, the reason for this lying on the one hand in the selected ratio of the furnace diameter to the height of the melting chamber and on the other in the choice of the most suitable electrode voltage for the operating conditions actually obtaining. The shockless raising, turning, and re-lowering of the cover preserves the lining and avoids cracking of the brickwork.

An innovation, as concerns the electrical equipment of the two furnaces, is the provision of an on-load tap-changing switch for the transformer. Although large furnace transformers had already been equipped with similar switches earlier, this was the first time that furnaces of the low rating in question had been provided with such relatively expensive apparatus. The operating results, however, warrant the extra initial outlay in every respect. The application of on-load tap-changing switches decreases the number of disconnections of the furnace from the supply system to three or four per charge, thus resulting in increased production due to the shortening of the charging time, reduced wear and tear on the main control gear, and less repercussions on the supply system.

Operating results obtained with these two furnaces have proved that the use of on-load tap-changing switches in arc melting furnace plants, when even of

[1] The Brown Boveri Review 1942, p. 147; 1943, p. 44.

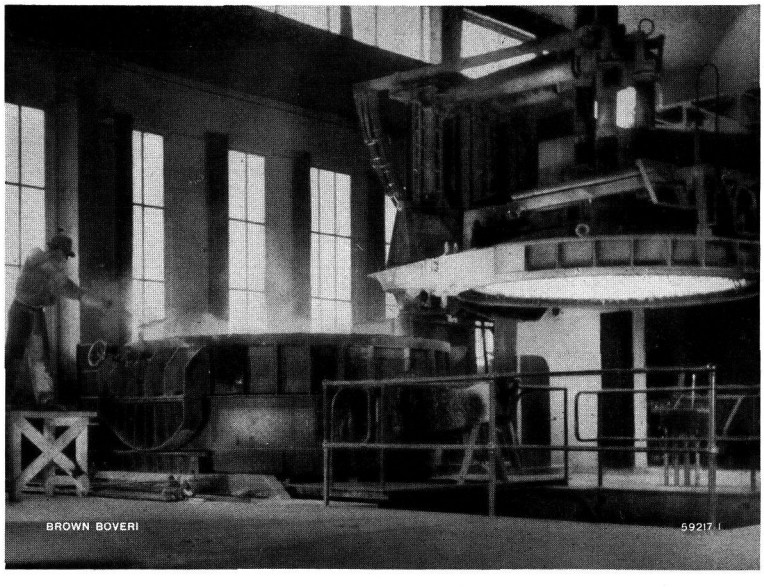


Fig. 106. — 5 t electric melting furnace with cover raised and swung off.

The life of the hearth is considerably lengthened due to the easy accessibility when the cover is swung off. To this advantage is to be added that of reduced charging time.

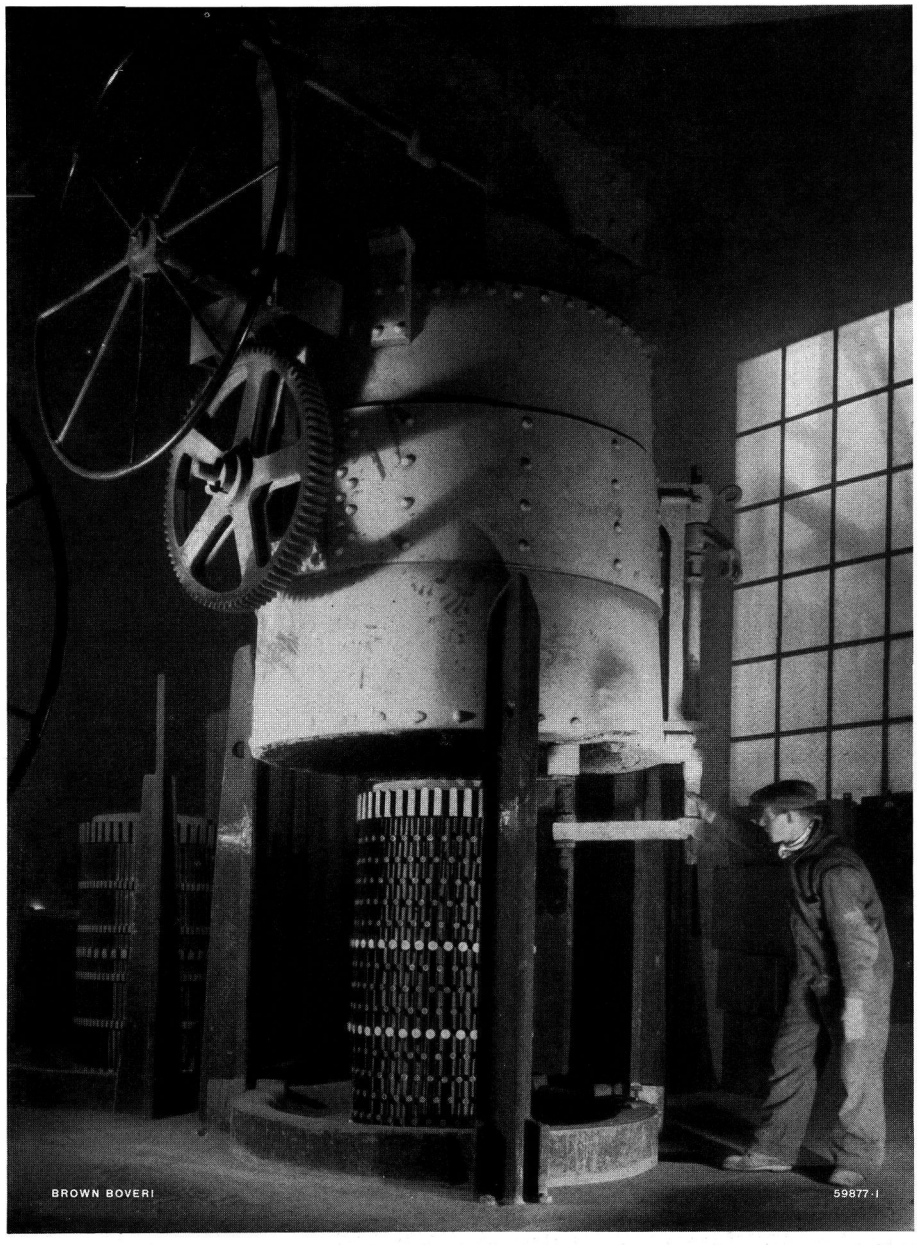


Fig. 107. — Electric foundry-ladle heater (capacity 12 t of molten steel).

Rating 100 kW connected to three-phase 500 V supply. The ladle lining is always uniformly and automatically brought up to the same temperature. The life of the lining is lengthened through the obviation of cracking. The 100% utilization of the heat results in savings on working costs compared to preheating with fuels.

only low capacity, are to the advantage of both the melting process and the supply system.

Another interesting innovation is the *electric foundry ladle heater*. The drying and preheating of ladles for molten steel or grey cast iron involves not inconsiderable quantities of fuel. For a 12 t ladle, for instance, up to 150 kg of coke or a corresponding quantity of gas is necessary. The requirements as to the grade of heat produced are far from severe, temperature fluctuations of $\pm$ 50° C being of little importance, so that the employment of the much higher grade electrically generated heat for this purpose appeared unwarranted hitherto. The fuel shortage, however, has resulted in increased attention being paid to this question.

The first electric heater for a 12 t ladle to be constructed (Fig. 107) immediately showed that the efficiency of fuel heating had been greatly exaggerated and that of electric heating considerably under-estimated. Moreover, the requirements as to the grade of heat had also been set too low. In lieu of the approximately 1 million kcal consumed with coke firing electrical heating involves a consumption of only about one-tenth of this figure and at the same time ensures all of the foundry ladles being preheated to the same specified temperature. Taking a monthly mean a consumption of 220 kWh is involved for the heating up of a 12 t ladle, the energy required for the individual heating-up operations varying between 160 and 400 kWh, according to the length of time the ladle is out of service. These results prove that the electrical heating of foundry ladles is also interesting from an economic point of view, even on the basis of pre-war fuel prices, without taking into consideration the additional advantages of uniform temperature of ladles, longer life of lining due to diminished cracking, practically total elimination of stopper troubles, etc.

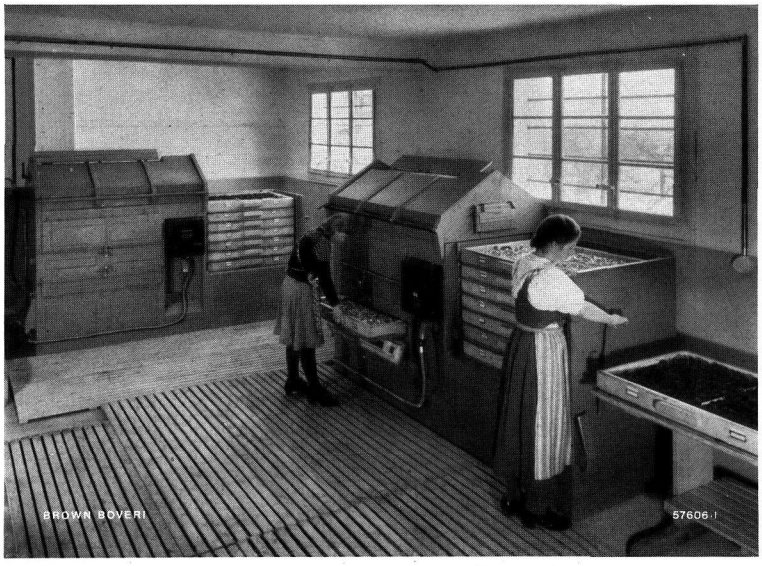


Fig. 108. — Two Brown Boveri universal electric dryers for grass, fruit, and vegetables.
Rating 10·5 kW. Due to the heat recuperation, energy consumption is low. This is an ideal apparatus for farmers for drying their own grass as well as for cooperative dehydration schemes.

The development of *grass dryers* was also continued during the period under review. Apart from the large model which has been supplied to cooperative undertakings in Switzerland during the past few years, a universal dryer, the first model of which to be constructed was mentioned in the corresponding number of this journal last year, is marketed for farmers' own private use and municipal and small cooperative dehydration schemes. Developments in this field are dictated more or less by the fact that due to the war Switzerland is no longer able to import concentrated fodder which is absolutely essential to permit a certain minimum head of cattle to be maintained. The universal dryer now enables farmers to make their own concentrated fodder for the winter, as well as dehydrate fruit and vegetables.

This dryer (Fig. 108), of which large numbers are already in service, operates very economically on the heat recuperation principle; its rating is 10·5 kW. It is furnished ready for connection to any desired system and is proving a useful adjunct in maintaining the food supply of the country.

D. ELECTRIC BOILERS.

During the year eighteen boilers with an aggregate rating of 33,660 kW were ordered. Since the manufacture of electric boilers was again taken up in 1933 a total of 171 electric boiler plants with an aggregate rating of 364,750 kW have been supplied or are in hand.

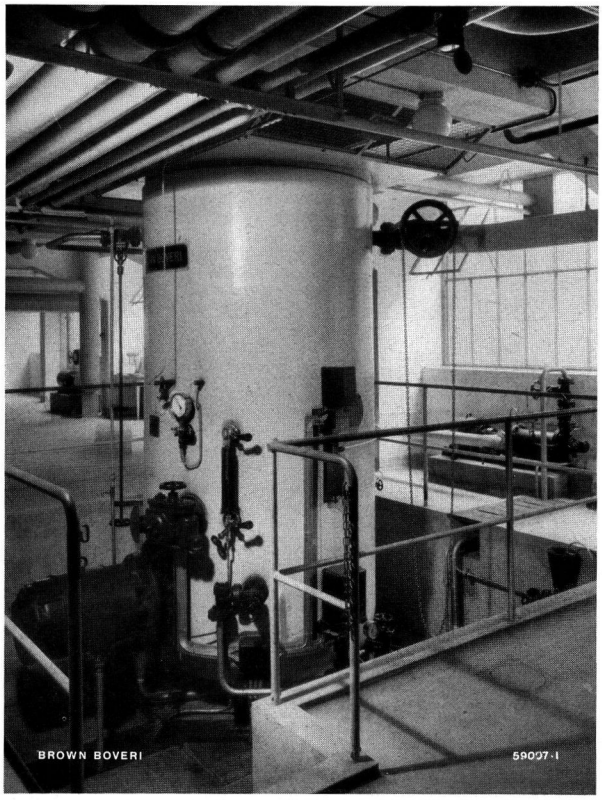


Fig. 109. — Electric boiler plant rated 3000 kW, 6000 V, steam pressure 13 kg/cm² abs.

Due to the restricted space conditions the overall height of the boiler is lower than standard. In order to fully utilize the supply cable its input is automatically regulated, so that the total energy required by the boiler and the works always remains constant.

Among recent installations a 3000 kW water-jet boiler supplied to a chemical works is noteworthy on account of its special automatic regulating gear. The energy available for the boiler depends on the load on a fairly long high-voltage supply cable. In order to be able fully to utilize the available power and thus save as much fuel as possible, the boiler is equipped with a current regulator which regulates the input to the boiler as a function of the cable current, so

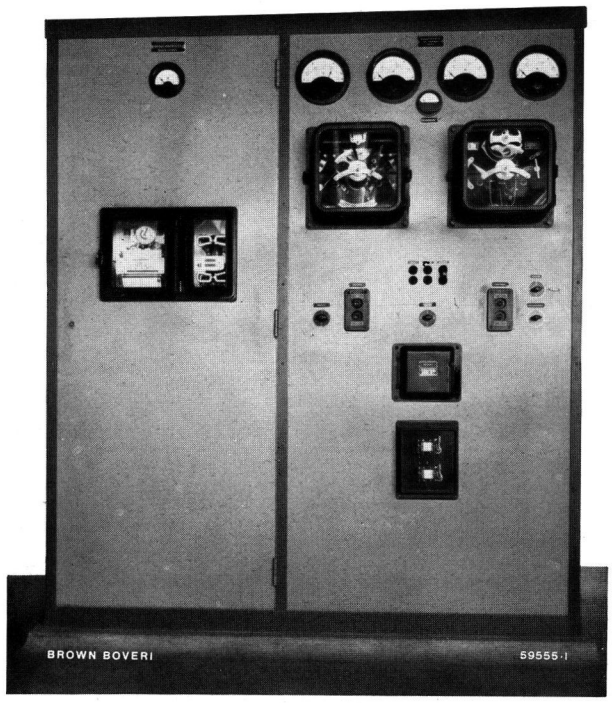


Fig. 110. — Control board for 3000 kW, 6000 V, 13 kg/cm² abs electric steam boiler.

One of the two regulators at the top of the board keeps the current in the works supply constant, the other the steam pressure. The two regulators are so combined that when sufficient steam is required the available electrical energy, and when little steam is needed the steam pressure, is regulated, the current regulator preventing overloading of the supply cable.

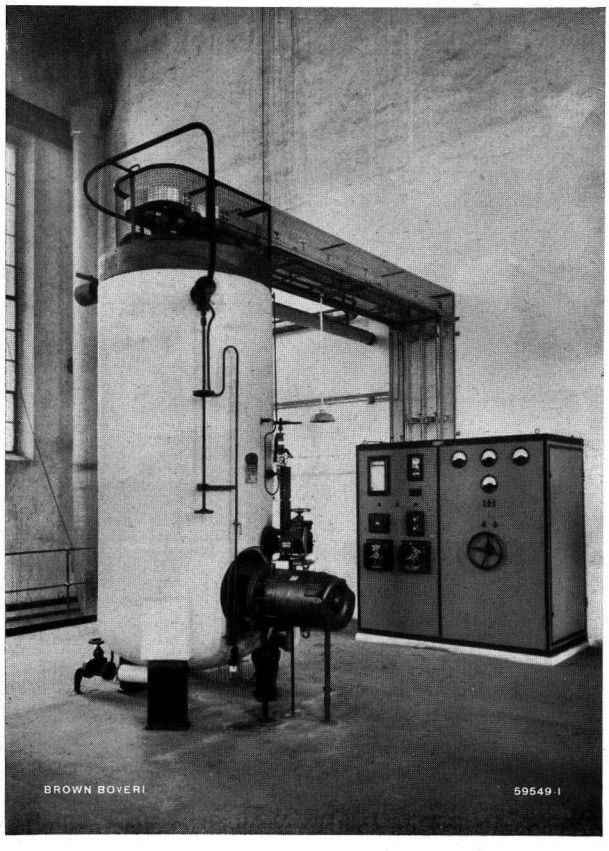


Fig. 111. — Electric steam boiler plant with an evaporation of 2800 kg/h at 16 kg/cm² abs, for industrial purposes; rating 2000 kW, for connection to a three-phase 500 V, 50-cycle supply.

The boiler is equipped with automatic pressure and power regulators and operates in conjunction with other boilers, whereby the energy available from the works power station is always fully utilized.

that the whole of the energy not required by the other equipment connected to the same cable is always made available to the boiler. During the daytime the steam from the electric boiler is delivered to the steam mains chiefly supplied by coal-fired boilers. At night, when very little steam is required, the electric boiler heats up boilers with large water spaces, which for this purpose are connected to it by special pipes. A pressure regulator combined with the current regulator takes care of the reduction of the current when the maximum admissible steam pressure is attained, so that the safety valves do not blow off.

Fig. 109 shows the plant, Fig. 110 the switchboard with current and pressure regulators.

Another electric boiler is depicted in Fig. 111. This is rated 2000 kW and is provided with immersed electrodes due to its being connected to a 500 V low-voltage system. This boiler is likewise equipped with regulating gear to enable the available energy from the works power station to be fully utilized.

E. COMPRESSORS AND BLOWERS.

1. *Turbo-compressors.*

The demand for turbo-compressors, especially for mines, was maintained during the period under review. Twelve sets—six of which with capacities over 50,000 m^3/h—are at present under construction at the different works of the Brown Boveri concern. Of the machines completed during the year one with a capacity of 80,000 m^3/h, a delivery pressure of 8·4 kg/cm^2 abs., and a rating of 7000 kW, is worthy of note. Another turbo-compressor supplied for a coal mine had a capacity of 30,000 m^3/h at 8·0 kg/cm^2 abs. and a rating of 2600 kW. This installation has also been tested since erection and found to have a steam consumption of 0·40 kg per m^3 of indrawn air actually delivered, i. e., much lower than originally guaranteed. Most of the orders were for isotherm-type compressors which are so styled because their compression characteristic approaches very closely the isotherm as a result of appropriate coolers. The power required to drive them is correspondingly low and their efficiency high, due to the particular care which has been given the design of their impellers, diffusers, and other air passages on the basis of modern aerodynamic principles. All Brown Boveri isotherm compressors are provided with a recuperation turbine, i. e., a turbine forming an integral part of the compressor in which any excess of delivery air is expanded and the greater part of the work performed in compressing it recuperated. Due to the excellent cooling and efficient water separation the air delivered by the isotherm compressors is comparatively cold and dry.

Figs. 112 and 113 depict two isotherm installations put into service last year.

Notwithstanding the outstanding advances made in the centrifugal compressor field many a problem still remains to be elucidated which can only be solved by systematic, experimental research. For this reason the firm has gone to the great expense of laying down a test-bed on which full-size impellers for high capacities and compression ratios can be developed and tried out, and which will also enable the physical behaviour of the media handled and aerodynamic and similar problems to be investigated.

2. *Blast-furnace and Steelworks Blowers.*

In the course of the year four large blast-furnace blowers were completed and dispatched, while a number are still in hand. Here, too, the conditions entailed by the war have often proved a real hindrance. In order to give an idea of the number of enquiries for blast-furnace blowers and the capacities and delivery pressures most frequently specified, the "normal points" of the blast-furnace blowers for which enquiries were received over a period of fifteen years are shown in Fig. 114. These vary greatly, but nevertheless it was found possible to meet the specified capacities with the recommended standard blast-furnace blower air volumes and pressures in the majority of cases.

Figs. 115 to 117 show, respectively, the blower room of an overseas blast-furnace plant, a blast-furnace blower, and a steelworks blower.

3. *Gas Exhausters and Boosters.*

The exploitation of natural gas, which abounds in many regions, has set the blower designer new problems. The gas not only has to be tapped at its source, but delivered over long distances and distributed to the points of demand. Turbo-machines are suitable for both the large blowers involved at the source and the smaller ones required at the points of distribution. Orders for a large number of such blowers were again received during the year (Figs. 118—120).

A further field of application for gas turbo-blowers is represented by gasworks and, in particular, coke-oven plants, where they are employed for exhausting purposes. In the case of a gas exhauster supplied to a municipal gasworks, the new suction pressure regulator, which has fully come up to expectations, was

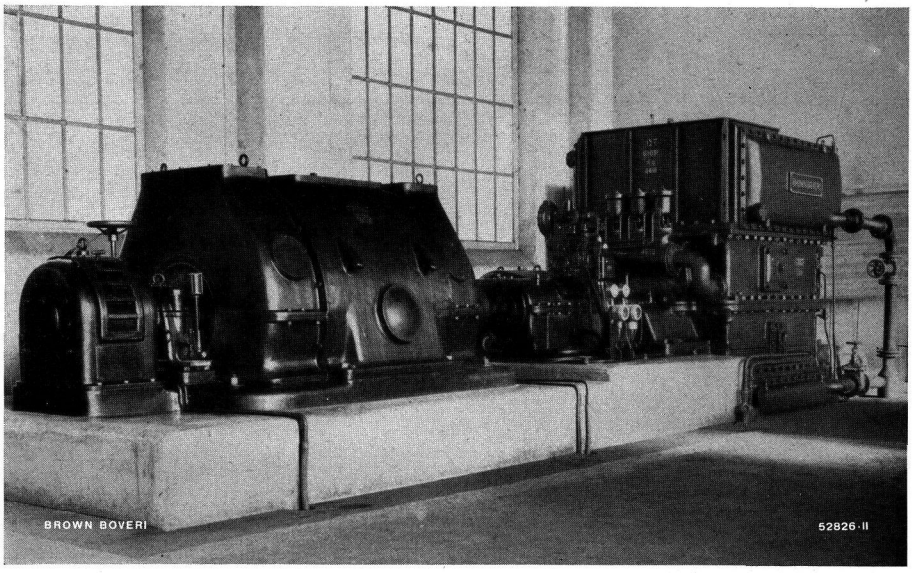


Fig. 112. — Isotherm-type turbo-compressor with a capacity of 12,000 m³/h and a delivery pressure of 8 kg/cm² abs.

A 1300 kW three-phase motor drives the compressor through gearing for 2970/8800 r.p.m. With the isotherm-type compressor the compression characteristic is made to approach the isotherm by a particularly effective method of cooling, whence the style "isotherm-type". In addition to high efficiency the excellent cooling conditions enable a relatively low final temperature to be achieved so that a big proportion of the moisture in the air is separated out and the air arrives at the point of consumption in a dry state, thus obviating freezing up of pneumatic tools.

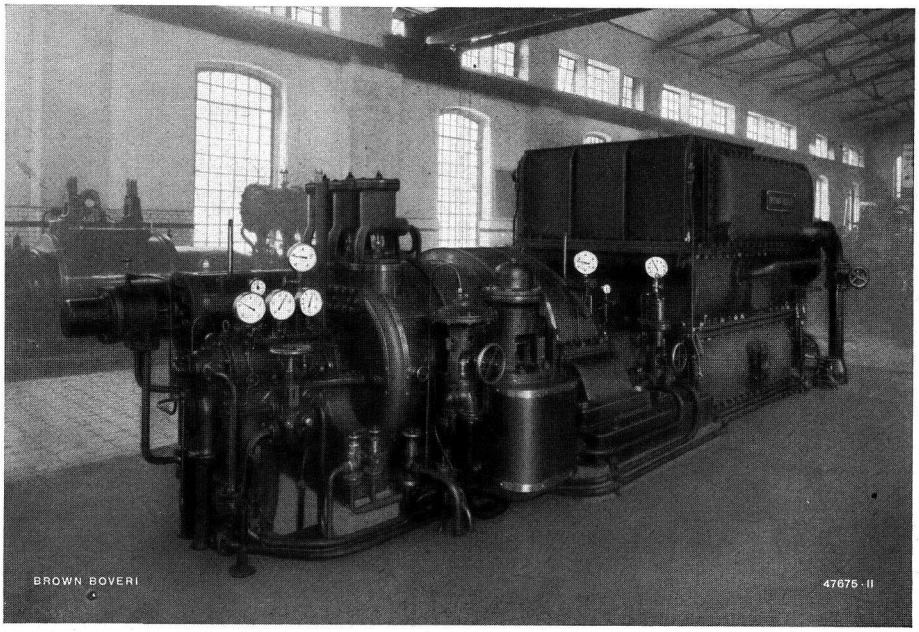


Fig. 113. — Isotherm-type turbo-compressor with a capacity of 25,000 m³/h at a delivery pressure of 8·0 kg/cm² abs, for a coal mine.

The prime mover is in the form of a 1700 kW mixed-pressure turbine driven by exhaust steam at 1·2 kg/cm² abs from the driving engines and made up by live steam. A special feature of isotherm compressors is an air turbine to recuperate the work of compression of the excess air blown off in the unstable zone of the compressor for purposes of regulation. Due to this recuperation turbine, the isotherm compressor operates economically and without surging (even with unchanged speed) at all loads between zero and overload.

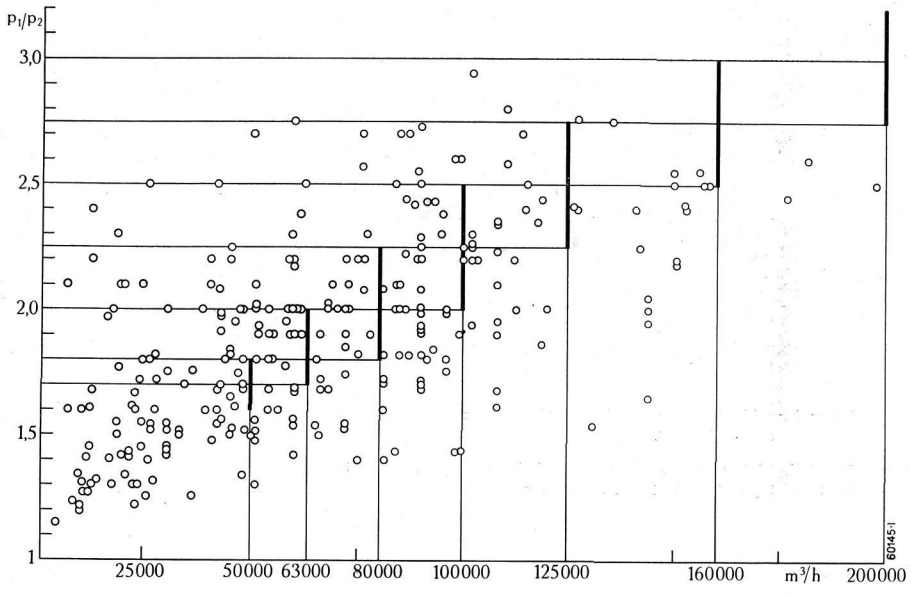


Fig. 114. — Delivery pressures and volumes of blast-furnace blowers for which enquiries were received by the Baden works alone between 1925 and 1940, plotted for the "normal point".

Of these approximately 350 enquiries 20% led to an order, while the number of blast-furnace blowers built to date amounts to over 200. The heavy vertical lines represent the delivery volumes with corresponding pressures recommended for a blast-furnace blower standard specification.

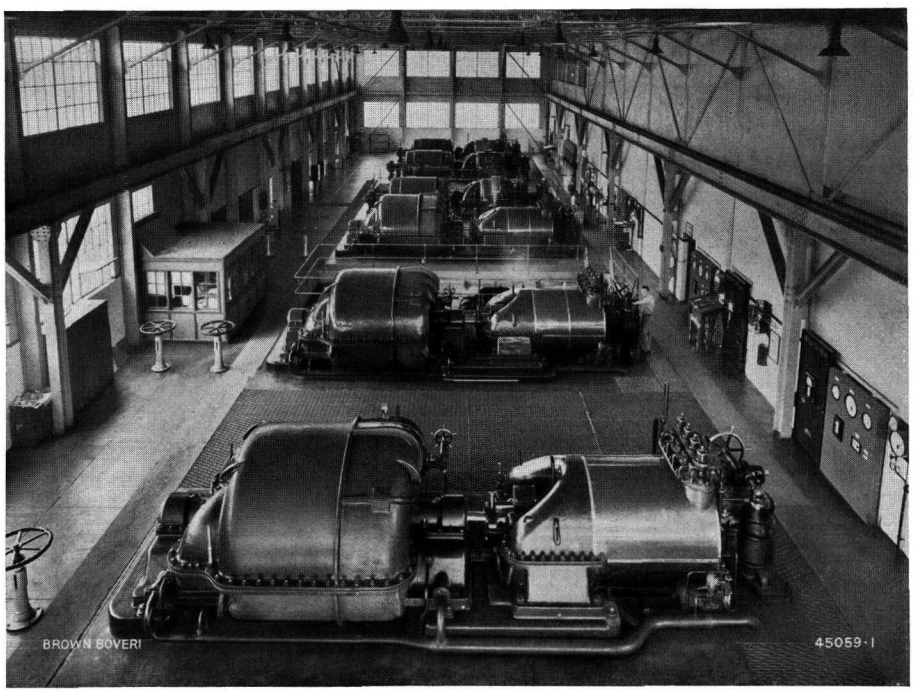


Fig. 115. — Blower room of an overseas blast-furnace plant.

In foreground, three Brown Boveri blast-furnace blowers for a total blast volume of 325,000 m³/h. Initial pressure 0·85 kg/cm² abs., final pressure 2—2·65 kg/cm² abs. The prime movers are in the form of 3800 kW steam turbines. All regulating problems connected with blast-furnace operation can be solved in a very simple manner with steam turbine drive. In consequence, this mode of drive is usually preferred for blast-furnace blowers, which are equipped with automatic governing gear to maintain the delivery volume constant, together with hand-operated diffusor regulating gear with which the surging point can be shifted in an economical manner. Blast-furnace blowers have always formed a Brown Boveri speciality. There are over 200 of the firm's sets in operation all over the world.

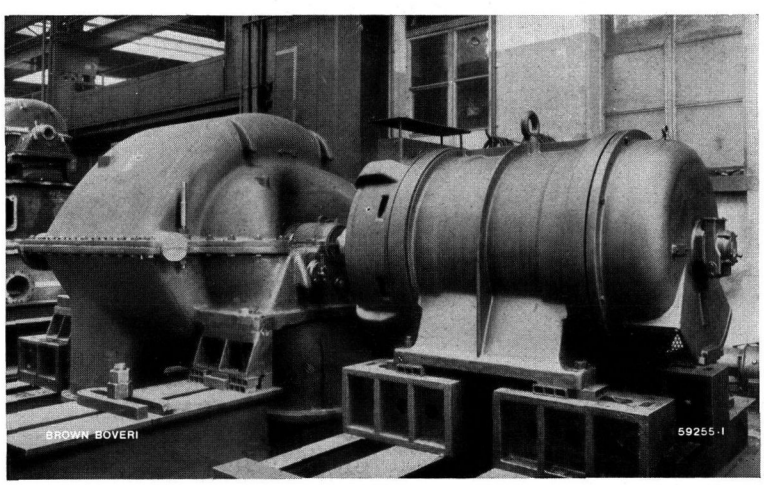


Fig. 116. — Blast-furnace blower for a blast volume of 45,000 m³/h at a delivery pressure of 1·6 kg/cm².

The drive is effected by a 870 kW, 2960 r. p. m. squirrel-cage induction motor which is started with a single-step starting transformer.

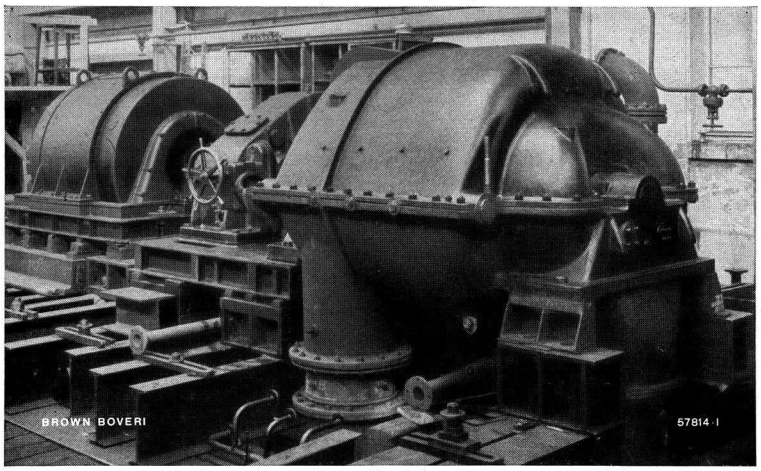


Fig. 117. — Steelworks blower with a capacity of 57,500 m³/h; intake pressure 0·887 kg/cm² abs, delivery pressure 3·0—3·5 kg/cm² abs.

The drive consists of a 3700 kW geared synchronous motor delivering 2000 leading reactive kVA. The hand-operated pre-rotation gear with which the blower is equipped enables it to be extensively and economically adapted to blast requirements without speed variation. The choice of a synchronous motor, with its well-known special advantages, was therefore entirely warranted.

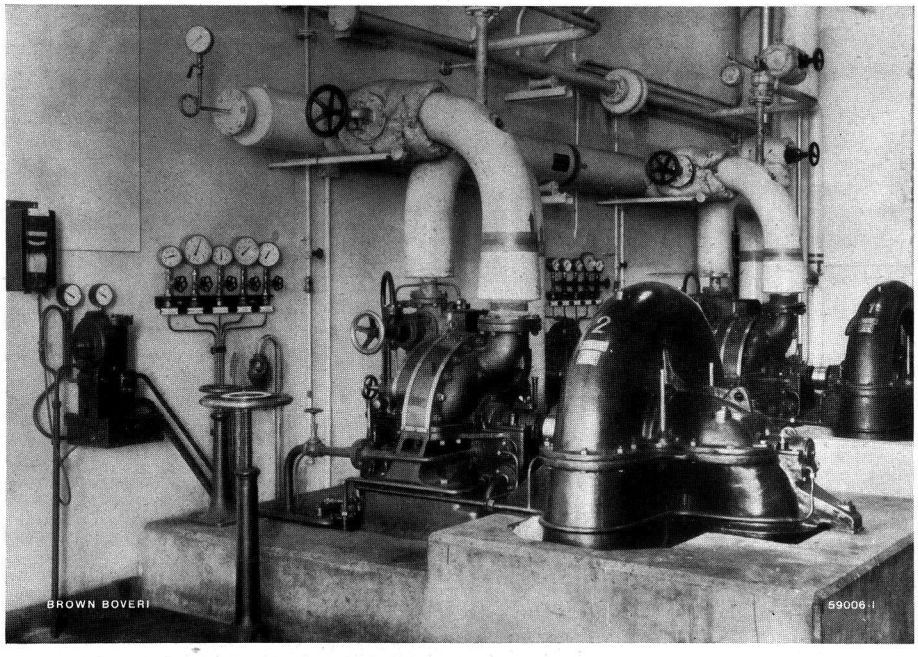


Fig. 118. — Two turbo gas-exhausters for dealing with 195,000 Nm³ of coke-oven gas each per twenty-four hours (inlet and outlet pressures —80 and +750 mm w. g., respectively), driven by 4400 r. p. m. impulse steam turbine.

Constant header pressure regulation can be readily achieved with steam turbine drive. The new Brown Boveri oil servo-motor governor will be seen in the foreground.

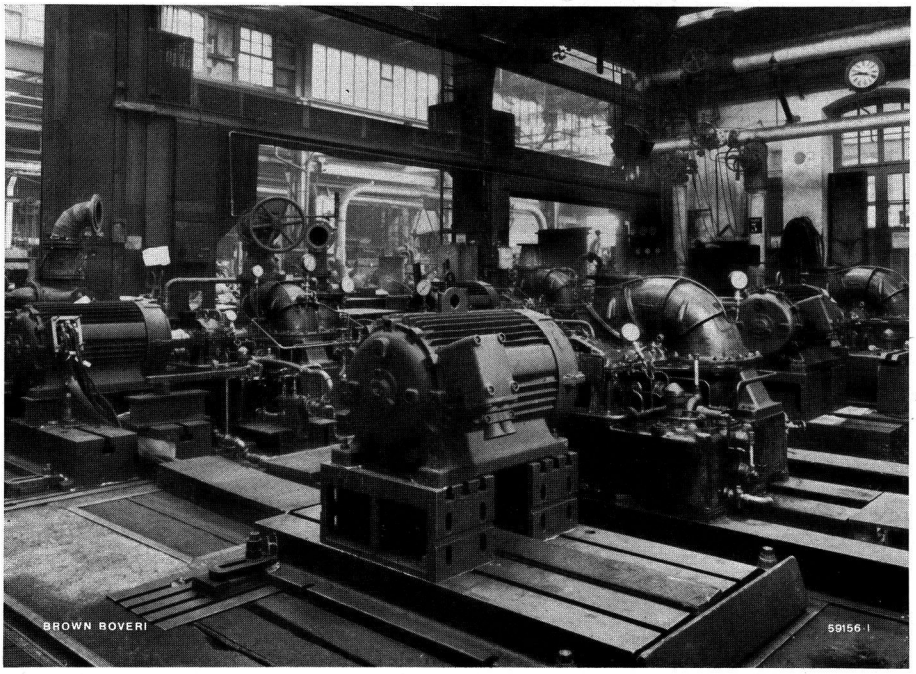


Fig. 119. — Workshop view of six turbo-boosters each with a capacity of 360,000 Nm³ per twenty-four hours; intake pressure 0·8 kg/cm², delivery pressure 4·985 kg/cm².

The natural gas abounding in certain regions is tapped at its source and delivered, usually by compressors, to the centres of consumption frequently miles away. Here the gas is taken to the individual points of consumption by smaller compressors. Turbo-machines are particularly suitable for both of these purposes.

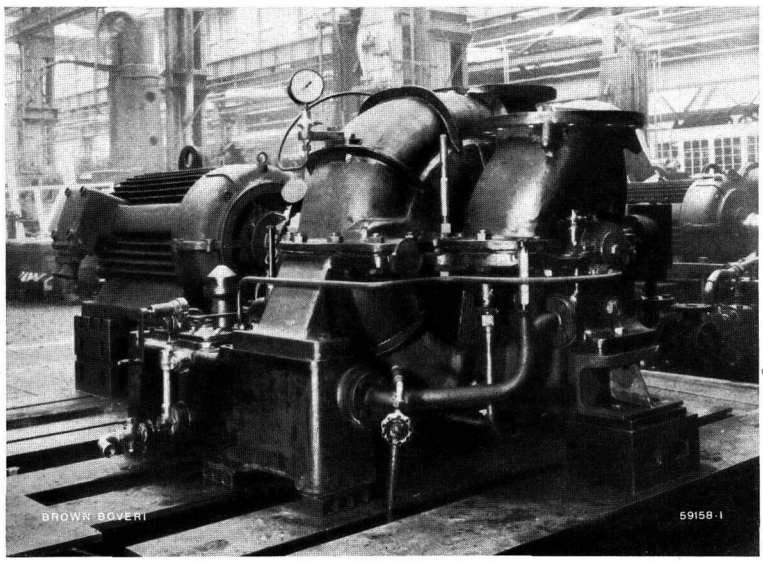


Fig. 120. — Booster for natural gas.

A geared three-phase induction motor serves as drive. In view of the conditions on site the squirrel-cage motor, is of the explosion-proof type. Due to the ribbed casing, over which a strong current of air is forced by a fan, the motor is very effectively cooled.

supplied. Details of this regulator as well as of a new regulating process are given under "Governing Gear" on page 13 of the present number of this journal.

4. *Turbo-compressors for Chemical Industries and in particular for Processes carried out under Pressure.*

Many processes are now carried out under pressure. Experience has shown that the chemical reaction is frequently accelerated and production and efficiency increased by raising the pressure. If exhaust gases are also discharged, which, by reason of the high pressure at which the process is carried out, still contain useful energy, they can be made to perform work in gas turbines, whereby the amount of energy recuperated will be greater the higher the temperature. In most cases this energy is employed to drive the compressor itself. Under the most favourable conditions more energy is even obtained than is necessary for this purpose.

According to the amount of energy which can be recovered from the exhaust gases, one of three methods of supercharging may be resorted to, i. e., straight supercharging without recuperation of the energy expended for the purpose, or the Velox process with which, apart from the energy required for supercharging purposes, additional energy is obtained either for the production of particularly high velocities and improvement of chemical reaction or heat transfer, or for the generation of electrical energy. The chargers employed as preliminary stages of reciprocating engines for high capacities and delivery pressures, as, for instance, in the synthesis of ammonia, belong to the same class of machine.

Turbo-compressors, either of the centrifugal or radial-flow type, are eminently suitable for all of these applications. The complete absence of oil is one of their most important advantages. Where corrosive media have to be dealt with non-corrosive materials can be employed, while the machines can also be built for very high temperatures.

Fig. 121 depicts a compressor for special gas.

5. *Heat Pumps.*

Heat pump applications were recently dealt with exhaustively in this journal (1943, pages 146—167), so that the present notes will be restricted to a number of plants which were completed during the year.

The most important of these was the installation supplied to the centralized heating station of the Swiss Federal

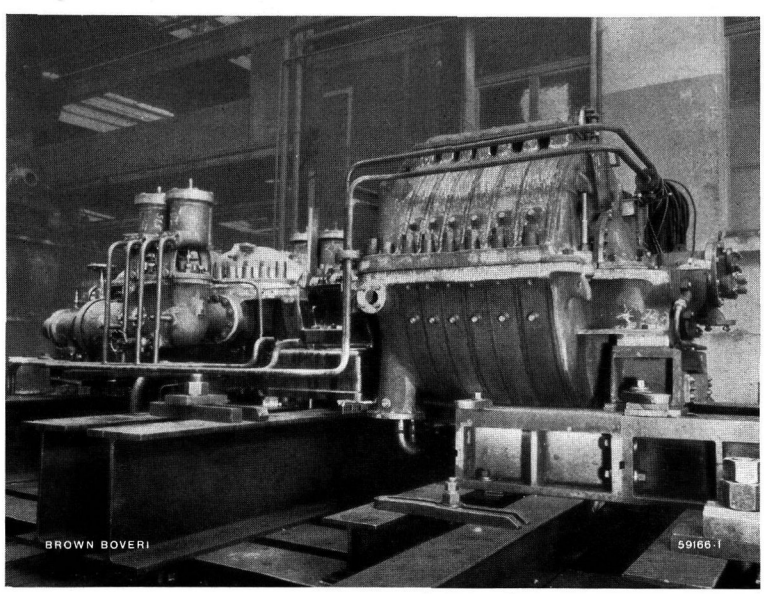


Fig. 121. — Turbo-compressor with a capacity of 15,000 Nm³/h, for compressing a special gas from 1·0 to 26 kg/cm² abs.

The compressor is driven by a 2800 kW back-pressure turbine. The sealing of such compressors presents a particularly difficult problem. In this case liquid-sealed glands are employed.

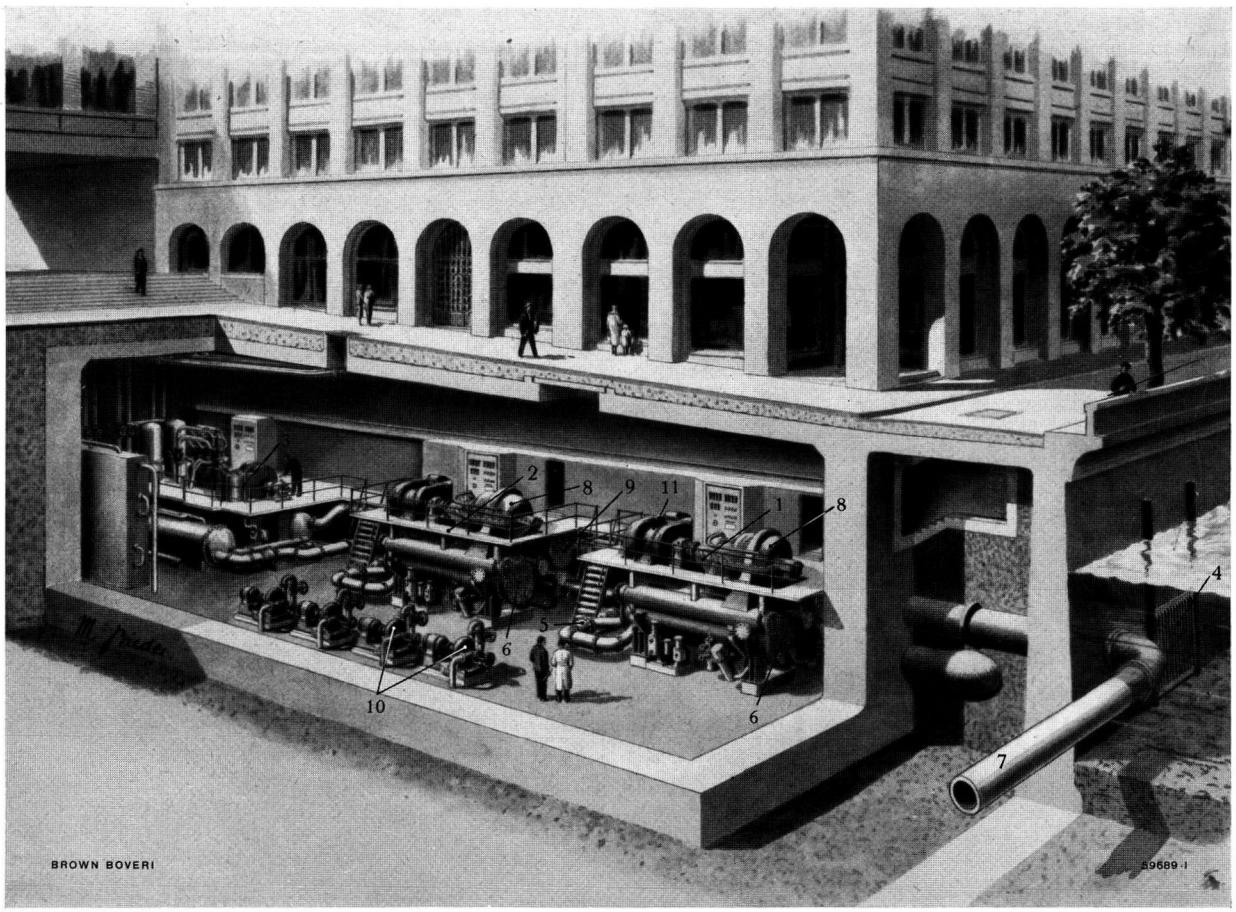


Fig. 122. — Perspective view of underground heat pump station of the district heating and power station of the Swiss Federal Institute of Technology, Zurich.

This station is erected on the banks of the River Limmat and contains two Brown Boveri thermoblocs (1) and (2) and a reciprocating heat pump (3) supplied by another firm. The source of heat is water taken from the River Limmat. This enters the station at (4), is forced through the evaporator (6) by the circulating pump (5) fitted in the pipe, and flows back into the Limmat through pipe (7). In the evaporator the water gives up a part of its heat to the working medium (Freon 11), which is thereby caused to evaporate. The resulting vapour is then brought up to a higher pressure and temperature by the compressor (8) and led to the condenser (9). Here the heat it has received is transferred to the heating water which is thereby heated. The pump sets (10) keep the heating water circulating and raise it to the approximately 50 m higher heating system. The maximum heating capacity of one thermobloc is about 2,500,000 kcal/h. Up to 1200 m³ of river water are required per hour, which is cooled by about 1½° C. The maximum leaving temperature of the heating water is 74° C, its rate of flow up to 100 m³/h. The maximum power required by the compressor motor (11) is 960 kW at unity power factor. The coefficient of performance, i. e., the ratio between the useful heating energy and the electrical energy consumed is slightly over 3. Each of the sets is expected to save about 1400 t of coal annually.

(The above illustration by M. Bieder is reproduced by kind permission of the Administration of the Centralized Heating and Power Plant of the Swiss Federal Institute of Technology.)

Institute of Technology, Zurich, comprising two heat pumps each for 1·5—2·5 million kcal/h (Fig. 122). They are expected to save about 2800 t of coal annually and to serve as an excellent reference plant. Numerous projects of a similar nature are already in hand, inasmuch as the interest in the heat pump increases as the coal shortage becomes more acute. Fig. 123 is a further view of the plant at Steckborn.

Another installation worthy of mention serves as a booster for two heating machines supplied earlier by Brown Boveri. This enables the temperature of the part of the water heated to 70° C in the existing thermoblocs to be raised to 85° C for processing purposes. The heating capacity is 400,000 kcal/h, the working medium being water.

In the refrigeration field two notable frigibloc plants were built and supplied during the year. They cool brine to a temperature of —27° C and have a refrigerating capacity of 500,000 kcal/h each (Fig. 124). Like the two thermo-blocs at the Swiss Federal Institute of Technology, Zurich, these employ Freon (F. 11) as working medium. As is common knowledge Freon is a chloro-fluoro-hydrocarbon derivative of the methane class which, apart from its favourable physical properties, has the advantage of being non-inflammable, non-toxic and non-corrosive.

A number of another class of heat pump, namely the thermo-compressor for the evaporation of solutions, was also built and supplied during the period under review.

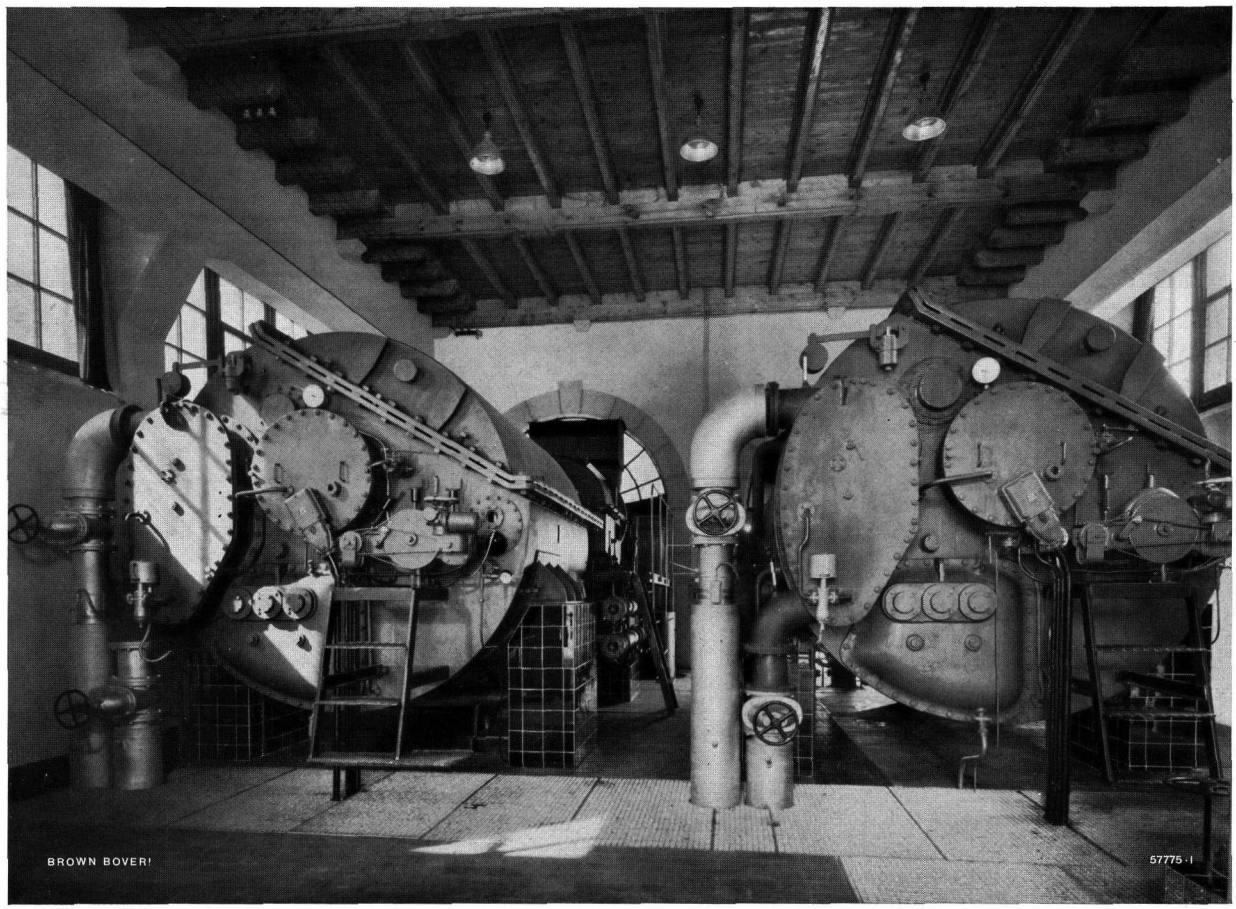


Fig. 123. — Heat pump plant of the Steckborn Artificial Silk Co., Ltd., Steckborn (Switzerland).

Two thermoblocs, each with a capacity of 1—1·7 million kcal/h, are installed in this plant. Lake water at, for instance 13° C, is employed to evaporate the working medium which, after compression, raises the temperature of the heating water to about 70° C. The lake water supplies about two-thirds of the heat to give the heating capacity of about 1·5 million kcal/h. The remainder is represented by the energy expended in driving the compressor. Each set enables about 2100 t of coal to be saved annually.

6. *Exhaust Turbo-chargers.*

(a) *Pressure-charging of Diesel Engines.*

In the corresponding number of this journal last year reference was already made to the efforts being made to pressure charge Diesel engines to a far higher degree than hitherto. Where 1·5 was earlier considered to be the maximum charging ratio, increases from atmospheric pressure to 2 and even 4 or 5 kg/cm² abs. are now within the realms of possibility. The single-stage centrifugal blower with single-stage turbine, as developed by Brown Boveri for normal low-pressure charging, can be used practically without modification for much higher pressures. In order to obtain the highest possible pressure the blower impeller is provided with a radial blading outlet, guide blade apparatus, and a spiral casing. Following standard practice the turbine casing is water cooled. The shaft runs in ball bearings, each of which has a separate lubricating oil system with an extremely simple, directly driven gear-wheel pump, or, in the case of small chargers, with small oil splash wheels.

Particular care has been paid to the design of the individual components to achieve maximum reliability. Different methods of mounting have also carefully been taken into consideration to enable the same set to be employed for engines of any make. Since this also renders possible manufacture on mass-production lines, particular importance has been attached to this question.

As an example of new manufacturing methods adopted, the blower impellers of the smallest types of charger can be quoted. Their blades consist of steel stampings, spot-welded on to the steel disc. These small impellers, which have a diameter of hardly 100 mm, are overspeed tested at more than 60,000 r. p. m. (Fig. 125). The fact that they withstand such stressing proves the quality of the welds made with the new Brown Boveri spot welding machines.

The new single-stage range of chargers is also employed for charging two-stroke-cycle engines as at pre-

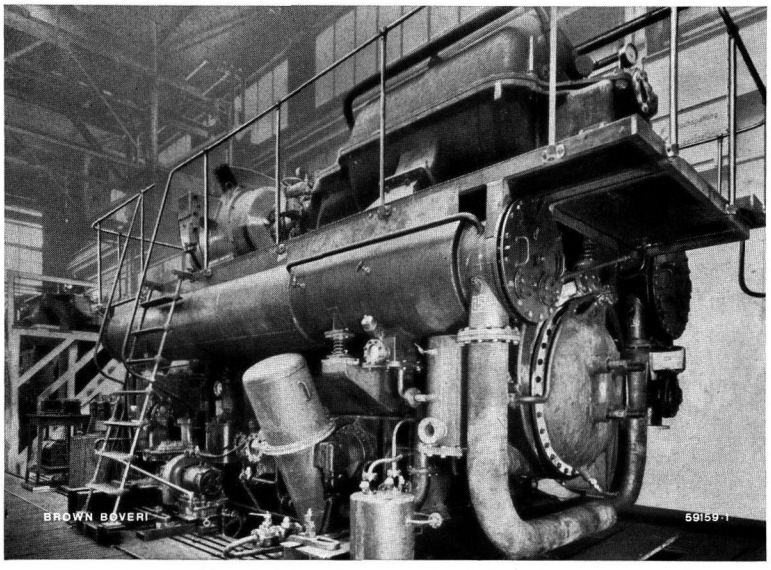


Fig. 124. — Frigibloc for cooling brine down to −27 °C. Maximum refrigerating capacity 500,000 kcal/h.

Workshop view. Freon 11 is used as refrigerating agent, which is well known for its excellent physical and entirely non-toxic qualities.

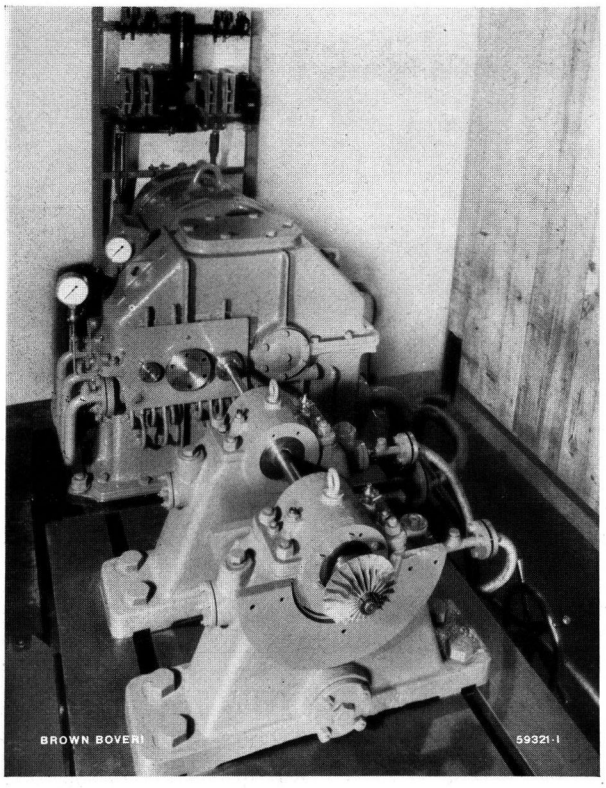


Fig. 125. — Small impeller wheel for an exhaust turbo-charger in the over-speed test plant.

The impeller is only about 100 mm in diameter. The blades are of pressed steel and are spot-welded to the steel disc. Such impellers are over-speed tested at about 60,000 r. p. m.

The over-speed test plant is driven by a 260 H. P. motor the speed of which can be raised by three-speed gearing from 3000 to a maximum of 18,000, 55,000, or 71,000 r. p. m., respectively. A separate pinion is employed for each of the three speed ranges and is coupled to the over-speed shaft as soon as it has been brought into the corresponding position by displacing the table on which the bearing pedestals rest.

sent manufactured by several engine-builders. Their maximum pressure differs with the peripheral speed and revolutions which can be allowed for the discs and bearings. A pressure ratio of 2, however, is usually ample.

More than twenty years' experience in the construction of chargers permits of sets being supplied to engine builders which are of better quality and of lower price than if manufactured by the engine-builders themselves. For instance, ten exhaust turbo-chargers have been supplied for the new 150 H.P. Saurer engines employed to drive Peter, Liestal, Diesel-electric snow ploughs, or for motor-coaches on several foreign rail-

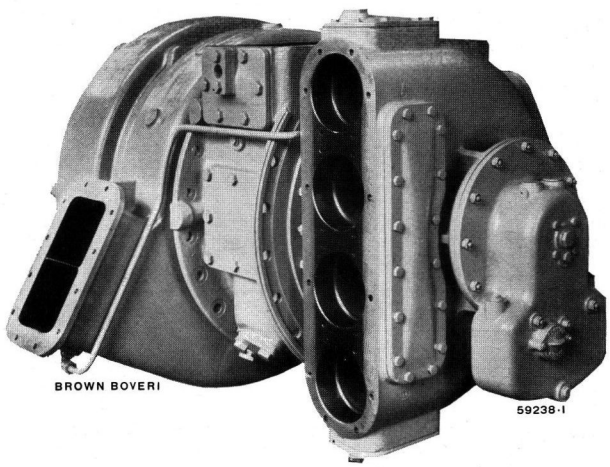


Fig. 126. — Exhaust turbo-charger, standard design with four separate gas inlets for eight and twelve-cylinder engines.

The individual parts are assembled by means of circular flanges and by mutually rotating them the inclination of the pipe connections can be adapted to any required arrangement.

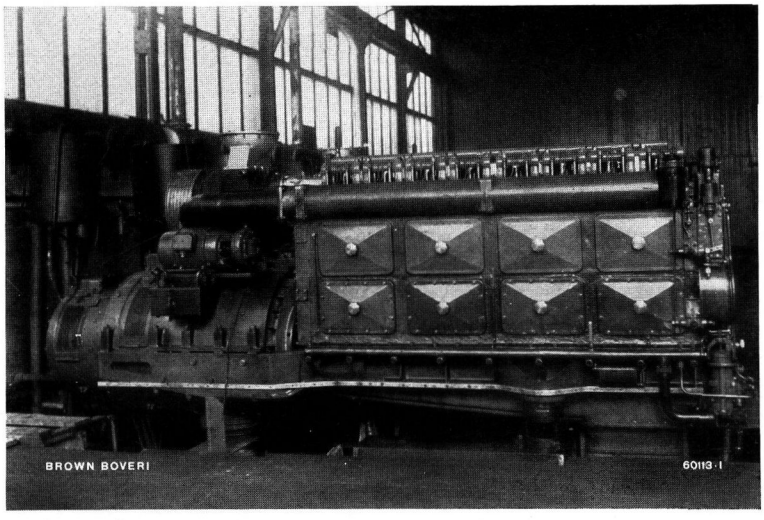


Fig. 127. — Foreign motor-coach engine with Brown Boveri exhaust turbo-charger on test bed.
Power of engine, turbo-charged 500 H. P. at 1000 r. p. m.

ways. As an example of the increase in power obtainable with turbo-charging a series of motor-coach Diesel engines of foreign manufacture may be quoted. With six cylinders these developed 250 H.P. without supercharging. After the total swept volume had been split up between eight cylinders and turbo-charging applied an output of 500 H. P. was obtained (Figs. 127 and 128).

Figs. 129 and 130 depict a ferry-boat of Det Stavangerske Damskibselskap which is equipped with two Deutzer-Diesel engines pressure-charged with Brown Boveri turbo-chargers.

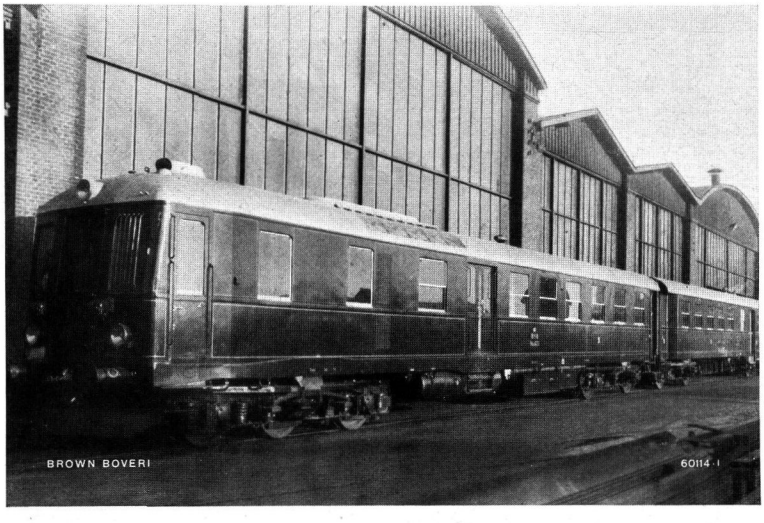


Fig. 128. — Danish State Railways motor-coach train.
Each motor-coach is equipped with two of the engines shown in Fig. 127.

(b) *Producer-gas Charging.*

Progress has also been made in wood-gas charging. The development of a small charger, the gas turbines of which differ somewhat from the standard design, has been completed and large numbers already manufactured and supplied (Figs. 131 and 132). Special attention has been paid to running conditions and in particular to the adaptation of the characteristic of the turbo-charged wood-gas engine to that of non-supercharged engines running on liquid fuels. It is recalled that with the latter the power and torque can be adapted to actual requirements either with the change gear or by regulating the fuel. In the case of wood-gas-operated engines, however, both gas production and charger revolutions must be adapted to the new working conditions. If, in the case of a charging set dimensioned so that its maximum speed and, in consequence, its maximum power, is not attained until the maximum engine revolutions are reached, a reduction in engine revolutions takes place, e. g., due

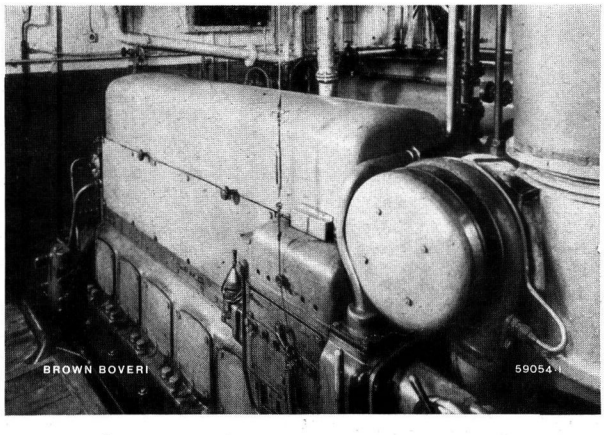


Fig. 129. — Ferry-boat engine with Brown Boveri exhaust turbo-charger.
Power of engine turbo-charged 375 H.P. at 750 r. p. m., non-supercharged 270 H.P.

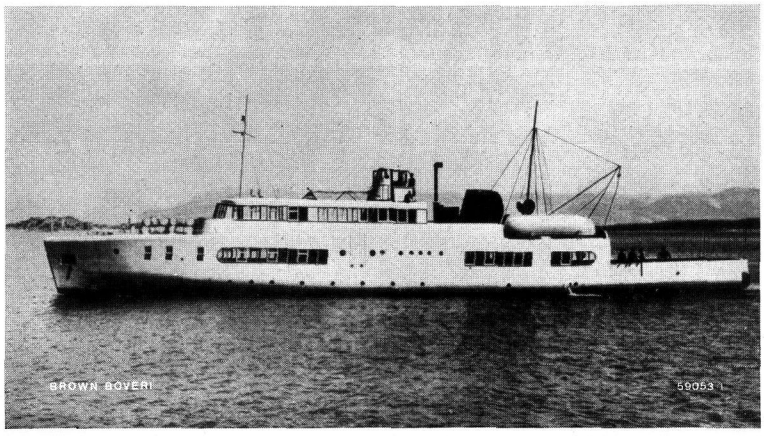


Fig. 130. — Ferry-boat owned by Det Stavangerske Damskibelskap equipped with two engines having Brown Boveri exhaust turbo-chargers, as shown in Fig. 129.

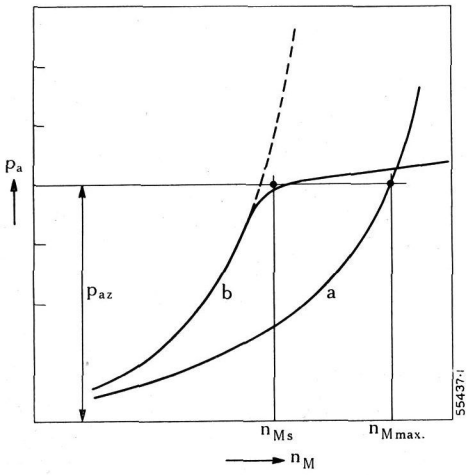


Fig. 133. — Characteristic of charging pressure p_a in wood-gas producer in relation to the engine revolutions n_M.

(a) For a wood-gas turbo-charger which only attains its maximum revolutions at maximum engine speed.

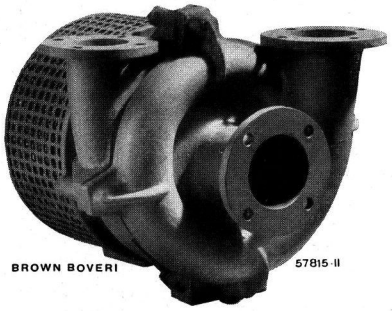
(b) For a wood-gas turbo-charger which attains its maximum revolutions at a lower engine speed and from then on only employs a part of the engine exhaust gases due to the opening of a regulating valve.

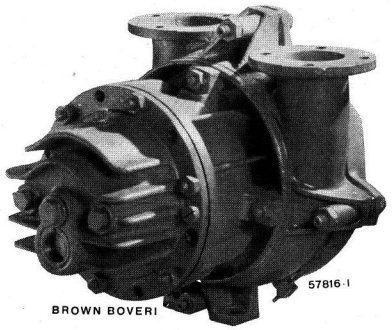
By dimensioning the charger so that it already attains its full revolutions at a fractional engine power the power-torque characteristic involved by operating conditions is also obtained with a turbo-charged engine.

to a sudden increase in the rolling resistance and to a diminution of the running speed, the power and torque of the engine will drop just at the moment when an increase is desirable.

This drawback can be overcome by so dimensioning the charger that it already attains its maximum revolutions and charging pressure at the mean engine speed and thus still supplies sufficient air when the engine revolutions fall off. At speeds above the mean engine revolutions part of the exhaust gases are released directly to atmosphere through a blow-off valve so that the charging pressure cannot rise any further. The maximum charging pressure is usually of the order of 0·3—0·4 kg/cm² gauge (Fig. 133).

Due to their small dimensions and light weight, the chargers can be fitted practically anywhere on the vehicle. In the case of the Brown Boveri trial lorry, for instance, it is slung underneath the engine (Fig. 134).





Figs. 131 and 132. — Exhaust turbo-chargers for 70—120 H.P. wood-gas engines.

Fig. 131 shows the charger from the gas turbine end, Fig. 132 from the air end (air filter removed). The charger is air-cooled, thus requiring no cooling water.

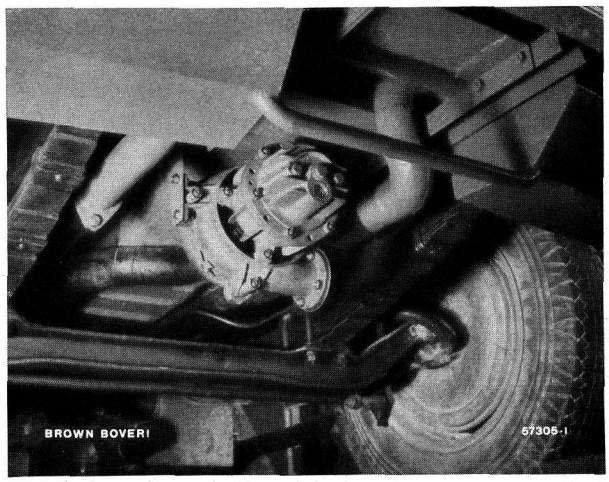


Fig. 134. — Exhaust turbo-charger fitted on a lorry.

The above vehicle is the Brown Boveri test lorry for the investigation of the engine and running problems connected with wood-gas operation. Its low weight (about 18 kg) and small dimensions enable the charger to be fitted in any desired position.

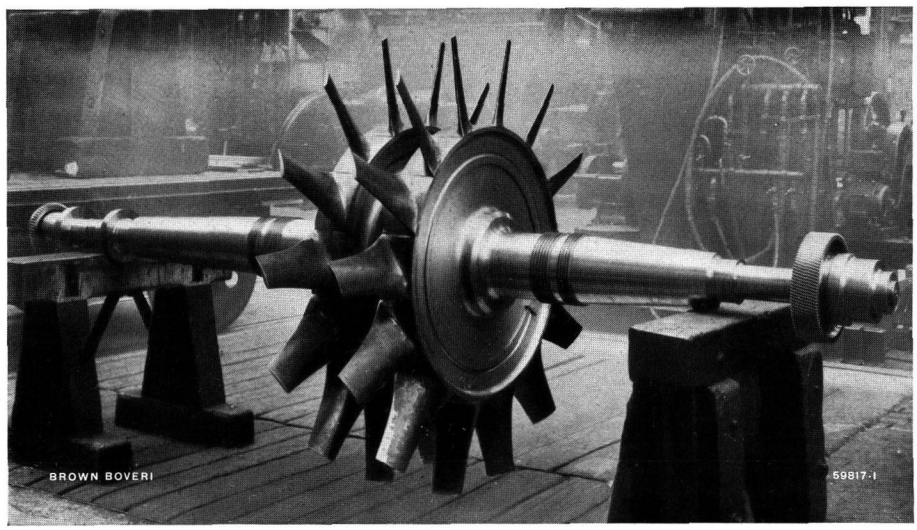


Fig. 135. — Impeller of two-stage axial-flow blower for hot gases.

The gas to be dealt with arrives at the blower at a temperature of about 530° C. Due to this high temperature the blades, disc, and shaft are made from highly heat resistant steel. The large blades are welded to the discs. The simple construction of axial-flow blowers enables them to be made from heat-resistant non-scaling material so that such machines can also be built for very high temperatures.

Interesting details of running conditions with turbo-charged wood-gas engines were published in the Brown Boveri Review for 1943, pages 184—187.

(c) *Chargers for Gas Engines.*

The tests with a view to the turbo-charging of gas engines were pursued in collaboration with other firms. During recent tests with supercharging and scavenging combined, whereby both the combustion air and the gas were compressed to the supercharging pressure, an increase in power of 50—60 % compared to non-supercharged operation was achieved. With scavenging alone an increased power of 30 % was still realized. A Diesel engine operated on gas can thus be given back its original power simply by scavenging. The scavenging blowers are coupled to gas turbines driven by a part of the engine exhaust gases.

7. *Axial-flow Compressors and Blowers.*

The development of this type of machine, on which much care had been spent, is temporarily considered as concluded, so that it was possible to turn attention to its applications. As is common knowledge it is chiefly the Velox boiler and the gas turbine which make use of the axial-flow blower. A further field of application is afforded in the production of blast for metallurgical plants, particularly where the prime prover is a gas turbine. In such cases, the compression of the air for the gas turbine and of the blast for the blast furnace can be carried out by the same blower. Two such installations are at present being built and would already have been put into service if conditions entailed by the war had not retarded their completion.

A further application of gas-turbine-driven, axial-flow blowers to blast furnaces, with which the combustion chamber of the gas-turbine also supplies the gases for the associated blast heater working on the Velox principle, has together with the latter, been thoroughly studied and developed, so that the firm is now in a position to submit proposals and quotations. A summary of these developments has already been published in the special mining and metallurgical equipment number of this journal (1943, page 356).

Interesting axial-flow blowers were supplied for a chemical works. These are noteworthy not only on account of their capacity, but also by reason of the temperature at which they have to operate, the gas dealt with attaining 530° C. The blowers are of the two-stage-type, directly coupled to their driving motors. Due to the high temperatures, special heat-resisting steels are employed for the blower rotor the discs forming the drum consisting of forgings on to which are welded cast blades.

8. *Aerodynamics.*

During the year under review many aerodynamic test plants have been planned. For instance, projects were elaborated for wind tunnels with super- and sub-sonic rates of flow and plant for testing aero-engines under high altitude conditions, whereby certain new and really interesting features were incorporated. Plants for testing aero-engines under high altitude conditions and several wind tunnels for supersonic rates of flow are at present in hand. The firm is now in a position to supply complete plants. Since very high powers (up to 40,000 kW) are often required for wind tunnels, but the loading period of the machines is usually only short, a straight combustion turbine is recommended as the most appropriate prime mover for the blower.

It is to be assumed that the demand for large research stations for the further development of civil aviation will continue after the conclusion of hostilities, so that preparations for this eventuality would appear to be justified. Two articles in the Brown Boveri Review for 1943, pages 168—175, give a good idea of the firm's contribution to this field.

F. GEARING AND GEARED COUPLINGS.

The development and standardization work in connection with planet gearing was pursued during the year. To date seventy planet gears have been supplied, while sixty more are in hand. Fig. 136 shows part of a consignment of motors combined with such gears, for a foreign customer.

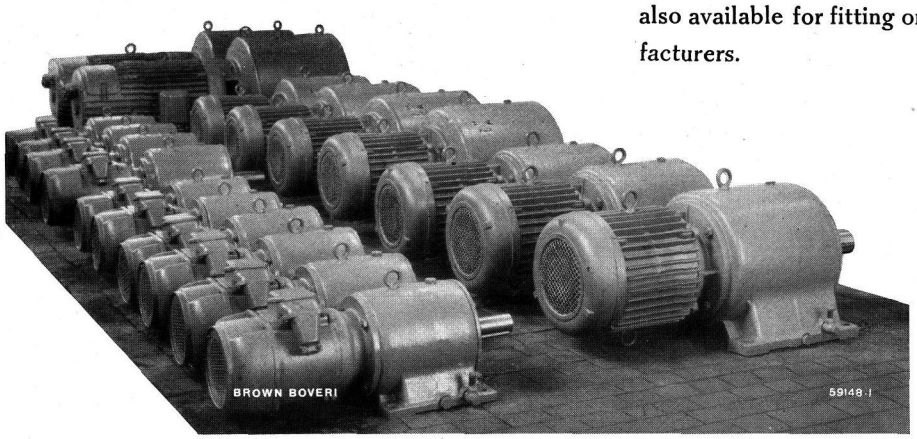


Fig. 136. — Part consignment of planet gears.

The motors are built on the gears which also form their support. The rating of the smallest sets on the left is 2 H.P. with a ratio of 1425/30 r.p.m., that of the largest machines in the background 30 H.P. with a ratio of 1470/15 r.p.m.

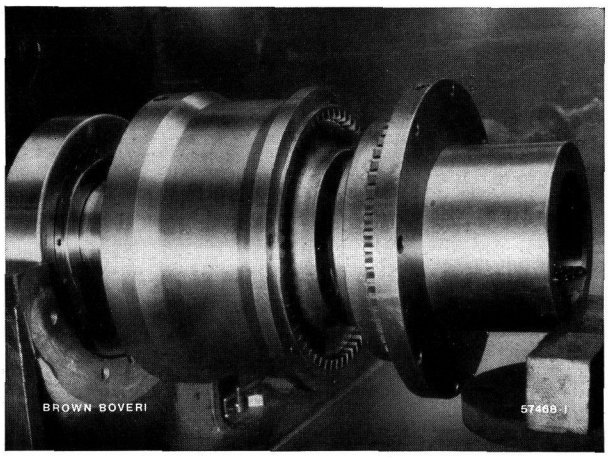


Fig. 137. — Brown Boveri geared coupling for a power of 1400 kW at 1500 r. p. m. (uncoupled).

These geared couplings allow large shaft misalignments. For low to medium speeds they are filled with oil in which the teeth are immersed. Larger models are available for powers up to 50,000 kW and smaller ones for speeds up to 25,000 r. p. m.

Geared couplings (Fig. 137) which were described in the special marine number of the Brown Boveri Review for 1942, page 310, for the first time, are in increasing demand for all kinds of applications. For high speeds oil spray lubrication, for low speeds, according to the application, oil or grease lubrication, is provided. The insensitivity of the coupling to unavoidable shaft displacements, either in the axial direction, or inclined to the axis, as well as against axial expansion, such as occurs with gas turbines and steam turbines operated at high steam temperatures, make it universally applicable.

To date 135 couplings have been supplied, while a further fifty-six are in hand. These couplings are not only manufactured for the firm's own installations, but are also available for fitting on the machines of other manufacturers.

IV. TRACTION.

A. ELECTRIC TRACTION AND TRAIN LIGHTING.

As in the preceding year activity in this field was practically exclusively confined to Switzerland due to the conditions imposed by the war. Within the limits set by the restricted supplies of raw materials, however, electric traction appears to hold out varied and interesting prospects for the next few years. This applies especially to private railways and more particularly to those which are still steam-operated and which electric traction would go a long way to putting on a sounder financial basis. There are also the railways of the same class, however, which have been operated electrically for a long time past, and the rolling stock of which needs modernizing. The scheme outlined above, which is of great financial and economic importance, has been rendered possible by the so-termed Private Railway Assistance Bill, and is being carried out as a work promotion measure with the backing of the Confederation.

In the case of the Swiss Federal Railways where the electrification of the Winterthur-Neuhausen (27·7 km) and Wil-Wattwil (20 km) routes, completed during the past year, has brought the total of the electrified lines up to 2331·871 km, or to exactly 80 % of the entire railway system, traffic on the remaining steam-operated sections, although only comparatively slight, proves so costly with the prevailing coal prices and, what is more, so uncertain in view of the present precarious coal supplies that the Federal Railways are determined to electrify practically all of these remaining sections, immaterial of the density of the traffic which hitherto was the sole criterion for the electrification of a line.

About ten years ago Brown Boveri initiated the era of lightweight designs in the electric traction field with the now familiar "Red Arrow" class of lightweight motor-coach Re $^{2}/_{4}$, series 201, of which seven exist altogether. In the interim development work has been systematically pushed forward in this direction and all components of electric traction equipment considerally reduced in weight. This was effected entirely on the basis of the new knowledge and progress made in dimensioning practice and not by increasing the stressing of the active material, which is moreover limited by the temperature rise specifications. A number of examples will serve to illustrate the progress realized.

For seventeen years shunting locomotives series Ee 3/3 of the same external appearance and general arrangement were supplied to the Swiss Federal Railways. A repeat order for fourteen similar locomotives bearing the serial numbers 16,381 — 16,394 afforded an opportunity of modernizing the electrical equipment. As a result the one-hour rating has been raised by 20 % to 708 H. P., the maximum speed by 25 % to 50 km/h, and the weight reduced from 46 to 41 t; the latter figure includes 3 t of ballast to increase the adhesion properties and to enable the tractive effort corresponding to the increased power to be utilized. The greater proportion of the reduction in overall weight achieved goes to the account of the traction motor, the weight of the entirely new design of which has been reduced to 3700 from 6900 kg, i. e., by nearly 47 %.

It was chiefly in the case of transformers for single-phase traction vehicles, which on account of the low frequency have the greatest specific weight of all of the components of the electrical equipment, that a reduction in weight had to be aimed at in the very first place. By introducing radially-laminated cores, together with a new winding arrangement, it has proved possible to reduce the dimensions and weights of such transformers by 30 — 35 %. Apart from these very desirable advantages which greatly faciliate the development of lightweight locomotives and motor-coaches for single-phase systems the saving in design material, i. e., laminations, copper, and oil, achieved in this manner is particularly welcome under present conditions; in

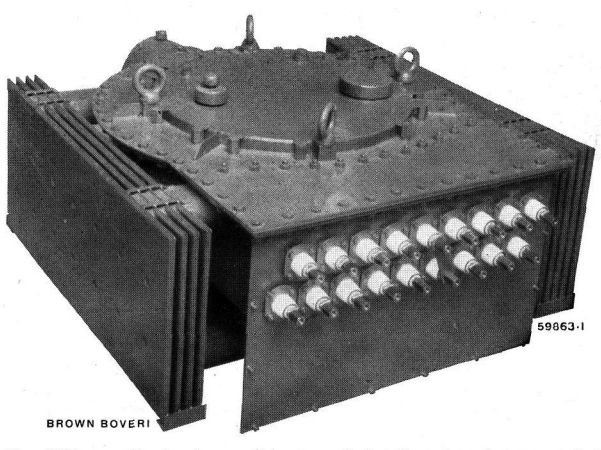


Fig. 138. — Single-phase oil-immersed traction transformer rated 410 (+ 72) kVA, 8000/110 — 624 (230)/110 V, 16 $^{2}/_{3}$ cycles, for a motor-coach on the Martigny-Orsières Railway.

Since the transformer was required for lodging under the floor of the coach a particularly lightweight, low model with radially-laminated core was selected.



6031. B.R.B 3. X 39.

Fig. 139. — Motor-coach train on the Chemins de fer fribourgeois (Gruyère).

This railway has a gauge of 1 m and gradients up to 31·5 in 1000. Several new motor-coaches and control cars with Brown Boveri electrical equipment for 850—1100 V d. c. operate over the line. The motor-coaches are equipped with four motors having a one-hour rating of 100 kW each at 36·5 km/h and Brown Boveri spring drive. They attain a maximum speed of 75 km/h. The control gear provided for series-parallel connection and short-circuit braking is characterized by a particularly low weight and permits of multiple-unit or remote control of the motor-coach and control car from the end of the train, as required.

the case of oil only 50 % of the earlier quantity is now required. The new traction transformers are of circular form. As a result lighter supports can be employed and the transformers fitted in or under the vehicle in a much simpler manner. Together with the high-voltage control gear, introduced by Brown Boveri for single-phase traction applications and which is incorporated in, and forms an integral part, of the transformer, very light, multi-step equipments are obtained. Fig. 138 shows such a transformer of the latest type with a continuous rating of 400 kVA according to R. E. B. rules.

Air-blast high-speed circuit-breakers were provided on the Ae 4/6 locomotives of the Swiss Federal Railways series 10,801 for the first time, in lieu of the hitherto conventional round-tank oil-circuit breakers. Experience has been excellent. In particular, it proved possible to discard the blocking device provided to protect oil circuit-breakers in the event of short circuits on the primary side of the locomotive. Nevertheless, the first locomotive-type air-blast high-speed circuit-breaker was still rather bulky. This drawback has now been overcome by a new design with considerably smaller dimensions. Apart from this the simple roof cut-out, arranged within an earthed frame, suffices as primary over-current protection in many cases, even where relatively large vehicles are concerned.

All of these new design features are being incorporated for the first time in two Bo-Bo locomotives, series 251, for which the contract was received, in conjunction with the Swiss Locomotive and Machine Works, Winterthur, from the Berner Alpenbahn Gesellschaft Bern-Lötschberg-Simplon, during the past year. The locomotives in question have four driving, but no pony axles. The total weight of the axles, $4 \times 20 =$ 80 t, is employed entirely to develop the tractive effort.

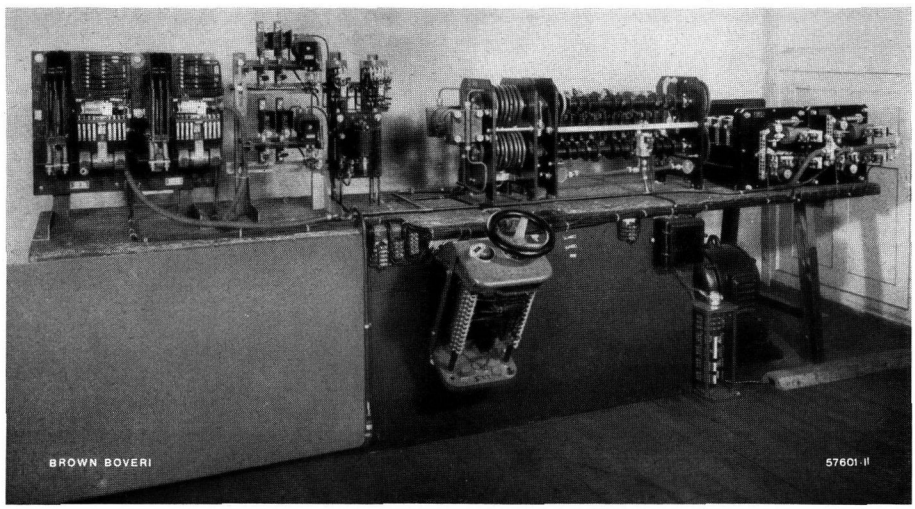


Fig. 140. — Multiple-unit control gear for the Chemins de fer fribourgeois (Gruyère) in the test bay at Baden.

Control current 36 V d.c. This control gear for four traction motors each with a one-hour rating of 100 kW, is designed for 850 V (maximum 1100 V) d.c.

These locomotives with their 4000 H. P. total one-hour rating (at 75 km/h), maximum running speed of 125 km/h, and stable running properties both on straight stretches and in curves, are to be built as bogie engines for reduced wear and maintenance and will incorporate many an outstanding advance.

For the control of a.c. lightweight motor-coaches only requiring a limited number of notches a cam-operated controller actuated by a d. c. servo motor (36—72 volts) has no superior on the score of simplicity, maintenance, and weight alike. Separate arcing switches are provided to take the switching arc so that the individual switch units function without sparking. No blow-out coils are therefore needed, while the interlocking contacts of contactor control gears which never operate absolute reliably, are also dispensed with.

Progress was also made in the development of control gear for *direct-current motor-coaches*, where the trend is likewise towards lightweight designs. During the period under review three metre-gauge motor-coaches (Fig. 139) and four control cars for a maximum running speed of 75 km/h were supplied to the *Chemins de fer fribourgeois (Gruyère)* which are operated with 800—1100 V d.c. The mechanical part was manufactured by the Swiss Car & Elevator Corp., Schlieren. The electrical equipment supplied by Brown Boveri comprises four motors with a one-hour rating of 100 kW at 36·5 km/h, driving the wheels through the firm's well-known spring drives, together with very lightweight control gear for series-parallel connection, short-circuit braking, and any desired combination of multiple-unit and remote control of the motor and control cars at the ends of the train. Fig. 140 shows the entire control gear set up for test in the test bay. It is a completely new design of remote and multiple-unit control for power running and electrical resistance braking and permits of automatic starting and braking with a large number of notches and an adjustable maximum current. Moreover, it is characterized by its light weight, low maintenance costs, and small dimensions. Fifteen series, ten parallel, two field reducing, and fifteen braking notches are provided. The control is based on the line switch principle and in the starting and braking zones contact burning is confined to the two line and bridging switches; as a result maintenance should be very slight. Notwithstanding the larger number of starting and braking notches the equipment is much lighter than standard contactor control gear. It is particularly suitable for lightweight motor-coaches of all kinds on city, interurban, and underground railways. Fig. 141 shows the driver's cab of a Gruyère motor-coach.

A platform-type multi-notch controller with twelve series, ten parallel (of which two for field reduction), and twelve braking notches has also been developed for four-motor power cars on interurban railways and tramways (Fig. 142). This is a combined cam-operated controller, with direct-actuated switch-units for a motor

voltage of 650 V, and a control switch with solenoid contacts for the remote control of notch contactors with 24 V. Ease of operation is a noteworthy feature of the controller. The large number of notches makes for smooth starting and braking with best possible utilization of the adhesion weight.

During the year seven further four-axle single-direction lightweight motor-cars of the 401 series with Brown Boveri-Simplex bogies were supplied to the Zurich Tramways. These vehicles, which can well be considered the most modern on the European Continent, have proved eminently satisfactory in service. One of the cars was lent to the Basle Tramways where it operated on different routes for a number of months entirely satisfactorily. This type of tramcar with its high acceleration and deceleration, together with other advantages, is thus suitable for tramways in towns with quite different local conditions.

Four electrical equipments with series-wound motors for large-capacity trolley buses of similar pattern to those at Zurich were supplied to a foreign municipality. The chassis of these vehicles were made by the A.-G. Franz Brozincevic, Wetzikon (Switzerland), while the

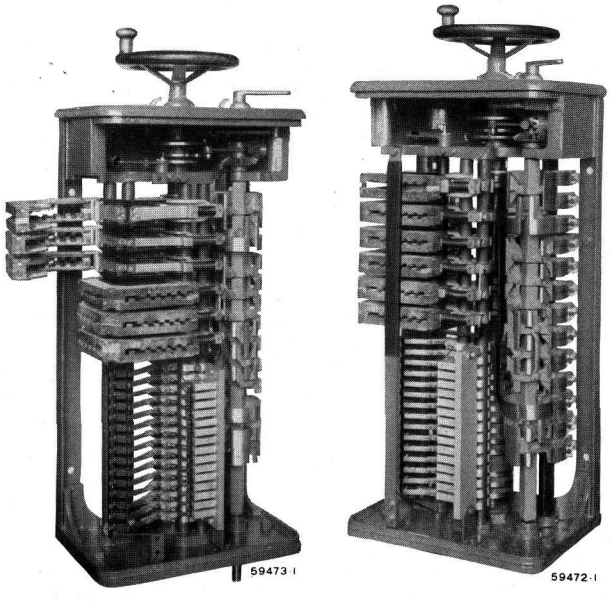


Fig. 142. — Cam-operated controller for the control of four d.c. series-wound motors each with a one-hour rating of 71 kW, 750/2 V, without casing, on right with closed, on left with three opened arc chutes.

The main drum of this new multi-notch platform-type controller has six 750 V cam-operated switch units, which carry the main current, on the top half, and fifteen 24 V control contacts for the control of the step contactors on the lower half. This controller design, combined with a bank of contactors, enables a large number of power and braking notches, i.e., in the present case twenty-two power notches, of which twelve series, eight parallel, and two field-weakening, together with twelve notches for electrical braking, to be lodged in a cam-operated controller of comparatively low height.



Fig. 141. — View of driver's cab of one of the new motor-coaches for the Chemins de fer fribourgeois (Gruyère).

Note the neat arrangement of the instruments and the unobstructed view all round the cab.

manufacture of the coachwork and erection of the electrical equipment were carried out in the country in question. Towards the end of the year under review the first of these trolley buses was successfully taken into service. The continual development of the electrical equipment for lightweight vehicles has also involved revision of auxiliary equipment designs to make them satisfy the more exacting requirements. During the year a new *single-phase/direct-current convertor set,* as required in the case of single-phase traction vehicles to generate direct current for the lighting and control circuits, was also evolved. This set is relatively small and of the monobloc type. It comprises a single-phase, 230 V, $16\,^{2}/_{3}$-cycle motor coupled to a d.c. generator continuously rated 1·1 kW at 37—45 V, together with starting and regulating gear to maintain the d.c. voltage constant. In conformity with its small dimensions the new set (Fig. 143) only weighs 135 kg. Starting is effected on the a.c. side and is carried out automatically should the voltage fail and return.

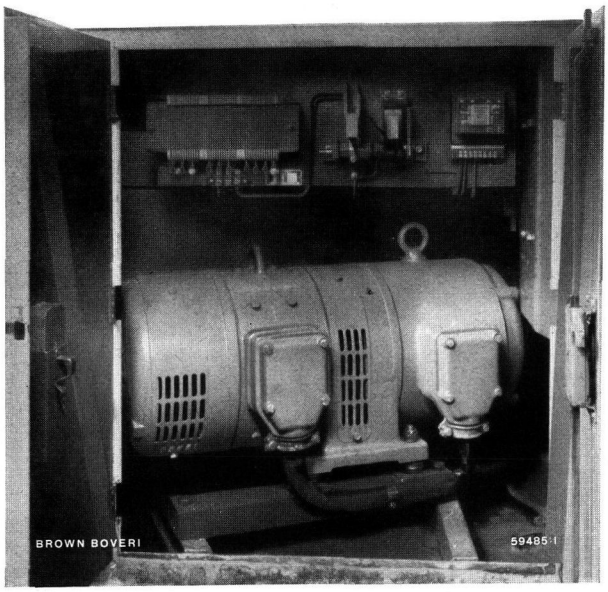


Fig. 143. — Monobloc convertor for lighting and battery charging on the motor-coach for the Swiss South-eastern Railway (S. O. B.)

The whole equipment comprises a single-phase 230 V, 16 2/3-cycle motor coupled to a d. c. 37—45 V generator with a continuous rating of 1·1 kW, together with the starting equipment and train lighting regulator. The new convertor set in the lower part of the ventilated cubicle to the left of the driver's cab is particularly small and light; it weighs only 135 kg. Features of the equipment are starting from the a. c. side, automatic re-starting upon return of supply voltage after failure, and quiet running.

Fig. 144 depicts a single-pole *lighting coupling* for voltages up to 1500 V and currents up to 60 A, devised during the year for connecting the lighting cable between motor and trailing coaches. A feature of the coupling is its very simple and robust design. Positive contact is ensured by the accurate guide between the plug and socket. The coupling is provided with a dust- and rain-proof cover, while the cable is safe-guarded against rupture by means of a special device.

Extensions to the existing Swiss *trolley bus systems* have unfortunately been rendered impossible through the tyre shortage, while even where services are already in operation the time-tables have had to be severely restricted to lengthen the life of the tyres. It has therefore only been possible to introduce slight improvements and auxiliary contrivances which have proved necessary from an operating point of view. For instance, a *radio interference suppression filter* for mounting on the roof of trolley buses (Fig. 145) has been devised which virtually suppresses the disturbing influence of high-frequency voltages emanating from switching and commutation sparks on wireless reception. The filter,

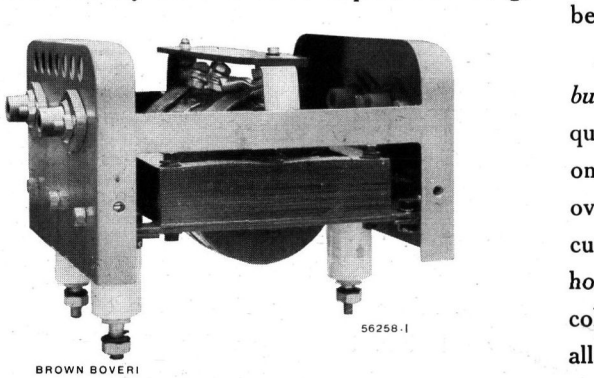


Fig. 145. — Radio interference suppression choke coil for trolley buses.

Service voltage 650 V, one-hour current 150 A, for roof mounting, weight 23 kg, casing removed. These radio interference filters virtually suppress the disturbing influence of high-frequency voltages emanating from switching and commutator sparks on wireless reception.

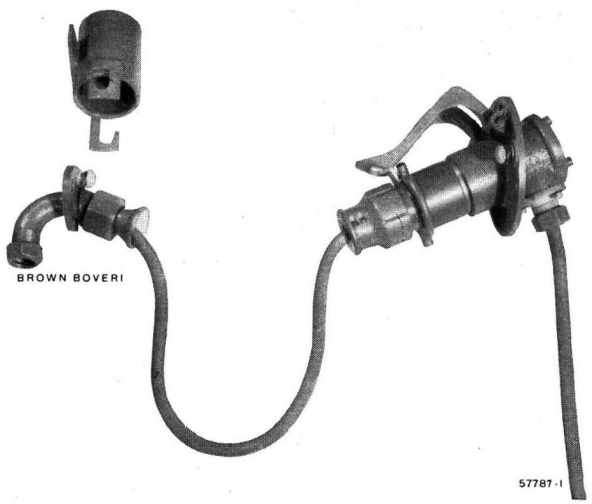


Fig. 144. — Single-pole lighting coupling for voltages up to 1500 V and currents up to 60 A.

A feature of this new coupling is its very simple and robust design. Positive contact is ensured in the control current coupling by the accurate guide between the plug and socket. The individual contacts are sprung to give an ample contact pressure. All couplings have a dust- and rain-proof cover and the cable is protected against rupture by means of a special device.

a combination of choke coils and condensers, is connected between the current collector and lead-in.

Another innovation is *thawing equipment* for *trolley bus contact wires*, where hoar frost and ice are frequently a source of great trouble during the first runs on cold winter mornings. By short-circuiting the wires over adjustable resistances and loading them with a current of 4—5 A/mm², they are thawed out and the hoar frost or ice is readily removed by the current collectors of the trolley buses which are simultaneously allowed to run over the route. Fig. 146 shows the equipment neatly arranged in a switch cubicle.

Ever increasing interest is being shown in the *electric trucks* built by the firm with which the driver steers the vehicle and operates the control with exactly the

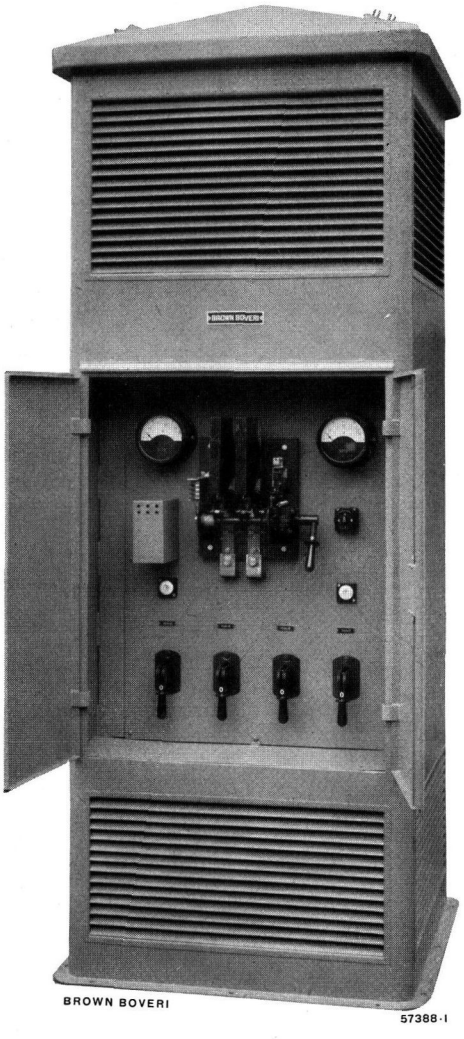


Fig. 146. — Thawing equipment for trolley-bus systems.

This permits the contact wires to be freed of hoar frost and ice which are frequently a source of great trouble during the first runs on cold winter mornings.

same lever and hand movements for both directions of travel. This results in easy and convenient manipulation as well as a high degree of safety in operation. Fig. 147 depicts an electric truck for a net load of 1500 kg which was built during the year. It is equipped with two series-wound motors each with a one-hour rating of 1·9 kW at 10 km/h. The maximum speed is 15 km/h. The practical *three-phase/direct-current charging sets* developed have gone a long way to popularizing our large and small battery-operated vehicles. Fig. 148 illustrates such a set for a charging current of 77—25 A and a charging voltage of 88—104 V with motor for connection to 220, 250, 380, or 500 V as required. After connection of the set to the supply the charging operation is carried out entirely automatically; the same applies to disconnection after the discharge voltage has been attained and the adjustable finishing charging time has elapsed. With this set charging times are short and the life of the battery lengthened. Combined with its control gear the set is also suitable for carrying on the battery-operated vehicle itself, to enable the battery to be re-charged on route, or for erection in garages or workshops.

Considerable progress has also been made in the design of *electric-train lighting equipment parts* on the score of weight, maintenance, and convenience. As proved by the adjacent table this applies in particular to the generator. The type B 36 train lighting



Fig. 147. — Electric trucks with a tare of 1500 kg Two series-wound motors with a one-hour rating of 1·9 kW each give a speed of about 10 km/h (max. 15 km/h).

Brown Boveri electric trucks are becoming more and more popular due to the driver steering the vehicle and operating the control with exactly the same lever and hand movements for both directions of travel. This results in easy and convenient manipulation as well as a high degree of safety in operation.

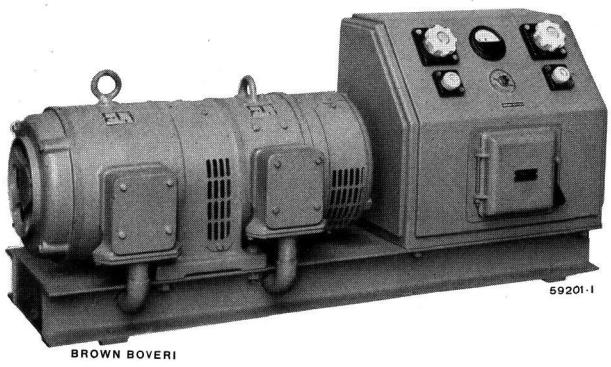


Fig. 148. — A. C.—D. C. charging set particularly suitable for the charging of vehicle batteries.

Charging current 77—25 A, 88—104 V, supply voltage 220—250 V, 50 cycles, or 380 or 500 V by changing over connections at terminals.

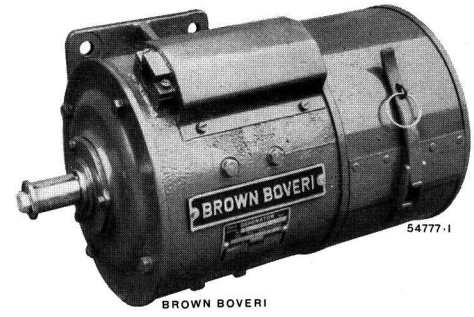


Fig. 149. — Train lighting generator type GZ 94 rated 2·5 kW, 36—45 V, 55 A, 650—2665 r. p. m.

Notwithstanding the increased rating of 22 % compared to the earlier model, the weight has been reduced to 93 kg, i. e., by 24 %.

generator belt-driven from one of the axles, which was the most frequently used up to 1931, weighed 200 kg, including the belt driving gear. With the change-over to cardan shaft drive the weight for the 18 % more powerful type GZ 104a generator dropped to 122 kg. The recently developed type GZ 94 train lighting generator illustrated in Fig. 149, with its 22 % higher rating, weighs only 93 kg. All of the new train lighting sets are designed for the same excitation current, so that given the same voltage the same regulator can invariably be employed.

Year	Model	One-hour current A	Weight kg
1912—31	B 36	45	200 *
1932—41	GZ 104a	53	122
1942—	GZ 94	55	93

* including pulley

The *cardan drive* (Fig. 150) is being exclusively fitted on all new rolling stock in Switzerland. Its advantages are: Absolutely reliable power transmission unaffected by the weather, attendance between normal coach overhauls unnecessary, minimum maintenance costs, simple erection, ready accessibility, freely movable wheel axle, standard wheel sets and axle boxes, and low unsprung weight.

Two recently developed types of regulator can be universally employed for a given lighting voltage: one for a practically constant number of lighted lamps with built-in or separate lighting resistance, the other for a greatly fluctuating number of lighted lamps with constant lamp voltage. The regulators are suitable for all types of batteries (lead, nickel-cadmium, and nickel-iron), various capacities, and the entire new range of train lighting generators. All of the regulators of each type are similar and interchangeable.

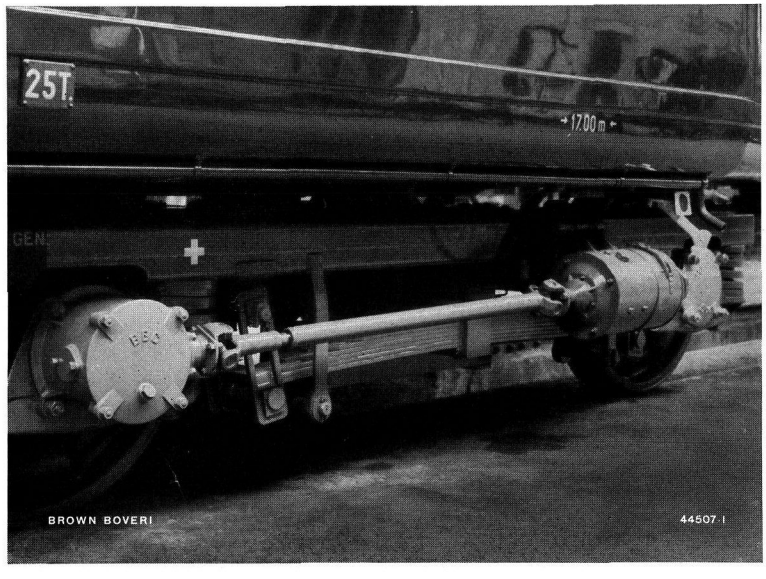


Fig. 150. — Cardan drive for train lighting generator type GZ 54a comprising axle box gearing with single ratio of 1 : 3·125 and cardan shaft with ball and socket joints and sliding piece.

The cardan drive illustrated is employed exclusively for all new equipment. Its most important advantages are: Absolutely reliable power transmission, unaffected by the weather, attendance between normal coach overhauls unnecessary, minimum maintenance costs, and simple erection.

B. GAS-TURBINE LOCOMOTIVES.

Gratifying news can be given of the first gas-turbine locomotive in the world (Fig. 151). Thanks to the comprehension of the authorities and notwithstanding the fuel shortage the Swiss Federal Railways have succeeded in obtaining sufficient fuel oil to put the locomotive into regular service. In point of fact, it has been hauling scheduled trains with loads of up to 300 t over non-electrified local lines daily since the 25th May, 1943. Since the 3rd June, 1943, it has operated on the Winterthur-Stein-Säckingen line, covering approximately 150 km daily. Mixed passenger and goods traffic is handled which, although not in conformity with the capacity of the locomotive on the score of speed (110 km/h) and power (2200 H. P.), gives an opportunity of collecting valuable operating experience. The frequent halts and starts, the shunting service, waiting periods, etc., involved on this line represent much more arduous conditions than express service over long routes at much higher powers and speeds.

Nevertheless, the gas-turbine locomotive has so far proved entirely satisfactory, no trouble of any importance having been encountered. This fact is all the more remarkable, inasmuch as, from experience, machines which have proved satisfactory in stationary service can frequently only be adapted to the exacting traction conditions with great difficulty and big modifications.

Up to the end of 1943 the locomotive had covered about 32,000 km. It is run on cheap fuel oil, high-grade Diesel oil only being necessary for starting. Immediately after ignition the fuel is changed over to the low-grade oil which in the quality employed has a viscosity of about 16° Engler at 20° C. To assist pulverization the oil is pre-heated to about 100° C by means of the heat inherent in the exhaust gases, being injected at a pressure of about 12 kg/cm². The fuel oil consumption of the gas turbine set is extremely low. In point of fact, practically no oil whatsoever has been consumed to date and its composition has suffered no deterioration, so that renewal should not be necessary for a long time to come.

The drivers have quickly made themselves familiar with the locomotive, like driving it, and praise its properties, which fact may chiefly be put down to the simplicity of its construction and operation.

The fuel available will enable the locomotive to be run for some time longer and thus enable valuable experience to be gathered under winter conditions.



Fig. 151. — The gas-turbine locomotive at a station on the line it is serving.

During short stops the gas turbine is allowed to idle, but when the halt exceeds ten minutes it is shut down. Three to three and a half minutes are required to re-start the absolutely cold turbine; should it still be warm 1/2 to 3/4 minute less is necessary.

V. HIGH-FREQUENCY AND COMMUNICATIONS ENGINEERING.

During the past year research and developmental work in the various branches of high-frequency and communications engineering has been carried on intensively. As the result of thorough investigations, we have succeeded in considerably improving various components of high-frequency apparatus. New components, which possess fundamental advantages in regard to mechanical and electrical properties, were also devised. *Developments* in the sphere of electrical filters and of transmitting and special valve types are particularly worthy of note.

The various specialized branches of high-frequency engineering, especially microwaves, multichannel communication and directional waves, formed the subjects of further investigations. Various novel principles were successfully tested and our endeavours to find original solutions have yielded several interesting and promising results in the past year. Fundamental improvements in regard to size and reliability of newly developed high-frequency apparatus were obtained by the application of new principles and components.

1. *Electrical Filters.*

An important component of most equipment used for communication purposes is the electrical filter. Since the quality and performance of the equipment as a whole is in many cases dependent on the properties of the filters, the development of various types received special attention. To act as a basis for design, tables and curves for the most widely varying basic types of high-pass, band-pass and low-pass filters were drawn up, a work which involved a considerable number of tedious calculations. With the help of these tables and curves it is a simple matter to design a filter with the desired properties in a very short time. As an example of the practical application, the calculated attenuation curve of a low-pass filter is shown in Fig. 152. It will be noted that the attenuation curve measured subsequently for the completed filter, shown dotted, agrees well with the calculations.

Coils with very low losses are indispensable for the construction of filters with a sharp cut-off at the boundary frequencies. We have succeeded in considerably reducing the coil losses by the development of powdered iron cores. Fig. 153 shows a new band-pass filter together with the powdered iron core used. Such filters are employed, for example, in multichannel communication apparatus and in equipment for the "scrambling" of speech. The quality of the filter may be judged by reference to the attenuation curve shown in Fig. 154.

Crystal filters, in which *piezo-electric crystals* are used instead of tank circuits consisting of coils and condensers, were also successfully developed. Up to the present time quartz crystals have been used in

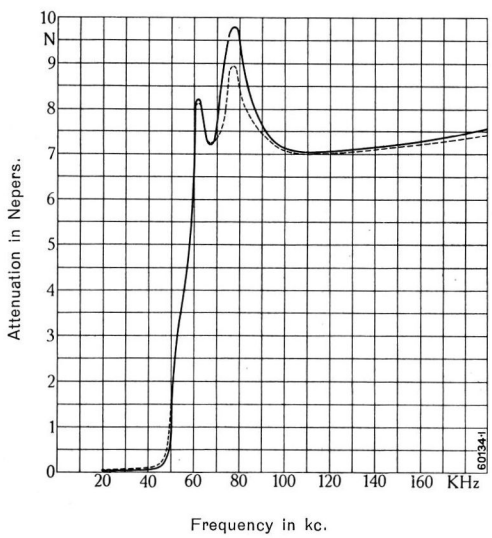


Fig. 152. — Attenuation curve of a low-pass filter.

The relatively good agreement between the calculated and measured values is noteworthy.

Continuous curve: Calculated values.
Dotted curve: Measured values.

the majority of cases for such filters. As these crystals are very difficult to obtain to-day, we are making use of artificially cultivated crystals manufactured by a process developed by Prof. P. Scherrer in the Physics Department of the Swiss Federal Institute of Technology, Zurich. In contrast to the well-known Rochelle salt crystals, their properties differ only slightly from those of the natural quartz used in oscillatory circuits. A fully grown, cultivated crystal is illustrated in Fig. 155.

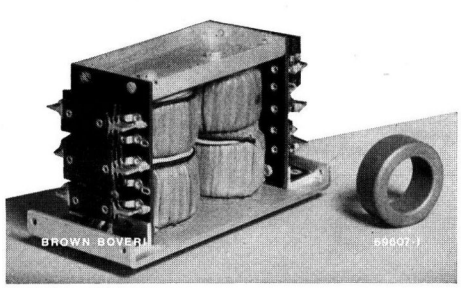


Fig. 153. — Band-pass filter with coils having powdered-iron cores.

The coil cores are made from powdered iron of a definite grain size. The grains are insulated from one another in order to avoid eddy-current losses. In this manner we obtain cores of the highest quality such as are necessary for high-frequency filters.

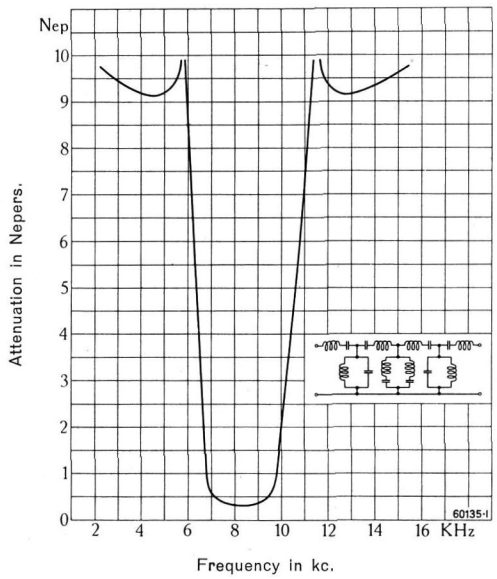


Fig. 154. — Measured attenuation curve of a band-pass filter with Brown Boveri toroidal coils.

The attenuation is plotted in function of the frequency.

The attenuation curve of a two-stage crystal filter is shown in Fig. 156. These filters, made for frequencies above 50 kc., are also particularly suitable for multi-

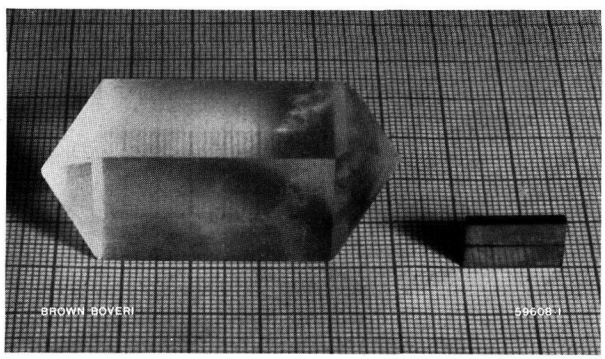


Fig. 155. — Artificially cultivated piezo-crystal.

Crystals such as the one shown on the left are cultivated by a new process for which patents have been applied for. By cutting, grinding and preparing these, it is possible to produce filter or oscillator crystals (see right-hand side of photograph) which can be used to advantage instead of natural quartz crystals which are at present exceedingly difficult to obtain. In high-frequency engineering there are innumerable applications for such crystals.

channel communication apparatus and for "speech-scrambling" equipment. Special advantages are their low weight and comparatively small space requirements.

2. *Multichannel Communication and Directional Waves.*

Our efforts have produced fundamental developments in *multichannel communication.* Filters and modulators, in the form of completely developed units, were used to build test apparatus with which to investigate the fundamental principles of multichannel transmission. Special supplementary multichannel units for use in conjunction with existing wireless equipment are being developed. By adopting a space-saving and light-weight construction, these units may be made portable.

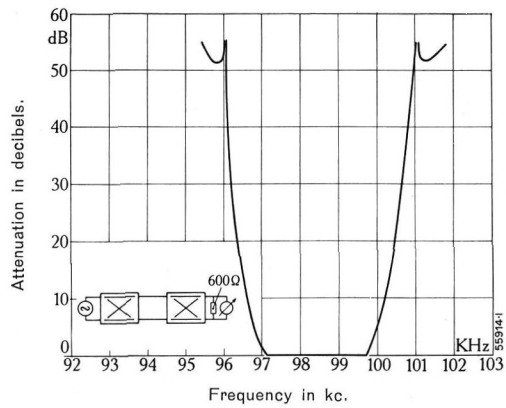


Fig. 156. — Attenuation curve of a two-stage crystal filter with artificially cultivated crystals.

The attenuation is referred to the output level of the frequency band transmitted through the filter.

For *directional wireless transmission* over long distances, we have developed sets which work with wavelengths of several decimetres and which are used in conjunction with unidirectional aerials. These sets may also be used for relaying. Communication between two stations when obstacles lie in the direct line of sight is made possible by the erection of one or more repeater stations. The repeater stations consist of directional transmitting and receiving units connected together.

Frequency modulation, which ensures a minimum of atmospherical disturbance, is employed in these sets.

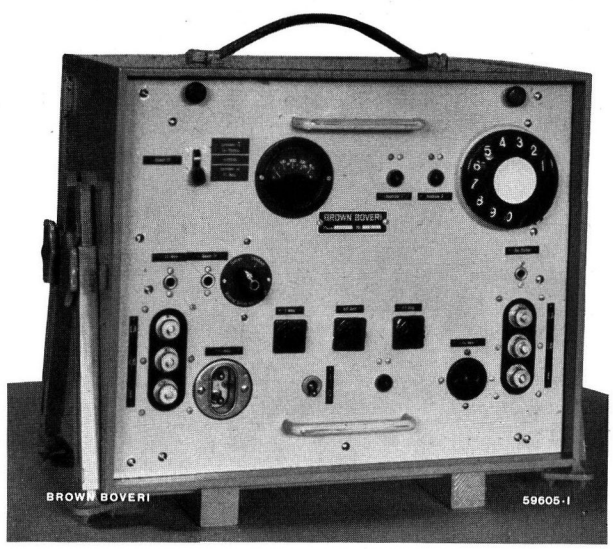


Fig. 157. — Auxiliary dialling unit, used in conjunction with transmitters, for automatic selection of telephone numbers.

Special auxiliary units are necessary for putting through automatic telephone calls when ultra-short-wave sets are used for communication. Dialling and calling impulses are transformed into corresponding audio-frequency impulses.

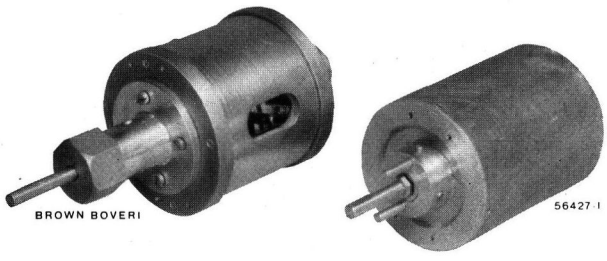


Fig. 158. — Adjustable cavity resonators for decimetre-wave sets.

Such tuning circuits play an important part in ultra-short-wave work. Tuning is effected by rotating the axial shaft. The cavity resonators are made with the greatest precision.

We have already successfully applied this kind of modulation previously, especially for police wireless stations, and it has the special advantage in the present case that non-linear distortion may be reduced to a minimum. By its employment, thoroughly reliable multi-channel communication, even when several *repeater stations* are interposed, is ensured. The small variations of the average frequency of transmission, which cannot be avoided in practice, are compensated by automatic tuning of the receiver. It is thus possible to use a simple, single-knob control and, moreover, the attendance during operation is reduced to a minimum. This is particularly advantageous in the case of repeater stations, which can be operated without continuous attendance. Previous experience with these novel equipments has been in every respect satisfactory, and has confirmed the fact that reliable relay operation is easily obtained with several repeater stations.

For the operation of the directional wireless units in conjunction with an automatic telephone system, an *auxiliary dialling unit* (Fig. 157) was developed. In this unit the dialling impulses are converted into corresponding, modulated audio-frequency impulses, the automatic selection of a given number over several repeater stations thus presenting no difficulties.

The components of these sets are also especially noteworthy, particularly the cavity resonators used for tuning the transmitters and receivers. Fig. 158 shows a cavity resonator, the tuning capacity inside the resonator being controlled from outside by an insulated shaft. The control is so arranged that no current flows in the moving parts, thus avoiding a condition which could otherwise, according to experience, give rise to disturbances.

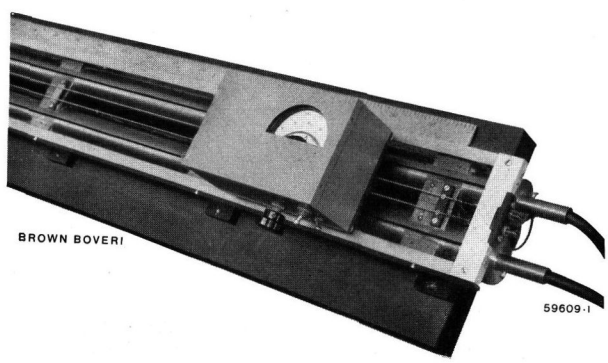


Fig. 159. — Impedance measuring device for ultra-short waves.

The voltage nodes and antinodes between the two shielded Lecher wires are found by means of the movable diode-voltmeter.

Various special measuring instruments for the exact measurement of impedance, power and frequency had to be developed for our investigations of ultra-short waves with wavelengths of several decimetres or a few metres. Fig. 159 shows an impedance measuring device for the measurement of the magnitude and phase angle of impedances. This instrument consists of a Lecher system with shielded conductors, the unknown values being easily ascertained from the position and amplitude of the voltage nodes and antinodes.

3. *Microwaves.*

Reports on the development of our microwave transmitting valves have already appeared in previous numbers of the Brown Boveri Review. These valves are known under the name of *"Turbator"*, and are oscillators which have been derived by systematic development from a magnetron of which the segments are connected to a cavity resonator. With such a valve it is easily possible to obtain wavelengths of about 10 cm. The behaviour of the valves could be exactly analysed mathematically, this leading to the manufacture of valves with oxide cathodes having a large surface which possessed a considerably increased efficiency at lower operating voltages. Specially noteworthy is the simple manner in which frequency and amplitude modulation are accomplished with the turbator. It was

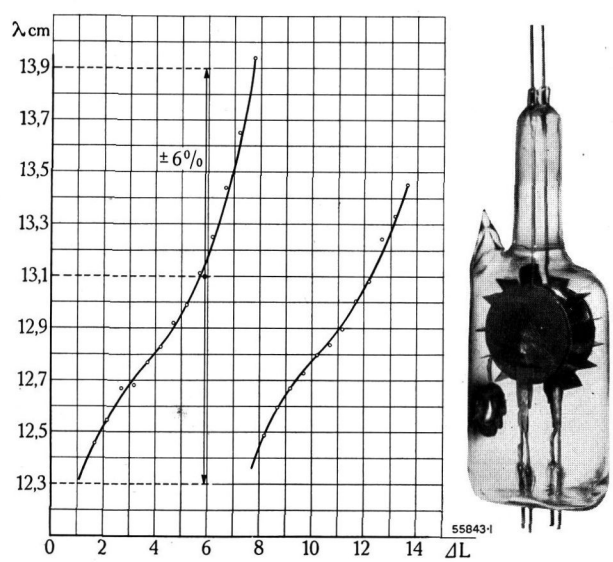


Fig. 160. — Turbator valve with internal and external tuning characteristic.

The frequency of the turbator can be influenced in a very simple manner by tuning an **external**, adjustable Lecher system.

Abscissæ: Tuning length. Ordinates: Wavelength.

possible, for example, to obtain practically linear amplitude modulation with a depth of modulation up to 70 %.

While, in the beginning, a constant wavelength was always used, investigations with the object of obtaining variable frequency tuning for constant operating data have been completed. Tuning may now be realized in practice by means of the transformation of the impedance of an external tuning reactance into the inside of the resonator. In this manner, a frequency variation of ± 5 % and more is obtained, which completely satisfies the normal practical demands. Fig. 160 shows such a valve and its tuning curve.

To render the reception of extremely short wireless waves possible, various means of reception were developed and tested, particularly *special diodes* and *receiving magnetrons*. In view of the extremely short electron transit times required, special demands are made with regard to the precision of the electrode construction and the smallness of the electrode spacing. In the case of the diodes, which are made as double rectifiers, a spacing of $^3/_{100}$ mm between anode and cathode is maintained. In the case of the magnetron, it was possible, by adaptation of the magnetic field to the wave length to be received, to obtain a considerable increase of sensitivity without sacrificing stability.

The development of *microwave communication sets* was continued. As the turbator can be operated under the simplest conditions, transmitters of extraordinarily small dimensions can be produced with very little material. In the preliminary tests over short distances, the previously mentioned receiving magnetron has proved to provide specially good reception. Various tests on superheterodyne reception with diodes were likewise successful, and the results achieved up to the present justify the assumption that clear superheterodyne reception with simple equipment will also be possible over large distances. Fig. 161 shows an auxiliary unit of a turbator transmitter which contains battery, vibrator and rectifier for power supply, and modulator for direct control by the crystal microphone. The turbator itself with permanent magnet and mirror can be mounted separately on a tripod.

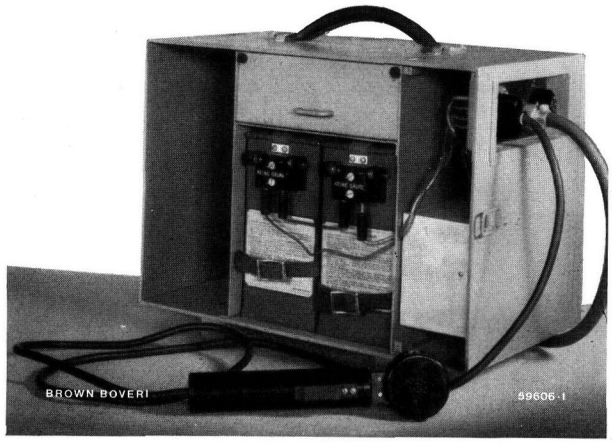


Fig. 161. — Auxiliary equipment of a turbator transmitter.

This equipment is for power supply and contains battery, vibrator and rectifier, modulator and crystal microphone.

4. *Construction of Valves.*

Various machines for the manufacture of *small, special valves* were designed, with the help of which production could be appreciably increased. A special technique was developed for making the seals between the glass and the electrode leads of our various valve types of low and medium ratings. The development of small valves included a number of types ranging from a small diode up to a pentode with a plate dissipation of 50 W. In addition to these, special valves for measurement and checking purposes were developed. Fig. 162 shows an electronic relay, similar to a magnetron, which is used commercially for supervising large d. c. currents. In this electronic relay, the flow of electrons is deflected from the normal, radial path by the magnetic field being checked, so that the plate current provides a basis for exact supervision.

Apart from *demountable transmitting valves*, which are intended chiefly for industrial oscillators, *sealed glass valves* for broadcasting transmitters were also included in our programme of development. Some of the new valves are provided with water cooling, others with forced draught cooling. Certain valve types are also provided specially for short-wave operation. The cathodes of all types can be heated by three or six-phase current, so that telephony is possible with a. c. heating. Fig. 163 shows a sealed transmitting valve with forced draught cooling.

5. *Transmitters.*

The following paragraphs contain a brief summary of some interesting reports on transmitters which we have already supplied.

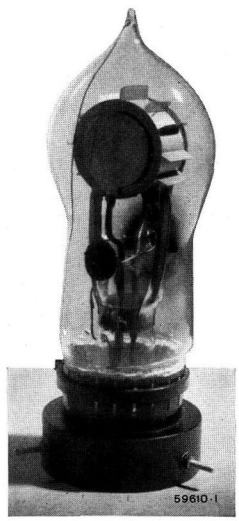


Fig. 162. — Electronic relay for supervising heavy d. c. currents.

The electron stream is deflected from its normal radial path by the magnetic field to be checked, the anode current being used as basis for the supervision of the field.

Medium-wave broadcasting transmitters and short-wave transocean transmitters have been put into service and have proved entirely satisfactory. The subdivision of our transmitters into easily transportable units, which can be quickly assembled on site, results in a considerable reduction of the time required for erection and is therefore very expedient. The auxiliary studio equipment, supplied with the transmitters, also satisfies the demands made on it. Such transmitters are being used more and more under present-day conditions for broadcasting and long-distance telephony. We have therefore laid down a stock of partly completed 10 kW transmitters in order to be able to supply these at comparatively short notice (Figs. 164 and 165).



Fig. 163. — Sealed, glass transmitting valve with forced draught cooling.

The same valve can be used with water cooling when provided with a special cooling jacket.

Police wireless.—As our police wireless equipment for the city of Zurich, consisting of stationary and mobile stations, works exceedingly well and proved to be of indispensable assistance to the police in their efforts to maintain law and order, we decided to further the sales of these equipments. The standardization of our mobile stations has been practically completed in the course of the last few months. The principal aim was the best performance with the minimum of material. The mobile police wireless sets are now made of units which may be easily assembled. By this means the sets are made universal in their application; they may be adapted to all requirements and can be modified or extended at any time. Stationary installations can be supplied, according to the desires of the client, with or without remote control of transmitter and receiver. Frequency modulation is employed, this having the advantage that atmospherical interference is small. They are built for one or two-way communication with ultra-short waves in order to obtain good results in spite of the use of small sets with short aerials. By the use of different wavelengths it is possible to establish duplex communication just as in the case of the normal telephone system. Attendance is simple and

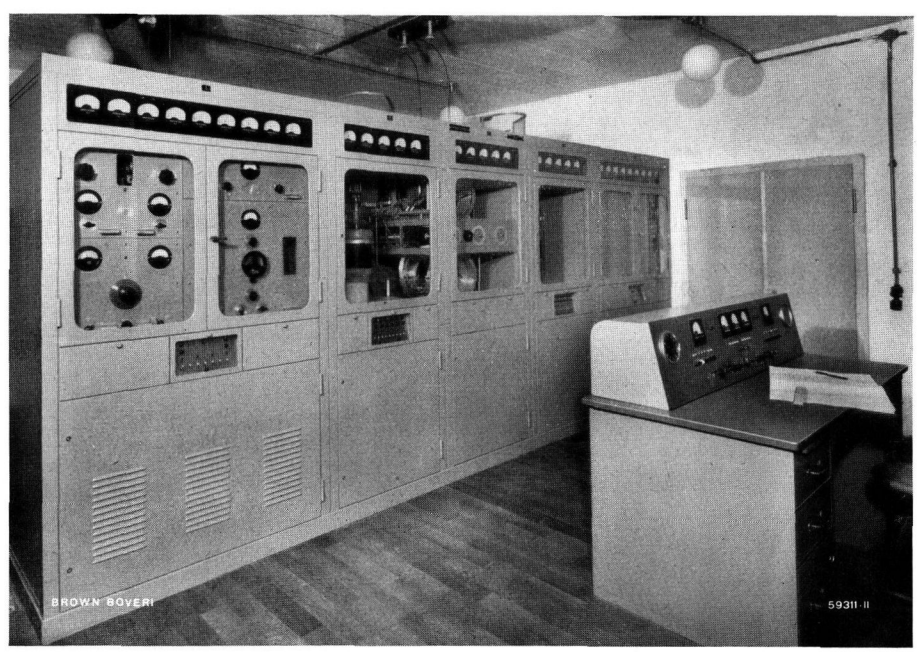


Fig. 164. — 10 kW, medium-wave, broadcasting transmitter.

The h. f. preliminary and final stages on the left, the a. f. preliminary and final stages on the right and the control desk in front show clearly the compact and easily supervised construction of the transmitter. Attendance is extremely simple as the transmitter is semi-automatic. The power supply equipment mounted behind the transmitter can also be controlled and supervised from the control desk.

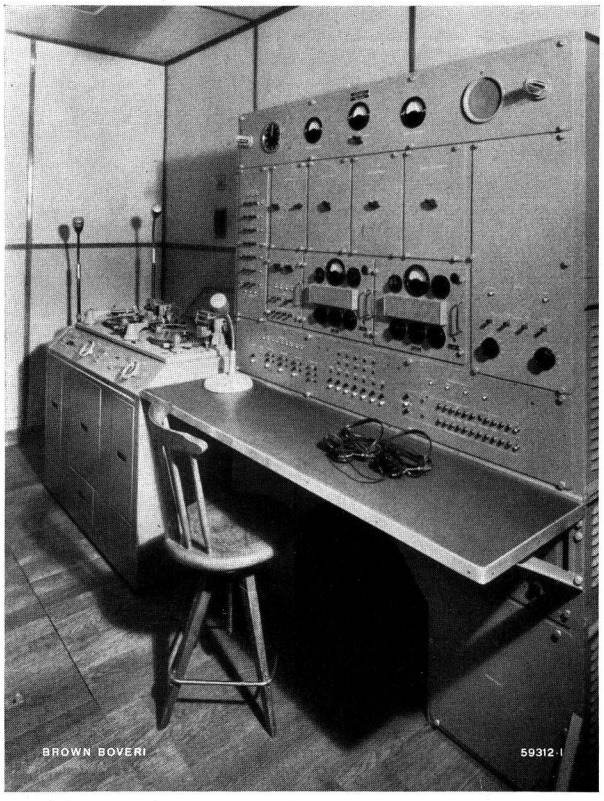


Fig. 165. — Auxiliary studio equipment for a 10 kW transmitter.
Such equipment, with control panels, amplifiers, interval signal unit, a. f. oscillator, turntables for recording and playing records, belongs to the studio of a 10 kW transmitter.

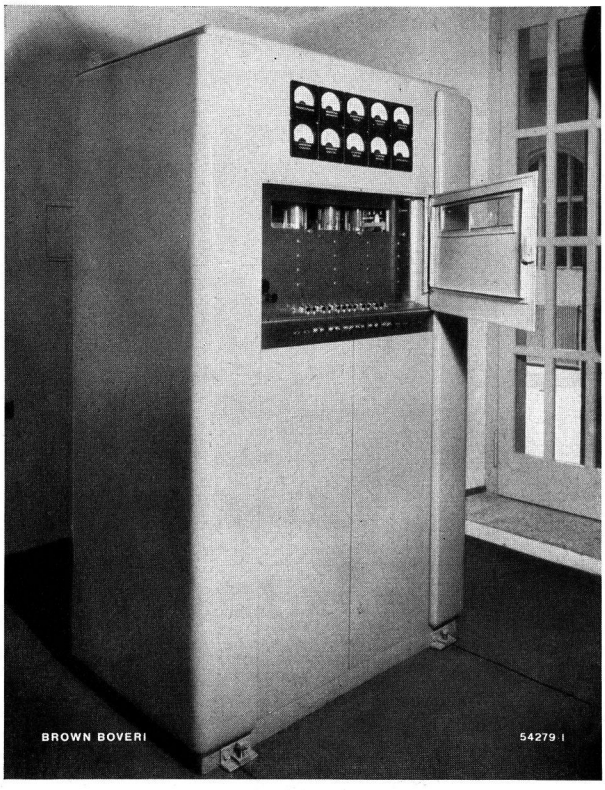


Fig. 166. — Stationary transmitter of the police wireless station in Zurich.
This transmitter, which can work on different wavelengths, is remote-controlled from the central control station, thus allowing a considerable simplification of operation.

requires no specialized knowledge. The Fire Brigade in Basle already operates a wireless installation of this kind and it is to be expected that the police forces and fire brigades of other towns will install wireless equipments of our design in the near future (Figs. 166, 167).

6. *Supervisory Control.*

In this branch of engineering, which is of interest chiefly for power supply concerns, we may mention the following:—

Telemetering.—Our telemetering system has proved satisfactory in all respects. The underlying principle consists in converting the values to be transmitted into audio-frequencies in such a manner that a definite frequency corresponds to each meter reading and a frequency band to each scale of readings. Several meter readings can be transmitted simultaneously over one and the same line by superposing the individual frequency bands on one another, while at the same time it is possible to conduct a conversation. A further advantage is the universal applicability of this telemetering system. Any desired readings (current, voltage, power, reactive power, power factor, frequency, levels, angles, temperature, pressure and vacuum) may be transmitted over any lines and over any distance.

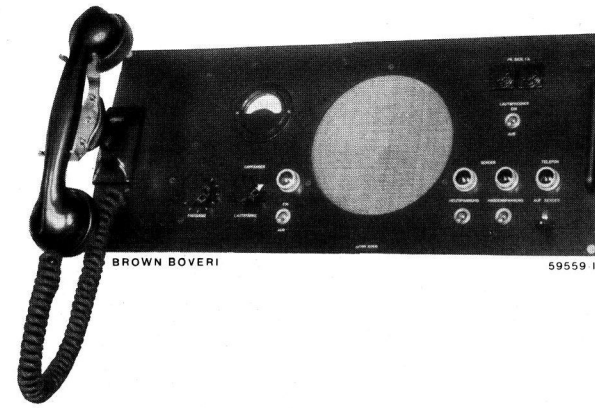
The great accuracy, the instantaneous transmission and the large torque available at the receiving end allow of the connection of automatic regulating devices, so that turbines, for example, can be governed in function of a power or a water level measured at some distant station.

It is possible, moreover, to connect several indicating and recording instruments to the same telemetering receiver (Fig. 168).

High-frequency telephony and supervisory control. Such installations, in which the power transmission lines are utilized for the transmission of the high-frequency currents, serve principally for private telephone communication between the load dispatcher or system-control station, power houses and substations, as well as with neighbouring networks. Besides telephonic communication between the most important points in the network, the same high-frequency equipment is also suitable for the transmission of meter readings and regulating values, of supervisory control signals and of impulses from the line protection relays for simultaneous tripping of the breakers at both ends in conjunction with reclosing equipment.

The high-frequency equipment can be built either for a single application or for a combination of the above-mentioned purposes. The high-frequency cubicle is





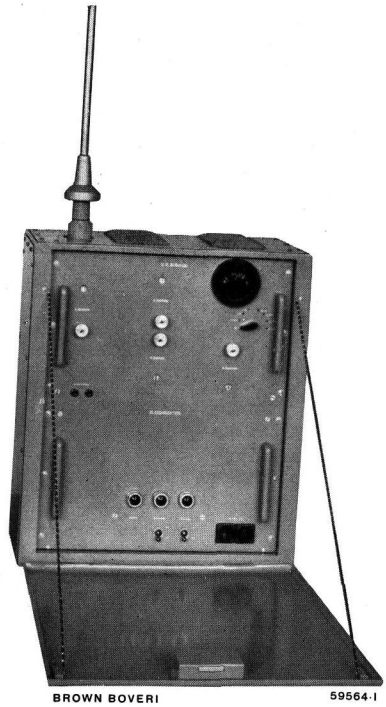


Fig. 167. — Ultra-short-wave transmitting and receiving set with frequency modulation for duplex telephony.

Noteworthy are the advantages of our versatile unit construction.

Upper left. Transmitter, receiver and converter set for feeding the apparatus from an accumulator, combined to form a single unit.

Upper right. Receiver alone with built-in rectifier unit for mounting in a desk, including switch and pilot lamp for the remote control of the transmitter which may be situated at any desired place.

Lower left. Remote controlled transmitter and rectifier built into a casing with lid.

divided into separate, easily interchangeable, standard panels which can be assembled as desired according to the purpose for which the equipment is intended. (Figs. 168, 169 and 170).

In connection with carrier communication over power transmission lines, comprehensive tests on attenuation due to the formation of hoar-frost were carried out at the beginning of 1943 on high-voltage lines in a mountainous district. The results of these tests will be communicated in an article in a subsequent number of this Review.

Low-voltage network telecontrol equipments. Developmental work in the sphere of centralized control by way of the low-voltage distribution networks for lighting and power supply has been brought to a successful conclusion. The apparatus developed may be called low-voltage network telecontrol equipment.

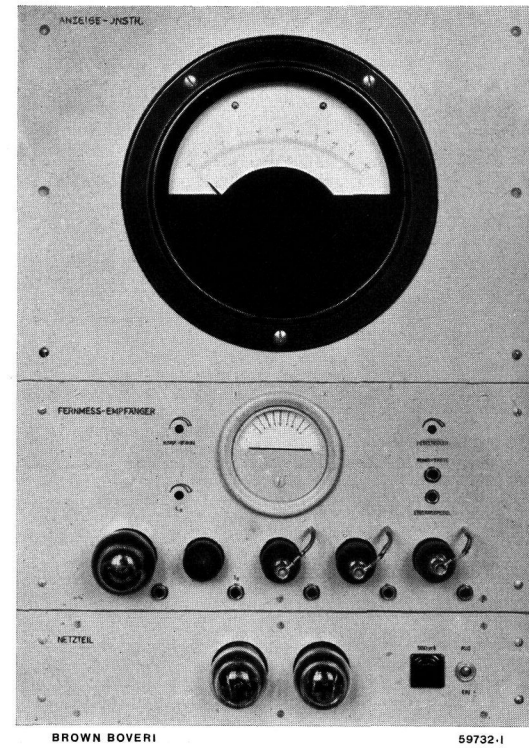
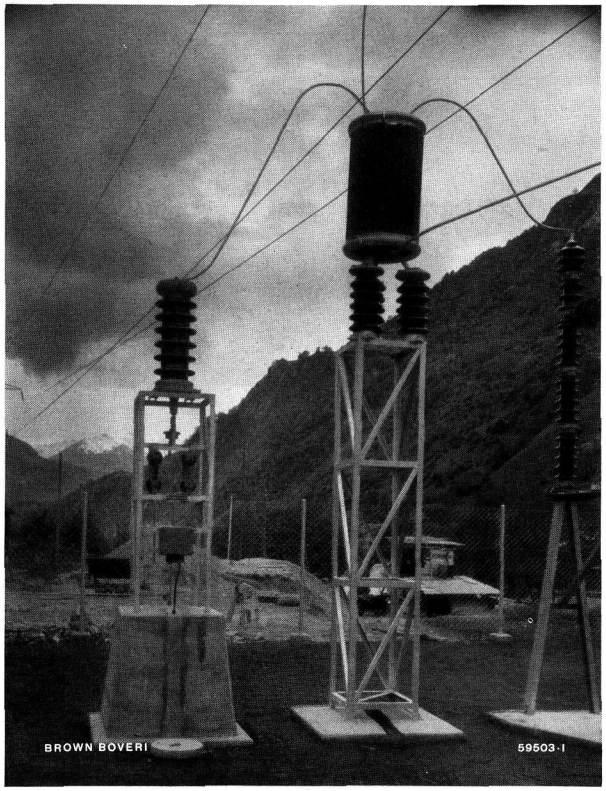


Fig. 168. — Telemetering receiver.

The variable audio-frequency signal transmitted according to the patented Brown Boveri telemetering system is converted in this receiver into a corresponding direct current which can be measured by standard indicating and recording meters with great accuracy.



6031 B. R. B. 3. X. 1939.

Fig. 169. — Coupling condenser and two-wave carrier trap unit in the Mörel power station.

The 700 A carrier trap unit and the 75 kV coupling condenser are mounted in an exemplary manner in this open-air station. The Resorbit arrestor visible on the right serves to protect the h. f. telephone equipment from excessive voltages.

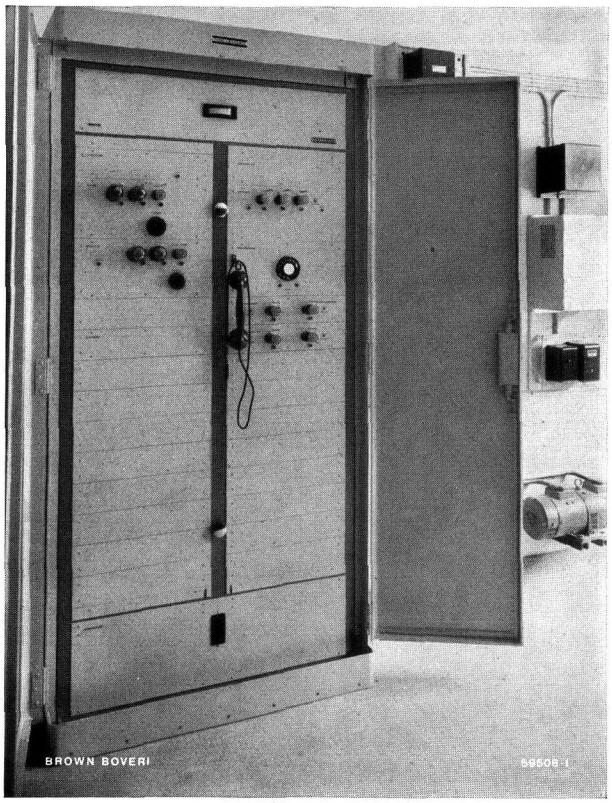


Fig. 170. — H. F. telephone cubicle in the Mörel power station.

The h. f. transmitting and receiving equipment is mounted on standardized, easily accessible panels in such a manner that each individual part can be easily checked. The vacant panels in the lower part of the cubicle are intended for subsequent extensions.

These devices are suitable for controlling street lighting, change-over switches for multi-tariff meters, domestic hot-water systems and motors, for the switching on or off of electric boilers and other consuming devices, all of which have to be remote controlled from one or more central points. These telecontrol equipments thus allow of an arbitrary *control of the power consumption* in the networks of electricity supply concerns.

No separate pilot lines are necessary in this case. The control signals are transmitted directly over the lines of the primary and secondary distribution mains, the erection of a complete telecontrol system consisting merely in the installation of the necessary transmitters, receivers and wave traps, a comparatively simple matter.

Several more supervisory control or related equipments were put into service during the year under review, e. g. the remote water-level indicator for the Laufenburg Power Station, by which the level of the Rhine is telemetered over a distance of about 7 km. For this purpose a telephone line is employed, telephone communication being unaffected by the water-level indication.

A telemetering equipment for power measurements in conjunction with apparatus for remote power consumption metering, which satisfied all demands, was put into service for the "Rhätische Werke für Elektrizität" in Thusis, Switzerland.

The carrier telephone equipment of the "Rhonewerke A.-G.", i. e. the Mörel-Turtmann installation, has been put into service and yielded good results. By way of private telephone exchanges in Mörel, Turtmann and Chippis, conversations may be conducted at will over a 65 kV transmission line between any of the automatic telephones (about 250) connected to these exchanges in the same way as for the normal public telephone system. The installation is capable of being extended for the connection of other power stations to the high-frequency system. Telemetering of one or more values over the same high-frequency equipment is also possible.

A series of special, selective receivers, combined with adjustable, audio-frequency oscillators, were supplied to the Swiss Telephone Department. These equipments are installed in main and terminal exchanges and serve for the remote supervision and limiting of disturbances in a telephone district.

VI. MARINE INSTALLATIONS.

A. VELOX STEAM GENERATORS FOR SHIPS.

In view of the post-war planning now everywhere in progress it appears opportune to refer once again to the fact that the Velox boiler possesses all the properties which are required by a marine boiler. Furthermore the Velox boiler also has a number of other advantages which no other boiler possesses to the same extent. These are its extremely small space requirements, its low weight and high efficiency, the very short time required for putting it into operation, and the ease with which it can be regulated. It can be installed in the same room as the propelling machinery, so that no special boiler room is required and service is simplified. Furthermore, no smoke flues have to be provided, so that there are no restrictions as regards the arrangement of the lower decks. The installation plans already published by us[1] show two different designs of boiler, one being the standard type as used for land installations and also for merchant ships, and a special design intended for such cases where a particularly low weight and small overall height is of special importance. Each particular case can be considered separately so as to decide which type is more favourable. Due to the numerous Velox boilers which we have built and which have now been in service for many years, we possess sufficient experience to be able to supply boiler plants which guarantee an entirely satisfactory service. Moreover, the operation and maintenance of a Velox boiler does not make any greater demands on the staff than any other modern steam boiler or even Diesel engine.

B. MARINE STEAM TURBINES.

It can be assumed that many of the machinery plants installed in the ships which are now being built so hurriedly will be replaced after the war by more economical plants or at least improved. The majority of the existing plants consist of reciprocating engines which will be replaced by geared turbines, whilst for improving existing plants exhaust steam turbines will be added to the installations. During the past year we have been making the necessary preparations for this post-war work, so that the required machines can be supplied without delay. In this connection we wish to remind readers that our exhaust steam turbines possess a special feature, namely the spring ring coupling, by means of which it is possible, despite the flexible connection, to reduce the torque fluctuations of reciprocating engines within a single revolution to such an extent that the increase in power of about 30 % resulting from the turbine does not necessitate a replacement of the propeller shaft. The coupling also prevents the engine and turbine from racing when the propeller comes out of the water during rough seas.

For new plants we recommend the steam turbine for powers down to 1500 H.P. if steam operation is desired. The turbine is more favourable than the reciprocating engine as regards weight and size and is just as economical when steam conditions in accordance with present-day standards are selected.

C. GAS TURBINES FOR MARINE DRIVES.

If for some time now we have repeatedly referred to the gas turbine as the coming machine for ships, this is due to the experience obtained with land installations and from the conviction that these favourable results are also entirely valid when applied to marine service, because they are due to those properties of the gas turbine which in ships are even of still greater importance. These properties are simplicity, safety of operation, and small weight.

We are fully aware that the ratio of cost of the ship and of the cargo to the cost of the propelling machinery is one of the reasons for the proverbial conservatism of the shipbuilder and shipowner. On the other hand in order to improve the efficiency and fuel consumption of existing ships' drives such measures have been adopted in some cases that there is no longer any trace left of that simplicity which is the best guarantee for the safety of operation of the plant.

Thus it is known to provide a reciprocating engine with an exhaust steam turbine and connect both together over gearing and a fluid coupling. When manœuvring it is necessary to disconnect the turbine.

The geared turbine has also not been simplified by the introduction of high pressures and temperatures, and the multiple tapping-off of steam for feed-water preheating purposes. Although these complications concern the boiler and its auxiliaries and the combination condenser—preheater—boiler more than the turbine, the operation of the entire plant requires, however, considerably more careful and conscientious attendance than was the case with former installatious.

[1] The Brown Boveri Review 1940, p. 63/64; p. 232/233; 1943, p. 65.

In an article entitled "Monstrously ingenious" "The Engineer" of October 29, 1937, discusses the presidential address of Sir John E. Thornicroft before the Institute of Mechanical Engineers, in which the head of the world-famed torpedo boat firm referred to the fact that the propelling plants of torpedo boats had become increasingly complicated since the last world war. There it is stated that: "To complicate is easier than to simplify, but perhaps some day there will arise a designer who has the ability and courage to outweigh the disadvantages and even to set the merits of simplicity and resulting trustworthiness against some loss of efficiency or convenience."

This opinion is not an isolated one, because in a discussion concerning a paper read before the Society of Mechanical Engineers [1] about the application of the combustion-gas turbine to the propulsion of ships, Captain Lybrand-Smith, U.S.A. Navy, Head of Research Branch, Navy Department, Washington, D. C. stated:

"Reliability is the great essential for marine machinery. Common sense would indicate that a rotating machine with the only rubbing parts being the two bearings, would be more reliable than a reciprocating machine with its inherent great multiplicity of rubbing and tapping parts. So far as marine practice is concerned, all data which the writer has ever been able to gather confirms common sense.

Marine-turbine machinery is more reliable than reciprocating machinery, whether the latter be steam or internal combustion. As a matter of fact there is very little trouble with marine turbines themselves. There is much more trouble with their necessary adjuncts, such as condensers and boilers. Since the gas turbine would eliminate condensers and boilers, it would eliminate such troubles at the same time.

Gas turbines as power generators are too new in the field to have developed actual data for operating reliability. However, inquiries about gas turbines used by oil companies indicate an extraordinary reliability."

The remarks made here about gas turbines in oil refineries refer to the gas turbines, about 20 in number, supplied by Brown Boveri and their former American licencees, which are used for the Houdry process and of which a large number have been in operation for many years without a reserve, although the entire operation of such oil refineries depends upon the reliability of these machines.

The cited opinions of these two experts from English and American marine circles thus show that simplicity and the reliability connected therewith is a primary requirement of marine plants and that according to their conviction the gas turbine fulfils this requirement.

In fact it is impossible to imagine a simpler machine than the combustion turbine developed by Brown Boveri and now proposed for the propulsion of ships.

A simple combustion chamber, which enables the cheapest fuel oil to be burnt and does not possess any tubes or elements endangered by heat, replaces the boiler with all its accessories, the only auxiliary machine needed being a small fuel pump. The combustion chamber being air-cooled does not require any cooling water. The gas turbine adjoins the combustion chamber. Its blade dimensions correspond to the blading of the intermediate pressure part of a large steam turbine. In accordance with the large quantity of gas the blades are large and very strong, the rotor being short because it only carries six to eight rows of blades. The critical speed lies above all service speeds; in brief the turbine possesses the most favourable conditions which it is possible to imagine as regards safety of operation and efficiency.

The exhaust gases leaving the turbine are employed in a heat exchanger to preheat the air which is compressed in a compressor and after being preheated is passed to the combustion chamber. This preheater consists of ordinary forged iron tubes, because the temperatures which occur there hardly exceed 350° C. By suitably dimensioning the heating surfaces of the preheater in accordance with the requirements of the type of ship or the ship's route it is possible to obtain an overall efficiency of 20—30% for the turbine plant, these being in extreme cases values such as hitherto could only be exceeded by Diesel engines, whereby it must be taken into account that the gas turbine burns a fuel which practically everywhere costs considerably less than Diesel oil.

According to the power and efficiency required, it is possible to employ either the simple combustion turbine or the combined combustion turbine plant. With the latter the compressor is driven by its own gas turbine; the compressor has about twenty stages also with very strong blades and operates within temperature limits of 140—200° depending on the initial temperature of the air which is drawn from the atmosphere and the final pressure after compression. This set can be operated at the speed which is most favourable for compression. The second turbine is that which supplies the useful power and drives the ship's propeller over a gear. This turbine is also very short and of powerful construction, and like the compressor turbine has about five to seven rows of blades which are, however, only half as big as those of the compressor turbine.

[1] Trans. Amer. Inst. Mech. Engrs., February, 1941.

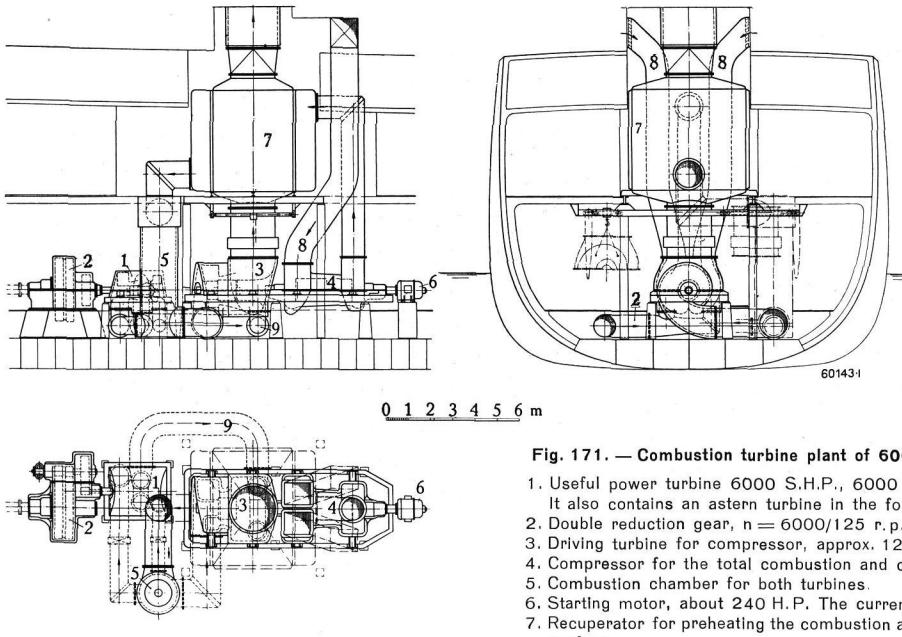


Fig. 171. — Combustion turbine plant of 6000 S.H.P. for a merchant vessel.

1. Useful power turbine 6000 S.H.P., 6000 r. p. m. It also contains an astern turbine in the form of an impulse wheel.
2. Double reduction gear, n = 6000/125 r. p. m. with propeller thrust bearing.
3. Driving turbine for compressor, approx. 12,000 H. P., n = 3000 r. p. m.
4. Compressor for the total combustion and cooling air of both turbines.
5. Combustion chamber for both turbines.
6. Starting motor, about 240 H. P. The current is supplied by a Diesel set.
7. Recuperator for preheating the combustion and cooling air, approx. 4000 m² heating surface.
8. Air suction pipe.
9. Exhaust gas pipe from useful power turbine.

Weight of both turbines including compressor and accessories	60 tons
Weight of gear and thrust block	45 tons
Weight of recuperator	50 tons
Total weight of machinery	155 tons
or 26 kg/S.H.P.	*Fuel consumption 250g/S.H.P.h.*

The combustion turbine is more favourable than the best steam plant both as regards weight and fuel consumption. It requires no cooling water, very little lubricating oil, and can be put into operation just as quickly as a Diesel engine.

The regulation of the plant is very simple. It influences the quantity of oil injected into the combustion chamber and furthermore actuates a two-way valve through which, according to the load, more or less driving gas is passed to the useful power or compressor turbine. This valve need never be fully closed, nor does it require to be a tight fit, so that it can be constructed as a very robust and insensitive element.

Thus when everything is taken into account a machine is available which as regards simplicity cannot be excelled and which up to the present, therefore, has proved to be extremely successful in all stationary plants. For travelling astern, it is necessary either to build a reversing stage (impulse wheel) into the useful power turbine or to employ a variable pitch propeller. The former element is simple and under much more difficult conditions has on innumerable occasions proved to be absolutely reliable in steam turbines. Also the second element, the variable pitch propeller is rapidly coming into general use. Up to the present such propellers have been constructed for powers up to 3500 H. P., some of these having to operate under very difficult conditions, for instance on ice-breakers, where they have proved very reliable.

We are prepared to build plants up to 10,000 S.H.P. with the usual guarantees as regards delivery time and oil consumption.

Fig. 171 shows a combustion turbine plant of 6000 S.H.P. for a merchant vessel. It comprises a useful power turbine which drives the propeller over a double-reduction gear, and a special turbine for driving the compressor. Both turbines receive their driving gases from a common combustion chamber. The recuperator is located above the machine plant and its exhaust gases can pass directly into the chimney.

D. MARINE AUXILIARIES.

Although our opportunities for supplying marine machinery are very restricted under present circumstances, during the past year we have nevertheless received a considerable number of orders for small turbines for driving ship's auxiliaries. Quite a number of the small turbine type depicted in Fig. 172 have been supplied by us for driving circulating pumps. We should like to emphasize particularly that our small turbines, due to their simple and robust design, are suitable even for the roughest operating conditions aboard ship and are therefore finding increasing application. Their simple attendance and easy operation can readily be undertaken by an untrained staff. The bearings are air-cooled and grease-lubricated, and the grease has generally only to be replenished about once a year.

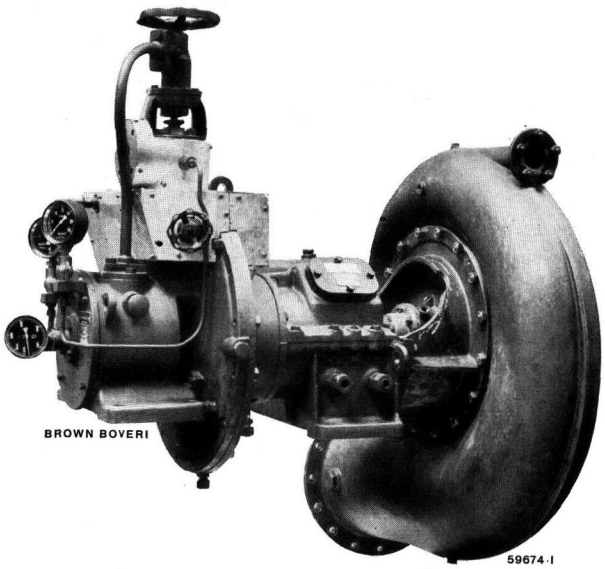


Fig. 172. — Small turbine for driving marine circulating pumps.

This small turbine has a rating of 25—60 H.P. It is of very robust construction, requires very little attendance and is easy to operate. Its roller-type bearings are grease-lubricated and air-cooled. The turbine is coupled over a gear with the machine which it has to drive and connected to it by means of flanges.

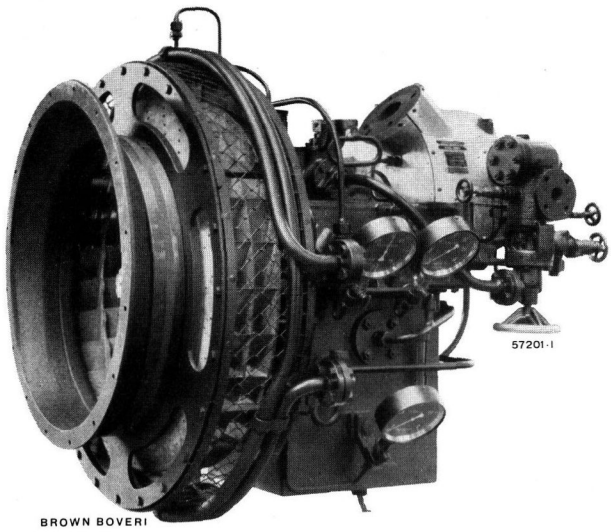


Fig. 173. — Boiler-room fan for torpedo-boats.

Delivery volume approx. 8 m³/s, driving power approx. 40 H.P. This arrangement with high-speed turbine and spur wheel gear results in a light and reliable set requiring very little space. The oil for the bearings and gear is cooled in a coil subjected to a cooling air stream. The hand-operated control valve also serves as a quick-acting stop valve.

Another constructional example is illustrated in Fig. 173.

We have again supplied complete electrical auxiliary equipments for a number of merchant ships. The splash-proof protection of our marine auxiliaries has been improved to such an extent that machines with this form of protection suffer practically no decrease in power when compared with those having drip-proof protection (Fig. 174). Our designs of electrical marine auxiliaries with drip-proof, splash-proof and hose-proof protection have been still further simplified. Motors with these forms of protection now only differ from each other in so far as the cover over the air ducts is constructed differently in accordance with the protection desired, whilst in all other respects the motors are identical. For some time now we are supplying both d. c. and a. c. machines for marine installations with aluminium windings; only the armatures of d. c. machines are still provided with copper windings. Special measures have been taken with the aluminium windings in order to protect the joints between the aluminium windings and the copper cable against the effects of the damp salt air which causes corrosion. The reliability of our construction was first tested very thoroughly, machines with aluminium windings at a standstill and in operation being placed continuously in a steam bath at 100° C and then left in a saline spray. Machines with aluminium windings supplied by us have therefore proved to be thoroughly reliable in marine service, so that the usual

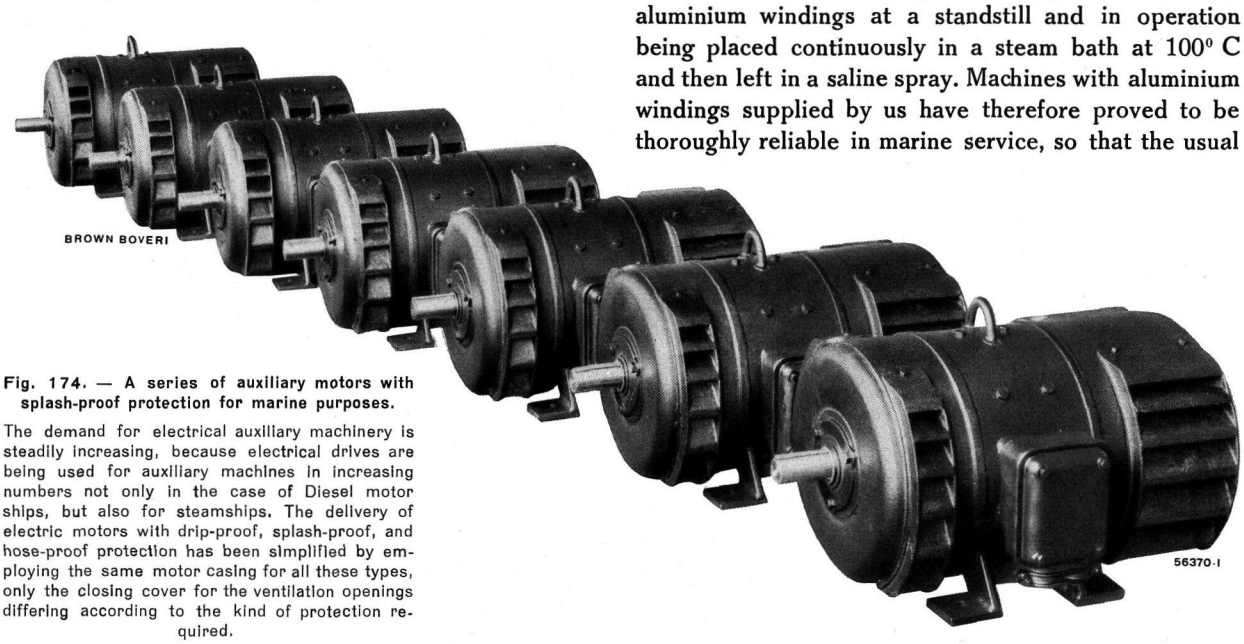


Fig. 174. — A series of auxiliary motors with splash-proof protection for marine purposes.

The demand for electrical auxiliary machinery is steadily increasing, because electrical drives are being used for auxiliary machines in increasing numbers not only in the case of Diesel motor ships, but also for steamships. The delivery of electric motors with drip-proof, splash-proof, and hose-proof protection has been simplified by employing the same motor casing for all these types, only the closing cover for the ventilation openings differing according to the kind of protection required.

objections to the use of aluminium for electrical machinery are absolutely unfounded.

During the past year we have again received a considerable number of orders for "Helux" equipments with automatic voltage and charging regulators. Our "Helux" sets for small powers are now also being used on river boats, because with our small regulator

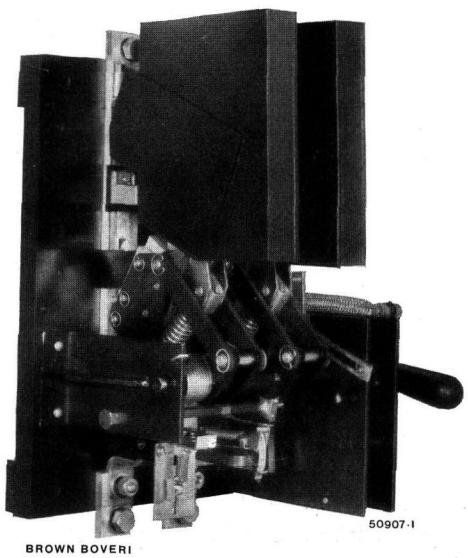


Fig. 175. — Automatic marine-type-circuit breaker for auxiliary power generators, direct current 250 A, 220 V.

Our new automatic circuit-breakers which are built for 100—2500 A, direct and alternating current, and a test voltage of 4000 V, have low weight and moderate space requirements. They are supplied according to requirements with thermal releases or excess-current time relays, reverse current and low-voltage release, and are either fitted with a hand-wheel or arranged for remote control.

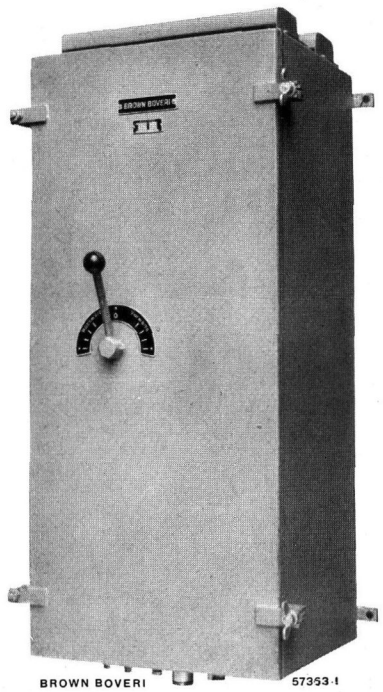


Fig. 176. — Marine-type reversing starter with series regulation for Diesel engine barring gear drives, splash-proof protection with double-pole network interruption, excess-current and low-voltage release, as well as four control positions for each direction of rotation.

The switching operations are performed by means of powerful switch elements operated by a cam shaft. The switch elements are provided with blow-out coils and sparking chambers and operate perfectly reliably with a minimum of contact wear even when operated very frequently.



Fig. 177. — View of the workshops where our d. c. marine starters for motors up to 70 H.P. are produced in series and kept in stock without resistance elements and coils, to enable them to be supplied at short notice.

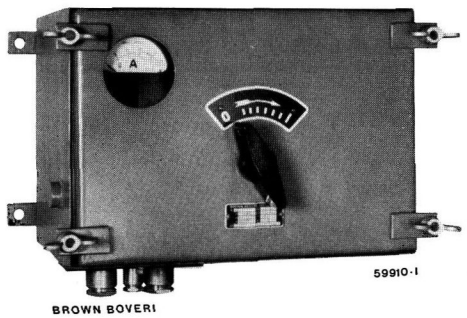


Fig. 178. — **Marine face-plate starter for small d. c. auxiliary drives up to 5 H.P.**

Compact design with excess-current and low-voltage release in a strong casing for bulkhead mounting.

the costs of the lighting plant are comparatively low. The battery is recharged automatically while the ship is under way, so that the lighting system does not require much attendance. Up to the end of 1943 we supplied up to a thousand automatic voltage regulators, current regulators, or automatic synchronizers for marine auxiliary power stations, this apparatus being in service on naval vessels of all types as well as on every size of merchant vessel, where it is operating to the clients' entire satisfaction.

Amongst apparatus we have supplied for marine installations is the new automatic circuit breaker for d. c. and a. c. generators built for current ratings of

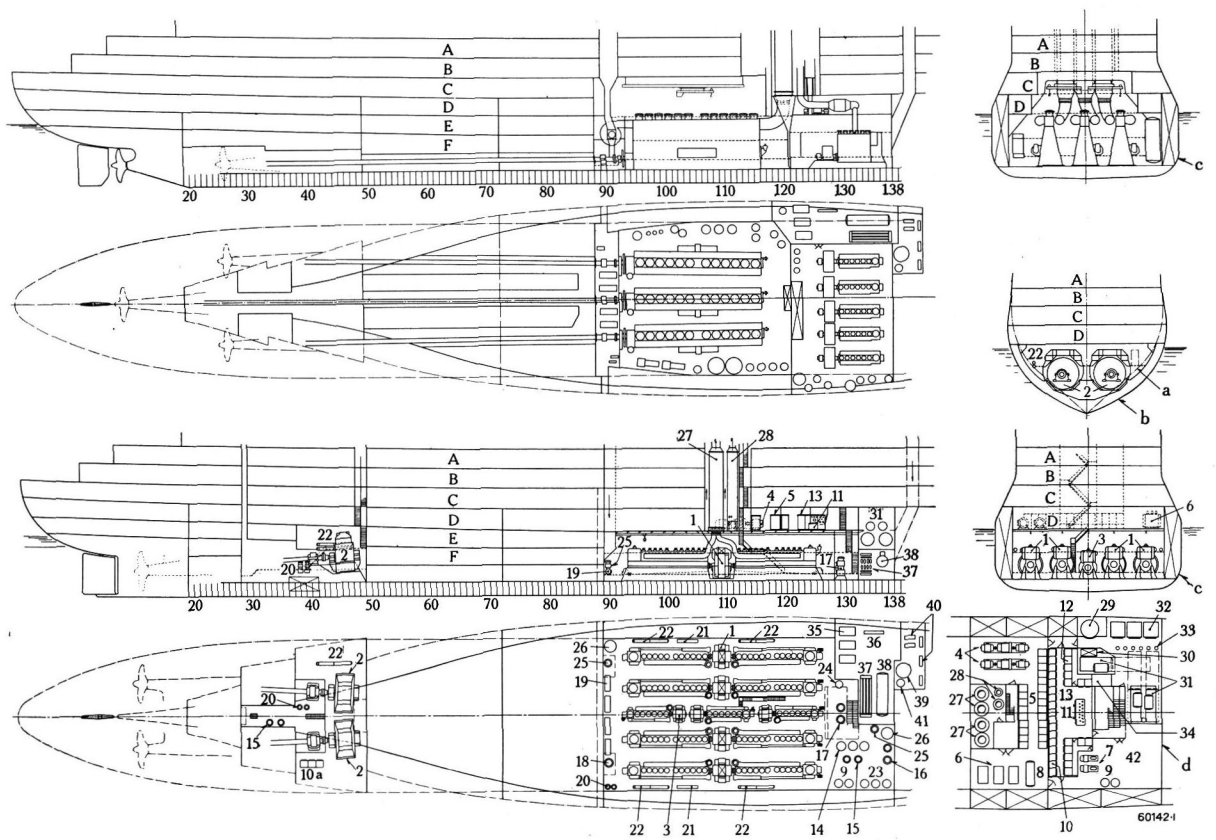


Fig. 179. — **The 3×12,500 SHP propelling plant of the motor passenger ship "Oranje" of the N. V. Stoomvaart Mij "Nederland" (above) compared with a Diesel-electric propelling plant of the same power (below).**

Normal Diesel engines with 320 r. p. m. and not special high-speed engines have been selected for driving the generators. Despite this the space required for the Diesel-electric drive is smaller than that required by the direct Diesel engine drive, valuable space amidships above the engine room being saved.

1. Main Diesel-generator sets.
2. Propulsion motors.
3. Harbour Diesel-generator sets.
4. Exciter sets.
5. High-voltage switchgear for main generators, propulsion motors, and transformers.
6. Transformers.
7. Compressors.
8. Compressed air tank for switchgear.
9. Starting-air tank for Diesel engines.
10. Switchgear for main generators, propulsion motors, exciters and transformers.
11. Control panel.
12. Switchgear for harbour Diesel-generators and low-voltage supply plant.
13. Control room.
14. Fresh water cooler for Diesel engines.
15. Sea water cooling pumps.
16. Reciprocating cooling pumps.
17. Fresh water cooling pumps.
18. Bilge pumps.
19. Lubricating pumps for main engines and generators.
20. Oil pumps.
21. Service oil pumps.
22. Oil coolers.
23. Sanitary pumps.
24. Ballast pumps.
25. Drain-water pumps.
26. Drain-water tank.
27. Waste-heat boiler.
28. Exhaust-gas and electric-boiler.
29. Steam separator.
30. Hot water tank.
31. Evaporator for drinking water.
32. Air-mixing tank for drinking water.
33. Norit filter.
34. Deaerating tank for drinking water.
35. Compressors for refrigerating plant.
36. Control panel for refrigerating plant.
37. Ammonia condenser.
38. Fresh water cooler for air-conditioning plant.
39. Cold water tank for air-conditioning plant.
40. Circulating pump.
41. Emergency bilge pump.
42. Space for workshop, auxiliary machinery, stores, etc.

a. Frame 37 b. Frame 49 c. Frame 100 d. Deck D

100—2500 A. These new circuit breakers, although they possess the same technical properties as the former design, are considerably more favourable as regards weight, price, and space requirements (Fig. 175). We have also received a considerable number of orders for our newly developed marine-type starters for d. c. motors, including a number of orders for reversing starters with series regulation for Diesel engine barring-gear drives, these starters being of a similar design to the cam-operated starters mentioned in our last report (Fig. 176). These d. c. starters are now kept in stock for motors up to 70 H.P. without resistance elements and coils, so that they can be supplied at short notice (Fig. 177). We have developed a new marine-type face-plate starter for d. c. drives up to 5 H.P., this starter being of a very compact design and combining the starting elements with over-current and low-voltage release, isolating switch, and ammeter in a single casing for mounting on the bulkhead (Fig. 178). We are, therefore, able to supply marine-type starters for all sizes of d. c. motors used on ships.

E. ELECTRICAL MARINE DRIVES.

The particulars given in numbers 9/10 of the Brown Boveri Review for 1942, concerning the Diesel-electric drive have aroused great interest in shipowners' circles, and have resulted in a number of interesting projects for marine drives which are to be realized after the war. These projects show that the Diesel-electric three-phase a. c. drive with the high-speed Diesel engines now available, results in very favourable conditions as regards weight and space requirements, and that particularly as regards special requirements in connection with main and auxiliary power systems it is more adaptable than any other kind of drive. In the periodical "Motorship", June, 1943, page 70, it is proposed that after the war the "Liberty" ships which are fitted with reciprocating engines and of which there will presumably be several hundred available at the end of the war, should be converted into vessels with a speed of 14—16 knots by means of geared Diesel engine or Diesel-electric drives, because their present maximum speed of 11 knots will no longer be adequate for post-war conditions. Our investigations have shown that such a conversion with a Diesel-electric a. c. plant comprising a propulsion motor and five Diesel-generator sets running at 375 r. p. m. and built for a ship's speed of 15 knots is quite possible; the existing engine room of the ship is not even fully required for this conversion, so that additional cargo space becomes available. Fig. 179 shows a comparison between a direct Diesel drive and an a. c. Diesel-electric drive for a large passenger ship. In this case it is possible to improve the propulsion efficiency of the plant by selecting a twin-screw drive instead of a triple-screw drive, because with electrical drives the power per shaft is not restricted in any way. The illustration shows that the space required for an electrical drive is considerably less than that for a direct drive, and that due to the much smaller overall height of the Diesel-generator sets when compared with the slow-speed Diesel engines much valuable space amidships can be saved for passenger cabins. Since the total propelling power only determines the number but not the power of the parallel connected Diesel-electric generator sets, motor-ships with a. c. Diesel-electric drives can be built for powers hitherto only obtainable with geared turbine or turbo-electric drives.

K. Sachs. W. G. Noack.
(E.G.W., D.S., Op.)

Published by BROWN, BOVERI & COMPANY, LIMITED, BADEN (Switzerland). Printed by Effingerhof A.G., Brugg, Switzerland.
Obtainable through A. Francke A.G., Berne and Rouge & Cie., Lausanne (Switzerland).