KRAFTWERK RYBURG-SCHWÖRSTADT A. G., RHEINFELDEN.
Three-phase four-winding transformer of 32,500 kVA, with separately mounted, specially cooled radiator battery.

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PROGRESS IN BROWN BOVERI DESIGN DURING 1930.

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STEAM TURBINES - GENERATORS - CONVERTERS
MERCURY-ARC POWER RECTIFIERS
ELECTRIC LOCOMOTIVES - RAILWAY MATERIAL
WINDING ENGINES AND WINCHES
ELECTRIC FURNACES
ELECTRICAL DRIVES FOR INDUSTRIAL PLANTS
ELECTRICAL DRIVES FOR AGRICULTURAL PURPOSES AND SMALL INDUSTRIES
ELECTRICAL EQUIPMENT FOR TRANSPORTING PLANTS AND CRANES
* TURBO-COMPRESSORS AND TURBO-BLOWERS
SHIP'S MACHINERY AND AUXILIARIES
ETC., ETC.
I. ELECTRICAL MACHINERY AND APPARATUS.

(1) Synchronous machines.

The tendency to increase the outputs of machines has led to very keen competition, particularly in the construction of two-pole turbo-generators where it is very essential to decrease the floor space occupied and to improve the steam consumption figures of the turbine. The progress made in metallurgy during the post-war period rendered it possible to produce cylindrical rotors as one-piece drop forgings with the large radial and longitudinal dimensions required for outputs up to about 40,000 kVA, though only after extended tests on the part of the manufacturers which led to delivery times being considerably exceeded. In the case of rotors for machines of over 40,000 kVA, however, great difficulties were encountered which induced experienced firms to move with caution for some time. Instead of proceeding along lines which, based purely upon supposition, are indicated in technical literature as the only ones offering ultimate success, we have elected to conduct fundamental tests and investigations on our own. For example, the primitive method of inspecting the bore of the rotor by means of mirrors was supplemented by taking numerous test specimens from the interior of the forging, some from points close to the circumference of the bore. By means of laboratory tests it was then possible to determine accurately the variations in the structure, which left much to be desired at points near the centre. As a result of long and methodical investigations, and after overcoming the greatest difficulties, metallurgists have succeeded during the past year in producing forgings which fully satisfy the most exacting requirements. The latest forgings are completely uniform, and the high ultimate strength obtained by suitable heat treatment persists without any appreciable variation throughout the whole piece. Internal stresses, which are incorrectly attributed to the heat-treatment process, are only present to such a small extent that they are below the limits of accuracy of measurement.

It will therefore be seen that from the metallurgical point of view it is now possible to make one-piece forgings of about 1100 mm diameter and a length of about five metres, these being the dimensions of a rotor for an alternator of about 100,000 kVA at 3000 r.p.m. Due to the uniformity and homogeneity of rotors as made at the present time, the use of aluminium for the windings would now be much more justified than previously. The chief advantage
of aluminium conductors is that they reduce the specific pressure, though according to our experience this can still be satisfactorily overcome even with copper windings at circumferential speeds up to about 150 metres/sec. The use of copper enables the depth of the coils and therefore of the slots to be kept appreciably smaller. This was a particularly important point where it was not possible to obtain forgings of reliable homogeneity, and where it was therefore necessary to keep the bore as large as possible in order to avoid impurities, and not to cut too deep into the external, well-forged zones and thus penetrate into material of inferior quality. In addition, expansion due to heat—which is very much to be feared in long rotors—is 50% greater for aluminium than for copper.

A number of large turbo-alternators between 30,000 and 50,000 kVA were again ordered from us during the past year. A machine of special interest is the second generator of 45,000 kVA, 12,000 V, 50 cycles, ordered for the Geertruidenberg Power Station of the N.V. Provinciale Noordbrabantsche Electriciteits-Maatschappij, s'Hertogenbosch, of exactly the same design as the one ordered in 1928 \(^1\); also a generator for 48,000 kVA, 3000 r. p. m., 5350 V, 50 cycles, for the Karoline Pit of the Witkowitzer Steinkohlengruben. The three-cylinder high-pressure turbine for the latter generator is described in another part of this number.

\(^1\) See the Brown Boveri Review 1929, No. 1, page 3.

The turbo-generator for a terminal pressure of 36,000 V, described in our last report, was finished during the past year. Fig. 1 shows the stator of this machine with covers removed.

In this machine an insulation of special composition, \(^2\) i. e., with new proportions of mica, paper and varnish, was used for the conductors. Fig. 1a shows the relationship between the unit loss \(p\) per


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Fig. 1a. — Variation of the dielectric losses according to the voltage in the 36,000-V turbo-alternator shown in Fig. 1.

1. Machine cold.

Fig. 1b. — Variation of the dielectric losses \(p\) according to the temperature in the 36,000-V turbo-alternator shown in Fig. 1 (curve 1), compared with a porcelain insulator (curve 2).
of insulation reduced to a field strength of 10 kV/cm and the voltage measured at the machine when warm and cold. Not only are the losses extremely small—considerably smaller, in fact, than in the case of the micafoarium insulation of usual composition—but the percentage difference between the losses measured on the machine when warm and cold is also small, and the increase in the losses caused by ionization is only noticeable to any appreciable extent above the rated voltage (36,000 V / \sqrt{3} = 20,800 V). The high quality of the new kind of insulation is illustrated still more clearly by Fig. 1b in which the unit loss mentioned above is plotted against the temperature. Compared with a bushing insulator of porcelain—up to the present the most homogeneous insulating material used in practice—the dependence of the dielectric losses on the temperature is less than half as great.

Of the generators ordered from us during the past year for coupling to water turbines, the following should be mentioned:

Two vertical-shaft three-phase alternators each of 23,000 kVA, 750 r. p. m., 8200 V, 50 cycles, for Monte Piottino Power Station of the Officine Elettriche Ticinesi. The rotors of these machines are already made as cylindrical drums like those of turbo-alternators.

Two horizontal-shaft three-phase alternators each of 33,300 kVA, 420/500 r. p. m., 8400—7600 V, 42/50 cycles, for Mese Power Station of the Soc. Elettrica Interregionale Cisalpina of the same design though for a 10% higher output than the machines supplied in 1926.

One vertical-shaft three-phase alternator of 35,000 kVA, 337 r. p. m., 8300—10,000 V, 45 cycles, for Galleto Power Station of the Terni, Soc. per l'Industria e l'Elettricità of the same design as the three machines already supplied.

In this connection a three-phase flywheel alternator of 10,800 kVA, 150 r. p. m., 8400 V, 50 cycles, for coupling to a Sulzer Diesel engine should also be mentioned. This machine was ordered by the Entreprises Electriques Fribourgoises, Fribourg (Switzerland), and is one of the largest Diesel-driven generators ever built.

Of the four vertical-shaft alternators of 32,500 kVA, 75 r. p. m., for Ryburg-Schwörstadt Power Station, mentioned in our last report, two machines (one made in our works in Baden and one by Brown, Boveri & Cie. A.-G., Mannheim-Käfertal) were finished, erected in the power station and put into service during the autumn of last year. Figs. 2 and 3 show some interesting views of these generators in the workshops and Fig. 4 the erection of the second generator in the power station.

The task of statically and dynamically balancing the pole wheels of these machines (which have a diameter of about 9-4 m and a weight including the shaft of 250 tons) in the shops was very difficult, as also was the overspeed test at 2-5 times the rated speed, i.e., at 185 r. p. m. The driving power for the dynamic balancing and for the overspeed test was obtained from a direct-current double armature motor fed on the Ward Leonard system by a converter set which, in addition to enabling fine speed regulation to be obtained, enabled electric braking with recuperation of the energy to be used. The speed was measured by a separately excited tachometer dynamo and a specially calibrated direct-current instrument. In order to reduce the heavy windage losses during the overspeed test, the pole wheel was enclosed in a wooden casing with iron reinforcements. (In Fig. 5 the casing has not yet been fitted at the front.)

(2) Induction machines.

In this connection we will first of all briefly mention the improvements made to our centrifugal starters for large motors, as already described in a previous number of this review.

It might be emphasized here that motors fitted with our centrifugal starters of patented design have found a very wide field of application in comparatively few years due to their excellent features. The interest in this type of motor appears even to-day to show no sign of diminishing, even though the out-of-date regulations which limited the use of the squirrel-cage motor have, in many cases, been withdrawn or severely modified.

These alterations in the regulations have been taken into consideration, as far as the small motors generally used in industry and agriculture are concerned, by using squirrel-cage rotors with an increased number of slots and conductors (multi-slot motors). As regards limitation of the starting current, such motors combined with star-delta switches are equal to the large number of double squirrel-cage motors at present on the market. In fact, due to

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1. See the Brown Boveri Review 1926, page 5, Fig. 3.
the smaller leakage they are superior to these both as regards the variation of the torque during the starting process and the power factor. Double squirrel-cage motors, or in general, motors whose action during starting depends on the skin effect in the rotor conductors through which current at approximately the mains frequency is flowing, should, in our opinion, be reserved for medium and large outputs. Wherever the starting torque must not be greater than approx-

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Fig. 2. — Machining half the pole wheel of the 32,500-kVA alternator for Ryburg-Schwörstadt Power Station.

Fig. 3. — Erecting the unwound stator of the 32,500-kVA alternator for Ryburg-Schwörstadt Power Station.

Fig. 4. — Erecting the second 32,500-kVA alternator in Ryburg-Schwörstadt Power Station.

Fig. 5. — 32,500-kVA alternator for Ryburg-Schwörstadt Power Station. Mounting the pole wheel for balancing.
imately half the normal torque, motors with deep-slot rotors, generally for coupling direct to the mains, should be used, and for higher starting torques double squirrel-cage rotors with star-delta starting. Figs. 6, 7 and 8 show the variations of the torque and the current consumption for these three types of motors.

A noteworthy improvement was introduced on our induction regulator control for automatic voltage regulation, a control relay (Fig. 9) being now used instead of the previous type of quick-acting regulator with resistances and contact sectors. As far as its external appearance and motive system are concerned, this control relay is exactly the same as our well-tried type of quick-acting regulator for alternating current. Instead of resistances which are switched-in or short-circuited one after the other by the sectors rolling over the contacts, the relay has two closing contacts of which only one can be closed at any time when the motive system moves in a certain direction out of the position of equilibrium. The fixed contact studs are fitted with permanent magnets and thus the contacts operate with a strong snap action. With the connections most usually employed for induction regulators, the control relay serves as a very sensitive contact voltmeter with double action; its contacts can carry an ample load and it can be readily adjusted so that the contact in question closes as soon as the voltage varies by 1% or more from the prescribed value. Two two-pole contactors for opening and closing the motor circuit are connected to the two closing contacts.

Fig. 6. — Motor with multi-slot rotor. Variation of the torque (D) and the current (S) while starting.

Fig. 7. — Motor with deep slot rotor. Variation of the torque (D) and current (S) while starting.

Fig. 8. — Double squirrel-cage motor. Variation of the torque (D) and current (S) while starting.

During the past year a number of large three-phase motors for driving rolling mills and pumps were supplied or put under construction, some in combination with phase advance or auxiliary commutator motors for speed regulation. For example, a motor of 1500 H. P., 428 r. p. m., 3000 V, 50 cycles, with phase advancement for 15% additional slip at full load, driven through gearing from the main motor, was ordered by the Forges de Gueignon for driving a sheet rolling mill. Further, an order was placed by Felten & Guilleaume, Carlswerk A. G., for a pipe-ventilated motor of 2800 H. P., 600 r. p. m., 5200 V, 50 cycles, for driving a wire mill. The motor is provided with a regulating set for sub-synchronous regulation between 600 and 460 r. p.m. with a constant output. The speed-regulating set consists of two three-phase commutator machines driven by an asynchronous motor of 1090 H. P., 1000 r. p. m., 5200 V, 50 cycles. Another interesting motor is one of 550 H. P., 428 r. p. m., 5600 V, 50 cycles, installed in the Argenteuil Works of the Soc. Electro-Câble for driving a wire mill. The same company ordered, for a rolling mill in Belgium, a motor of 750/375 H. P., 428/214 r. p. m., 5500 V, 50 cycles, with poles variable in the...
ratio of 2:1. This motor will serve as a stand-by to one which was supplied in 1929.

The continually increasing extent to which large networks are being interconnected has caused great interest to be shown for some time in the problem of flexibly coupling networks, i.e., of enabling power to be interchanged at will in either direction between two independent networks. As already described in previous issues of this review, we have followed this development by building a special converter set, comprising essentially an asynchronous and a synchronous machine, connected to the networks to be coupled. The rotor of the asynchronous machine is connected to a special Brown Boveri Scherbius commutator machine mounted on the same shaft. This latter machine is excited from the slip rings of the asynchronous machine and also by a special three-phase exciter of a frequency changer mounted on the shaft of the converter set; the slip rings of the frequency changer are connected to the same network as the asynchronous machine. Thus in addition to a voltage proportional to and opposing the slip voltage, a voltage which can be adjusted at will is also introduced into the rotor circuit of the asynchronous machine. The magnitude and direction of the excitation voltage supplied by the frequency changer can be varied either by controlling the applied voltage by means of an induction regulator or else by shifting the commutator brushes of the frequency converter, this being supplied with a constant voltage. If the excitation voltage supplied by the frequency converter is kept constant, then the power flowing through the set is constant. If this voltage is varied according to the frequency of one network or the other, then the magnitude of the power transmitted through the coupling alters proportionally. By adjusting the direction of the voltage supplied by the frequency changer, the asynchronous machine can be made to run either as a motor or a generator. The direction of flow of power from one network to the other can be varied at will. The converter set can therefore supply a constant power adjustable between any desired limits in both directions independently of the frequency of the two networks coupled.

During the past year, three large converter sets of this type were put into operation. One of these,
installed in Mezzocorona Power Station of the Società Generale Elettrica Tridentina is particularly worthy of note. It will be used for coupling the 16⅔/2-cycle three-phase railway network supplying the Bozen-Brenner section of the Italian State Railways with the 42-cycle three-phase industrial network of the company mentioned. Fig. 10 shows the complete set, with a rating of 9200 kVA, and Fig. 11 the Scherbius machine into the rear end shield of which the frequency changer is built. The regulating set for this converter is illustrated in Fig. 12. The voltage on the primary side of the frequency changer is adjusted by means of a double induction regulator (or two single regulators coupled together), operated by a turbine governor. If the power must be regulated according to the frequency of one of the two networks, the governor is controlled by a pendulum dependent on the frequency. If the power must be regulated to a constant value adjustable at will in magnitude and direction, a power regulator is used. The horizontal turbine governor is driven by a synchronous induction motor connected to that network according to whose frequency the power must be adjusted.

The mode of operation of the set is shown most clearly by Figs. 13a to 13d and Figs. 14a to 14c. The set has now been in service for some time and is running very satisfactorily, after overcoming the original difficulties due to the novelty of the conditions to be fulfilled and the fact that the plant comprises so many machines. Figs. 13a to 13d show the readings of the recording instruments, first when the set is operating as a buffer plant, regulated to constant frequency of the synchronous machine connected to the railway network. Figs. 13a and 13b show the heavy variations in the voltage and frequency of the industrial network, while the frequency of the railway network (Fig. 13c), in spite of the naturally heavy load fluctuations (Fig. 13d), is only subject to very small variations. When the industrial network is fed from the railway network and is regulated to constant power, Figs. 14a to 14c show the frequency variations of both networks, and finally the power of the industrial network.

Fig. 15 illustrates a second frequency changer set, put into service during the past year, for coupling two networks of 50 and 42-5 cycles respectively. The voltage of the frequency changer visible on the extreme left is regulated by brush displacement, the brush gear being controlled by a regulating set of similar design to that shown in Fig. 12, though naturally the two induction regulators are not required.

The excellent results obtained in service with the network coupling sets described led to four other sets of this description being ordered during the past year. Three sets will be installed in Pontremoli Power Station of the Acciaierie e Ferriere Lombarde for flexibly coupling the low-frequency three-phase railway network of the Apennine section from Sarzana and Spezia to Parma and Fidenza (the electrification of which is now in progress) with the three-phase industrial network of the steel-works mentioned. Each of the three sets comprises a four-pole synchronous machine of 7500 kVA at a power factor of 0-67, 462—513 r. p. m., 3600—4000 V, 15-4—17-1 cycles, coupled to the railway network; an asynchronous machine (with poles variable from 10 to 12) of 5500 kVA at unity power factor, 462—513 r. p. m., 6000—6600 V, 47-2—51-7 cycles, or 39-6—43-4 cycles; and the regulating equipment which consists of the direct coupled commutator machine with frequency changers used for running the asynchronous machine on either 50 or 42 cycles. Further, there is a separate exciter set with two three-phase exciters and common asynchronous driving motor together with the requisite regulating equipment, double induction regulator, power regulator and power factor regulator.

It is required that the set should transmit a constant power, adjusted as desired between no-load and full-load, in both directions independently of frequency variations in either network; a power in both directions according to the frequency variations in the railway network; a power in one direction or the other according to the deviation of the frequency ratio from a given adjustable value; and finally that it should be possible to adjust the power factor of the asynchronous machine to unity when running as a motor or generator.

The asynchronous machine is also required to run separately as a generator, when it will be excited with direct current from the commutator machine. Another interesting set for network coupling which was ordered during the past year will be installed in Seebach Substation of the Swiss Federal Railways. This substation is intended as a power reserve, and by coupling the single-phase 16⅔/2-cyle network of the Swiss Federal Railways with the 50-cycle industrial network of the Nordostschweizerische Kraftwerke, will be able to supply the load peaks which occur in the former network in and around Zurich. The set will comprise a four-pole synchronous machine coupled to the single-phase network, and at twelve-pole asynchronous machine fed...
Fig. 13a—d. — Soc. Generale Elettrica Tridentina, Milan. Mezzocorona Power Station. Readings of the recording instruments when working as a buffer plant and when regulating to constant frequency of the railway network.

13a. Voltage of industrial network.

13b. Frequency of industrial network.

13c. Frequency of railway network.

13d. Output of railway network.
Fig. 14a—c. — Soc. Generale Elettrica Tridentina, Milan. Mezzocorona Power Station. Readings of the recording instruments when regulating to constant output in the industrial network.

14a. Frequency of railway network.

14b. Frequency of industrial network.

14c. Power of industrial network.
from the industrial network. When running as a generator, the former will supply 8600 kVA at a power factor of 0.7; as a motor it will develop 6700 kW at unity power factor; and as a phase advance with zero power factor will supply 7200 kVA over-excited and 4000 kVA under-excited. The second machine when running as a generator will supply 8600 kVA at a power factor of 0.7; as a motor it will develop 6700 kW at unity power factor, and as a phase advance when running either over or under-excited will supply 7000 kVA at zero power factor. Direct coupled to

the main set is a three-phase commutator machine and a frequency changer, and on the side of the synchronous machine the corresponding exciter. The plant to be supplied also includes a separate exciter set comprising two three-phase exciters and common driving motor and also the requisite regulating equipment, double induction regulator, power and power factor regulators. The chief requirement is that a constant power shall be transmitted. In addition, the power of the set must be regulated according to the frequency variations in the railway network. Furthermore, it must be possible for the synchronous and asynchronous machines to work alone as phase advancers.

(3) Direct-current machines.

An order has been placed with us by the S. A. Standard Elettrica Italiana, Milan, for seven combined excitation and high-tension units for wireless transmitting stations. Each unit consists of an exciter set (comprising three machines) and of a high-tension set, also comprising three machines. The high-tension set includes the generator for pressures from 0 to 1600 V (rating 5.6 kW) and a generator for pressures from 0 to 2400 V (rating 7.2 kW). The generators can be used separately or can supply a combined pressure up to 4000 V.

As regards heavy-current machinery, a direct-current generator for
with the separately excited direct-current generators it forms a three-bearing set.

Fig. 17 shows the heavy-current primary machine for the Ackersand Power Station of the Lonza Elektrizitätswerke und Chemische Fabriken A.-G., which we mentioned in our last report. This machine, of 2750 kW, 500 r.p.m., 5500 A, 500 V, was put into service during the past year.

A number of direct-current machines driving motor is coupled to a 5100-V three-phase supply and is designed as a synchronous induction motor with stator which can be removed axially; together

of special design have again been supplied to some foreign navies. Fig. 18, for example, shows a double-armature propulsion motor for a submarine; it has a one-hour rating of 500 H.P. at 310 r. p. m. and a terminal pressure of 210 V.

Fig. 20. — Double-armature direct-current generator of $2 \times 350$ kW, 250 V, 500 r. p. m., with auxiliary machine of 100 kW, 220 V, 500 r. p. m., for an electrically driven coastal defence boat.

Fig. 21. — Double-armature propeller motor of $2 \times 250$ H.P., $2 \times 250$ V, 100 r. p. m., for an electrically driven coastal defence boat.
During the past year, the electric equipment was delivered for two electrically-driven coastal defence boats. In each vessel there are four Diesel-driven generator sets comprising a six-cylinder four-stroke Diesel engine coupled, in the case of two sets (Fig. 19), to a single-armature direct-current generator of 700 kW, 250 V, 500 r. p. m., and an auxiliary machine of 100 kW, 220 V, 500 r. p. m. In the two other sets (Fig. 20) each Diesel engine is coupled to a double-armature direct-current generator of 2×350 kW, 250 V, 500 r. p. m. and an auxiliary machine of the same size. All the four Diesel-driven sets supply, on the Ward Leonard system, two double-armature propulsion motors (Fig. 21) of 2×850 = 1700 H.P. per shaft, 2×250 = 500 V, 180 r. p. m., with rotating stator frames and closed-circuit cooling.

The Ward Leonard controller is operated by the same kind of electro-pneumatic control apparatus as that which we have developed for locomotives. The reversing tests under full load carried out in our workshops showed the superiority of electrical propulsion for ships as regards manœuvrability. It was possible to reverse the propeller motors from full speed ahead to full speed astern in 10.5 seconds.

(4) Industrial drives.

First of all the development of drives with push-button control for cloth-printing machines and mercerizing machines should be mentioned. These render the control of the machines very simple. Direct-current driving motors with Ward Leonard control are used which enable the speed of the motor to be suitably adjusted for all working
started, stopped and regulated for purposes of inspection, or if they are required to run alone, in a simple, convenient, and reliable manner. The push-buttons are arranged in a completely water-tight cast-iron box and are always mounted on the frame of the machine to which they belong so that the result of operating the push-buttons can be clearly observed. By using a time-lag switch with switch drum for closing the contactors and the auxiliary circuit, the driving sets are always started up at the correct time. The switch is set for a given starting time according to Fig. 25.—Sectional motor drive of a newsprint making machine, 4-15 m wide across the wire with a maximum paper-making speed of 350 m/min.

speeds and accurately maintained. A small switch cubicle contains all the apparatus, namely, contactors, field regulator and remote control. Fig. 22 illustrates two cloth-printing machine drives with push-button control, Fig. 23 the appropriate switch cubicle, and Fig. 24 the drive of a mercerizing machine.

Our sectional motor drives for paper-making machines, which we described in our last report, have also been considerably improved by incorporating push-button and contactor control. This enables the separate driving sets to be

The draw control for each part of the machine can also be combined with the push-button control; the belt running on the conical pulleys is then moved by a remote controlled auxiliary motor.

On high-speed newsprint machines — similar to that shown in Fig. 25 with a width of 4-15 m over the wire and a maximum paper-making speed of 350 m/min — the equipment just mentioned can be used to particular advantage as it enables the attendants to give their full attention to the machine itself, thus improving and increasing production.

Fig. 26 illustrates one half of the switchboard for a sectional motor drive with contactor control. All the apparatus is readily accessible and no difficulty

Fig. 25.—Sectional motor drive of a newsprint making machine, 4-15 m wide across the wire with a maximum paper-making speed of 350 m/min.

Fig. 26.—Switchboard for the sectional drive of a paper-making machine with contactor control.

Fig. 27.—1920-kW three-phase motor driving two wood grinders with a continuous supply of wood.
Fig. 29. — Six-fold rotary newspaper printing machine driven by six three-phase commutator motors each of 90 H.P.

is encountered in supervising it (particularly the contactors) and maintaining it in correct working order. In the upper part of the switchboard are arranged the measuring instruments and the electrical draw control devices, mentioned in our last report, for each driving set. These draw control devices have been perfected during the past year and successfully introduced into practice. Many drives of this type with contactor control have been supplied, and all are proving extremely satisfactory.

Fig. 30. — One of the 90-H.P. three-phase commutator motors for the rotary printing machine shown in Fig. 29.

A large number of motors of drip-proof and splash-proof patterns have been supplied for driving wood grinders, and according to modern practice have welded frames. Fig. 27 shows a drive of this description with a 1920-kW three-phase motor for two grinders with a continuous supply of wood.

In co-operation with Messrs. Voith of Heidenheim, we have developed and applied for a patent for a new grinder regulation which regulates the power consumption of each separate press to a constant value, thus producing more uniform pulp. The arrangement avoids the disadvantage of the previous system of regulating electrically driven grinders, with which, when filling one press, the other presses were more heavily loaded because the regulation was effected...
requirements placed on the drive and its control, have increased very considerably. In this connection a series of very important improvements have been introduced. Fig. 28 illustrates a calender drive with booster regulation.

Our highly successful drives for rotary newspaper printing machines with a.-c. commutator motors and full automatic control have been applied to some very large machines. For example, a drive for a six-fold rotary machine was supplied to the "Frankfurter Generalanzeiger". The equipment comprises six three-phase commutator motors of 90 H.P. each, the brush yokes of which are driven by small motors controlled by means of push-buttons. Fig. 29 shows the complete rotary machine from the operator's side, and Fig. 30 one of the 90-H.P. motors.

Fig. 31. — Centralized control desk for the motors of the rotary kiln plant in a cement works.

according to the total power consumption of the grinder motor.

The drives for the calenders used for ironing the paper have kept pace with the developments in the drives for paper-making machines. The power of the driving motors used, and also the

Our drives for cement works have been further improved.

It has been found expedient to control the motors of rotary kiln plants from the burner's platform so that all the machines necessary for the operation of the kiln can be controlled from this one point. A centralized control desk of this description is shown in Fig. 31.

The feeding mechanisms are driven by variable-speed d.-c. motors controlled

Fig. 32. — Automatic sack filling plant in a cement works.

Fig. 33. — Motor room with six three-phase slip-ring motors of 850 H. P., 146 r. p. m. each, with phase advanceers, for driving tube mills in a cement works.
By operating one of the push-buttons, the controller is moved compulsorily to the required position and the movement signalled to the control post by means of a lamp. False manoeuvres are thus out of the question.

The equipment for automatic sack filling plants (Fig. 32) is an interesting development. The cement is carried to the sack filling machine by a bucket conveyor fed from the silos by means of worm conveyors. The quantity of cement to be delivered depends on the number of valves of the filling machine in use and results in a larger or smaller load on the bucket conveyor motor.

The direct-current motors driving the worm conveyors are connected to a Ward Leonard dynamo, the voltage of which is automatically regulated according to the current consumption of the bucket conveyor motor, i.e., according to the amount of cement being conveyed. This not only simplifies the operation very considerably but eliminates disturbances caused by putting too much cement into the sack filling machine.

Fig. 33 illustrates six tube mill drives for the new plant of the S. A. des Ciments Portland de Lorraine, Heming (France). The motors, of 850 H.P. each at 146 r. p. m., are installed in a room separate from the mill house, and each is provided with a phase advancer by means of which about 400 kVA of wattless...
power are saved per motor. The current consumption was reduced in this manner to such an extent that in spite of the considerable enlargement of the plant, the existing works power station was still able to meet all requirements.

Our single-phase commutator motors combined with the regenerative lowering brake control which we have developed, are being used to a continually increasing extent for large cranes (see Figs. 34, 35 and 36).

Tests in actual installations have shown that with the single-phase commutator motor a lower power consumption is obtained than with any other system of regulation for hoisting appliances. These motors also develop an appreciably higher torque and thus enable the load to be accelerated in the minimum time.

In brief, these advantages enable a higher discharging capacity with a minimum power consumption to be obtained, ensure that the whole mechanical equipment is subjected to as little wear as possible, and therefore that the useful life of the whole crane is prolonged.

The following are some interesting plants for which we have recently supplied the electrical equipment:

Four loading bridges for Dordrecht Harbour, each with a hoisting motor of 60 H.P.
Two swivel cranes for Dordrecht Harbour, each with a hoisting motor of 60 H.P.
Twelve swivel cranes for Amsterdam, each with a hoisting motor of 60 H.P.
Four loading bridges and two gantry cranes for Helsingfors (Finland), each with a hoisting motor of about 100 H.P.
Four packed-goods cranes for the harbour at Ghent, each with a hoisting motor of 65 H.P.
One loading bridge for the Steenkolen Handelsvereeniging S. H. V., Rotterdam, with a lifting power of 150 H.P. (Fig. 34).

The objections originally raised against connecting single-phase commutator motors to three-phase mains have proved to be entirely groundless. In no instance has the three-phase network been found to be unfavourably loaded, whether merely one crane has been connected or several large loading bridges.

(5) Transformers.

During the past year orders were again placed with us for a number of interesting power transformers as, for example:

Three three-phase three-winding regulating transformers for Winkeln Substation of the Nordostschweizerische Kraftwerke. These transformers are for outdoor erection and have radiators with compressed-air nozzle cooling. Each is designed for an output of 25,000/25,000/7500 kVA, 150,000/54,000 ± 3 X 1500/8000 V, 50 cycles.

Four single-phase transformers each of 29,000 kVA for Marèges Substation of the Paris-Orléans Railway. These transformers have compressed-air nozzle cooling of the radiators and are for a three-phase set of 60,000 kVA (with one reserve transformer), 90,000/220,000 V or 220,000/90,000 V, 50 cycles, with insulated neutral point.

One three-phase outdoor transformer, with external water cooling, for 35,000 kVA, 105,000/5750—4750 V which can be changed over by a switch mounted outside the cover to 11,500/9500 V, and with a 30% tertiary winding, 50 cycles. This was ordered for Hattingen Power Station of the Vereinigte Elektrizitätswerke Westfalen, Dortmund.

Two three-phase three-winding transformers, each of 32,000/32,000/6000 kVA, 10,000/115,000/16,000 V, 50 cycles, for Häusern Power Station of the Schluesselwerk A. G.

Two three-phase transformers with external water cooling each of 33,000 kVA, 8400—7600/130,000—145,000 V, 42/50 cycles, for Mese Power Station of the Soc. Elettrica Interregionale Cisalpina.

One three-phase outdoor transformer with compressed-air nozzle cooling for 46,000 kVA, 8200/145,000 ± 5% V, 50 cycles, for Monte Piottino Power Station of the Officine Elettriche Ticinesi. The delta-connected low-tension winding is split into
two similar parts so that either two generators of 23,000 kVA each can supply the transformer separately, or one generator alone. As regards the rated capacity this is the largest transformer without water cooling that has ever been built.

The Elektrizitätswerk Olten-Aarburg also ordered a three-phase three-winding transformer for Betteningen Substation, with compressed-air nozzle cooling for the separately-mounted radiator batteries. It has a rating of 32,500 kVA, a 145-kV star-connected high-tension winding with voltage variable in \( \pm 10 \) steps of 3340 V, an 85,000-V delta-connected medium-tension winding, and a 53,700-V star-connected low-tension winding dimensioned for 18,000 kVA. The medium and low-tension windings can be changed over to 53.7 kV and 8.6 kV respectively with star and delta connections.

The Nordostschweizerische Kraftwerke ordered 52 potential transformers with insulation casing as described in our last report. 32 of these are for a high tension of 50 kV and the remaining 20 for a high tension of 150 kV.

The first of the two 32,500-kVA four-winding transformers for Ryburg-Schwörstadt Power Station, mentioned in our last report, was delivered during the past year. The illustration on the front cover shows this transformer erected in the outdoor switch-gear plant of the power station.

A recent interesting apparatus is the portable welding transformer (Fig. 37). This is suitable for use where the purchase of a d.c. welding set cannot be considered on account of its higher price or where the quality of the weld is not of predominating importance.

Our welding transformers are of the air-cooled type. The live parts are protected by a sheet-metal cover provided with ventilation openings. The transformer is fitted with broad wheels and handles so that it can be easily wheeled about or carried. The cover is detachable and the transformer itself can be readily dismantled. Connections to the primary and secondary windings are made by means of specially designed plugs which cannot be interchanged; the primary is connected up at one end of the transformer and the secondary at the other. The primary terminals not in use at any time are protected by covers. At the end where the high-tension terminals are situated, a wing screw is provided for earthing the transformer tank.

The transformer core has three limbs, only the two outermost of which are wound. One carries both the primary and secondary windings and the other the windings of a choke coil. The primary winding has three tappings by means of which the transformer can be connected to a mains pressure of 500, 380 or 220 V. The choke coil is in series with the secondary winding. The leakage lines of the primary winding close through the central unwound limb; the leakage of the choke coil is very small. In order to adjust the welding current between about 35 and 250 A, the choke coil is provided with ten tappings.
The welding transformer can also be worked in parallel with a condenser for improving the power factor.

Fig. 38 shows a condenser shell being welded by means of a transformer.

(6) Rectifiers.

With regard to rectifiers, the most noteworthy is a new type with 18 anodes for 8000 to 10,000 A, designed according to the latest principles as mentioned in our last report.

In order to obtain wider subdivision of the series of high-power rectifiers, a new type for 12,500 A has been developed.

The research with high voltages, already described in this review, has been successfully continued. With a rectifier similar to that shown in Fig. 39, d.-c. pressures up to 30,000 V have been produced without difficulty and without reaching an upper limit. As a result of these tests, unsuspected prospects of transmitting energy by means of high-tension direct current have been opened up.

Supplementary to these tests, some very interesting investigations were carried out during the past year regarding the possibility of reversing the action of the mercury-arc rectifier. A "primary" rectifier was supplied through its transformer from a three-phase network, and connected to a "secondary" rectifier working as a regenerative valve and connected through its own transformer to the same primary three-phase network. The cathode of the secondary rectifier was connected to the star point of the secondary winding of the transformer of the primary rectifier (three-phase-d.-c. set), and the cathode of the latter to the star point of the transformer of the secondary rectifier (d.-c.–three-phase set) through a switch in parallel with an ammeter and testing resistance. The anodes of the secondary rectifier were fitted with controlled grids.

The arrangement works as follows:

In the secondary winding of the transformer of the secondary rectifier there are two superimposed voltages, viz., the a.-c. voltage induced by the primary winding and the d.-c. voltage from the primary rectifier. The grids of the secondary rectifier are controlled in such a manner that each anode is "released" at the instant the voltage of the phase concerned is opposed to the incoming d.-c. voltage. According as to whether the anodes of the secondary rectifier are released earlier or later, i.e., whether the difference between the d.-c. voltage and a.-c. voltage is greater or smaller, the power converted is greater or smaller. Since the anodes are released according to the phase displacement between the anode voltage and grid voltage, the load of the primary rectifier is a direct function of this phase displacement.

It is thus possible, with this arrangement, to supply electrical energy from a d.-c. network to a three-phase network, the frequency either being determined by the generators supplying the three-phase network or being adjusted as desired by a special frequency indicator supplied from the direct-current system.

The use of this arrangement is not restricted to the transmission of electrical energy by means of high-voltage direct current; it possesses many important advantages for the coupling of independent, polyphase networks of various frequencies and also for boosting three-phase networks by means of accumulator batteries for the purpose of overcoming load peaks, thus enabling rotating machinery to be completely dispensed with. The rectifier with controlled grids is thus, in certain respects, reversible.

Another arrangement using controlled mercury-vapour valves which appears to offer many interesting advantages when applied to electric traction is at present being tried out in our testing departments. The object in view, namely, the development of a traction motor with series characteristic capable of being fed with single-phase current at any frequency—in particular, the industrial frequencies of 50 to 60 cycles—was attained by employing a controlled mercury-vapour valve with several anodes instead of the usual commutator and brushes. The external appearance of a valve-controlled series-wound motor of this description is exactly the same as that of a normal synchronous machine. The absence of the commutators enables the tapping switch and reversing switch on the locomotive to be dispensed with and thus the last movable contact in the motor circuit to be eliminated. The arrangement developed by us is such that the electric valve controlling the motors operates simultaneously as starter, rectifier and commutator.

In this respect the mercury-arc rectifier opens up unthought of possibilities for the future.

An interesting development introduced during the past year is the water-temperature regulator (Fig. 40) for obtaining more economical water consumption in the case of fresh-water cooling. According to the load, it automatically regulates the flow of water so that the rectifier is kept at a practically constant temperature. This is a feature of great
importance for the reliability of rectifier plants with intermittent or heavily fluctuating loads. In addition, large pressure variations in the water mains are rendered harmless.

The apparatus consists of the regulating valve V and the thermostat T. The valve V is included directly in the fresh water supply pipe and is designed as a piston valve with ports so that it operates practically independently of the water pressure. It has a by-pass, which can be readily adjusted from outside, for supplying the basic quantity of water. The thermostat T is included in the cooling water outlet pipe and communicates with the regulating valve V by a small tube R in which the transmission medium circulates. The apparatus operates as follows: The thermostat is directly influenced by the temperature of the cooling water flowing out of the rectifier. By means of an auxiliary medium it controls the regulating valve in the water supply pipe in such a way that the temperature of the rectifier remains practically constant independently of the load.

During the past year a large number of rectifiers and complete rectifier plants were again ordered. The following deserve particular attention:

In a substation of the Copenhagen Power Supply two more rectifier sets, each for 6000 A and a direct-current pressure of 440—500 V, with full automatic control, were put into service. On the primary side, the plant is supplied with three-phase current at 5900—6400 V, 50 cycles. Both sets supply current for lighting and power, and according to the load automatically work in parallel with each other and with the existing rotary converters and accumulator battery. The d.-c. pressure is automatically regulated so that it is constant at the point where it is fed into the network. Voltage regulation is effected by tapping switches built into the transformer and provided with electrical synchronous control. The transformers have separate oil coolers with forced air cooling; in view of the limited space available, the coolers are installed in the basement. The rectifiers are cooled by sea-water which flows through a closed circuit cooling set. Two more similar sets, each of 2000 kW, have since been ordered for another substation of the Copenhagen Power Supply. This constitutes the third order for full-automatic rectifier plants which this authority has placed with us within the last two years.

A substation of the Sango Kyuku Railway was equipped with three rectifiers each of 2000 kW at a full-load d.-c. pressure of 1500 V. The sets can carry an overload of 50 % for two hours, 100 % for one minute and 200 % momentarily. The rectifiers with accessories, the d.-c. apparatus, and also the switchgear for the four outgoing lines and for the auxiliary services, will be installed in a new building. The high-tension apparatus and rectifier transformers are designed for outdoor erection.

In the Nation, St. Antoine, Louvre, Italie and Lilas substations of the Paris Underground Railway our rectifiers have been operating with complete success for many years. The Daumesnil, Vanneau and Auteuil substations of the same company have now been equipped with eleven further rectifiers with an aggregate output of 21,500 kW for a d.-c. pressure of 615 V. This brings the total output of all the rectifiers we have supplied to the Paris Underground Railway up to 40,980 kW.

As already mentioned, there appears to be an important field of application open to the high-voltage mercury-arc rectifier in wireless transmission stations in place of the high-voltage motor generators or thermionic-valve rectifiers previously used. At the end of 1928, already, Marconi’s Wireless Telegraph Co., London, ordered from us a trial rectifier for 400 kW at a full-load direct-current pressure of 12,000 V. The set was first installed in the experimental laboratory of the company mentioned at
Chelmsford, but in September of 1929 was put into actual service. It proved so satisfactory that rectifiers of our manufacture have been selected for the new transmitting station at Warsaw. Two separate rectifier sets were ordered during the past year, one to serve entirely as a stand-by. Each set comprises a regulating transformer, rectifier transformer, rectifier and accessories. The rating of each unit is 500 kW at a d-c pressure of 15,000 V. The sets are started by the regulating transformer at a d-c pressure of 5000 V.

A high-voltage rectifier plant was also ordered by the Marconi Company on behalf of the Swiss Postal Authorities for the wireless station at Münster, near Lucerne. This is a 270-kW set for a d-c pressure of 10,000 to 12,000 V, and has a regulating transformer by means of which the d-c voltage can be stepped down to 5000 V (Fig. 39).

The rectifiers for a d-c pressure of 3000 V ordered during the past year for the electrification of main-line and secondary railways in Italy are of great interest, as high-tension direct current is being used there to an ever increasing extent for railway electrification.

We are installing full-automatic rectifier plants in three substations, namely, Due Ponti, Bagnaia and Fabbrica, for supplying the Rome-Civita-Castellana-Viterbo section of the Società Romana per le Ferrovie del Nord which is being electrified at a contact-wire pressure of 3000 V. The first two substations each contain two 1200-kW rectifiers, and the third has two 800-kW sets.

The Soc. per la Ferrovia Voghera-Varzi, Milan, ordered a rectifier plant—to be erected at Gadiasco—for supplying the contact wire of this railway. The plant will contain two rectifier sets, each for an output of 900 kW at 3000 V, and will be provided with full-automatic control gear.

A full-automatic rectifier substation with two rectifiers, each of 600 kW and a d-c pressure of 3000 V, is to be provided for the railway from Rimini to San Marino.

At present the Italian State Railways are also electrifying a number of their sections with high-tension direct current at 3000 V. Two substations, viz., Caserta and Napoli, will supply the Benevento-Naples section at present being electrified at a d-c contact-wire pressure of 3000 V, and each will contain two 2000-kW, 2900-V rectifiers of our manufacture. The rectifiers will be connected through their transformers to a primary three-phase supply of 60,000 V, 45 cycles. The Napoli substation is so equipped that later on it will be possible to add the equipment for remote control without difficulty. Some rectifier sets and also two portable rectifier substations have been ordered for the new line from Bologna to Prato di Toscana (Florence) which passes under the Apennines through a tunnel. When the line is opened in the autumn of this year, it will be operated by direct current at 3000 V. The rectifier sets in the stationary plants are for a d-c rating of 2000 kW at 3000 V. The sets for the portable substations are specially designed for mounting on railway wagons. The rectifier cylinder rests on spring supports and the air pump set, comprising the preliminary and high-vacuum pumps, is secured to the cylinder. The rectifier is cooled by a closed-circuit cooling set with forced draught, the same kind of cooling being also used for the high-vacuum pump. The rectifier transformer is supplied on the primary side with three-phase current at 60,000 V, 45 cycles. The rectifier set is protected on the primary side by a three-pole oil circuit breaker with over-current release and on the d-c side by a high-speed breaker with over-current and reverse-current releases. The portable plant is also equipped with the requisite apparatus for automatic operation. When placed in close proximity to a stationary plant, its various auxiliary services are supplied from the latter and the rectifier plant works completely automatically. The plant is then started up and shut down by a remote control switch in the stationary rectifier substation. Any disturbances occurring in the portable plant are notified in the substation by an alarm device. When the portable plant is not in the immediate neighbourhood of a substation, the auxiliary services will be supplied from the secondary side of the main transformer. In this case, automatic operation is confined to the d-c side (reclosing of the d-c breaker in combination with an earth current testing device).

The German State Railway also ordered a portable rectifier substation with two rectifier sets for assisting the rectifier stations supplying the Berlin Tramways. Each set comprises a rectifier, transformer, absorption choke coil, selective transformer and auxiliaries, has a continuous rating of 1200 kW, a d-c pressure of 800 V, 1500 A, and is supplied with three-phase current at 31,500 V, 50 cycles. The portable rectifier substation consists of the actual rectifier wagon and the control car. It can be brought up to any of the substations of the Berlin Tramways.
and connected to three 30-kV bushing insulators, as provided at each substation.

The five full-automatic rectifier plants ordered by the Long Island Railroad are particularly worthy of note. Each plant has an 18-anode rectifier for 3000 kW at 650 V and, according to the requirements of the railway, each rectifier must be capable of taking an overload of 50 % for two hours, 200 % for one minute, and 225 % for 20 seconds.

Finally, three rectifier sets for supplying current for aluminium furnaces are of particular interest.

On the d.-c. side, the rated output of each set is 5000 kW at 590 V and the current therefore 3 × 8500 A. The d.-c. pressure is regulated in steps between 190 and 590 V.

The plant is provided with automatic tapping switch control adjusted for constant current and maximum voltage. The operating current for each set is limited to 8500 A and can be regulated between 8500 A and 6500 A in steps of 100 A by means of a sensitive current relay of the type shown in Fig. 9; the sensitivity of the control relay can be adjusted between 100 and 500 A.

The adjustment to a maximum voltage was required because the individual rectifier sets will supply various series of furnaces and therefore, according to the number of furnaces, different working voltages will be encountered. Furthermore, the automatic regulation is such that two of the three sets can always work in parallel in each case. The current distribution between the two sets working in parallel must not differ by more than 5 %. In order to reduce the number of switching operations to a minimum, each set is provided with a time-lag relay adjustable between half a minute and ten minutes.

The tapping switch regulation takes place in 3 × 10 steps (total 60 steps), the phases being switched separately. In view of the fact that the rectifier transformer itself is complicated, a special regulating transformer is provided for the large regulating range. This is combined with the rectifier transformer and the tapping switch into one transformer. This enables a considerable saving in space to be effected, results in a convenient arrangement, and renders the connections simple and easily supervised.

This is the first heavy-current rectifier plant in which 18-anode rectifiers have been used. In order to obtain as uniform a distribution as possible of the phase currents to the various anodes, three anode choke coils are included between the transformer and the corresponding rectifier. This also serves to split the six-phase system into the 3 × 6-phase system necessary for the 18-anode rectifier. The rectifiers are also equipped with two-core absorption coils for reducing to a minimum the effective value of the anode currents by increasing the time during which the various anodes operate.

(7) Apparatus.

In our last report, details were given of a series of tapping switches for regulating the voltage of transformers under load. The two largest types, for 150 and 187 kV, were of particular interest. During the past year, the opportunity presented itself for the first time of building a switch of this type for 187 kV in connection with the 32,500-kVA regulating transformer for Ryburg-Schwörstadt Power Station. A tapping switch is provided for each limb of the transformer and is mounted in a special tank connected with the oil conservator of the regulating transformer. Each tapping switch (Fig. 41) consists of a two-part oil-filled porcelain insulator, the lower end of which carries the main fixed contacts, which correspond to the tappings on the transformer. As in all tapping switches, contact is made with the fixed contacts by means of two arms, each of which is rigidly attached to a bush. These two bushes are arranged concentrically one within the other and have teeth cut on

![Fig. 41. — Tapping switch for the 32,500-kVA regulating transformer for Ryburg-Schwörstadt Power Station.](image-url)
The hand control (Fig. 42) consists essentially of an eccentric gear with locking device mounted on a driving shaft and enclosed in a two-part casing. The motor control (Fig. 43) is employed where the tapping switch is mounted at a considerable distance from the control room or where, for some other reason, direct control by hand is only possible in exceptional circumstances during normal operation. The motor control is also necessary for all automatic regulating devices. To prevent the tapping switch coming to rest between two positions due to a failure of the current supply to the control motor, the motor can be provided with a "power conservator". Fig. 44 illustrates a control of this type as built for the first time for the tapping switch shown in Fig. 41 for Ryburg-Schöorstadt.

Our controllers for starting and stopping three-phase motors used for intermittent service were re-designed during the past year. A series of controllers for maximum stator and rotor currents of 200 and 300 A respectively, and comprising six types, is specially adapted for crane motors. Figs. 45 and 46 illustrate a controller of this series for a motor of 64 kW, 660 V, 120 A. As will be seen from the illustrations, this is a drum-type controller with a series of contact fingers. The controller comprises essentially the switch drum with the corresponding contact fingers and the casing. The switch drum consists of a malleable iron shaft of square section on to which the segment holders are clamped over layers of insulation. The copper segments, which are subject to wear, are screwed on to the holders. In the three largest types of controller, the parts of

The tapping switches can be operated either manually by means of a crank or else by means of an electric motor and a special control apparatus.

The tapping switches can be operated either manually by means of a crank or else by means of an electric motor and a special control apparatus.
the stator segments which wear most are designed as readily-interchangeable arcing tips. The various positions of the switch drum are indicated by means of a ratchet wheel secured to the shaft and a roller-ended lever with spring fixed to the cover. The robust contact in the back and kept in position by two strips of wood. The baseplate and cover are each provided with two lugs for securing the controller to a wall; four holes in the baseplate enable it to be bolted to the floor.

A series of controllers comprising five different types is used for very heavy duty (Fig. 47). Like our locomotive controllers, these are provided with switch elements carrying their own blow-out coils inside readily detachable arc shields of fire-proof insulating material. The switch elements are closed separately by powerful springs and are positively opened by the cams, of extremely strong insulating material, mounted on the hexagonal part of the operating shaft. A ratchet wheel is secured to the driving shaft and in combination with a roller-ended lever and spring ensures that the controller always takes up the correct positions. A compensating device consisting of a reverse cam with roller-ended lever enables the torque to be maintained constant for all positions of the controller. The torque required to rotate the drum was reduced to a minimum by mounting the operating shaft in ball bearings. The controller is thus

fingers are carried by holders clamped to a square bar. They are provided with special readily interchangeable arcing tips. By means of a screw, the contact fingers can be adjusted to allow for wear of the contacts. To prevent flash-overs when opening the contacts, arcing shields of non-inflammable material are fitted between the contact fingers of the stator and all the controllers. In the three largest types they are also fitted between the contact fingers of the rotor.

The casing consists of a cast-iron baseplate and cover plate with four strong supports in between, a rear plate, and a detachable cover which protects the switching mechanism from accidental contact. In the three largest types, the cover is fitted with a detachable plate carrying the bearing for the operating shaft and also enabling the complete drum to be drawn out for purposes of inspection without removing the cover. The cables are introduced through a slot particularly suitable for frequent operation. The casing again consists of a cast-iron baseplate and cover, connected by six strong bars, and a rear plate of sheet metal. A readily detachable
sheet-iron cover, lined with insulating material, protects the switching mechanism from dirt and accidental contact. The cover is fitted with a plate in which the bearing of the operating shaft is fixed, so that the drum carrying the cams can be easily and quickly dismantled. The cables are led in through a slot in the back and kept in position by two strips of wood. The controllers can be mounted on a wall by means of four lugs, or bolted to the floor, for which purpose holes are provided in the baseplate.

According to the manner in which it is mounted or the purpose for which it is used, the crane controller can be operated by a handle or handwheel (Figs. 45 and 46), or by means of a cable, lever,
Fig. 52. — Carbon regulator for a wide regulating range.

Fig. 53. — Regulating diagram obtained with the carbon regulator as in Fig. 52 in Ryburg-Schwörstadt Power Station.
A, B. Artificially produced alteration of the voltage.

Fig. 54. — Distance relay testing apparatus with door opened and cover removed.

return spring brings the drum back to the switching-out position when the handles are released. The lever control is executed either with bevel wheels (Fig. 49) or ordinary gear wheels, according as to whether the lever is moved in a direction parallel to or at right angles to the controller shaft. The universal control (Fig. 50) enables two controllers to be operated by one lever. The neutral position of the lever may be either vertical or horizontal.

Controllers for heavy duty can only be provided with handle or handwheel control.

We have recently adapted our well-known oil-filled porcelain bushing insulator terminals to another purpose by fitting a metal sleeve (lining) between the Bituba tubes surrounding the central metal tube. In this form, it is used as an electrostatic potential divider for supplying an electrostatic synchroscope made by Hartmann and Braun of Frankfort a. M. according to principles laid down by us. It can also be employed for supplying an electrostatic frequency meter or voltmeter. The use of expensive and unreliable connections for increasing the output of the dielectric transformer by means of amplification tubes or resonance circuits can thus be avoided. Fig. 51 illustrates a 150-kV oil circuit breaker set in Innertkirchen Outdoor Substation of the Kraftwerke Oberhasli. On the insulators of this
set will be seen the connecting leads (laid in tubes) of an electrostatic synchroscope of our design by means of which units up to 30,000 kVA can be synchronized.

In connection with the large and extremely slow-running generators for Ryburg-Schwörstadt Power Station, the difficult problem was encountered of regulating between 4 and 57 A (full-load current 35 A) the current of the auxiliary exciter flowing through the field windings of the main exciter. This is necessary, on the one hand to ensure stability under a heavy capacitive load, and on the other hand to obtain super-excitation when certain disturbances occur in the network. This problem was solved by means of a carbon regulator (Fig. 52) the resistance of which is indirectly regulated according to the generator voltage by one of our quick-acting regulators. The disadvantages of the electro-magnets with vibrating contacts, and operation dependent on the voltage or current, previously used for controlling carbon regulators are thus avoided. Fig. 53 shows the regulation obtained with this regulator, or better, regulating set, the curves being taken by a recording instrument in Ryburg-Schwörstadt Power Station. It will be seen that after variations in the voltage up to $\pm 30\%$ had been produced, the normal voltage was attained in 1.4 to 1.6 seconds; the whole regulating process until stable conditions were again reached lasted from 10 to 14 seconds.

Our distance relays are proving extremely satisfactory even in cases where the short-circuit current is smaller than the guaranteed minimum operating current (Société Générale de Force et Lumière) or in networks with earthed neutral (Tennessee Electric Power Co.).

The Brown Boveri distance relay protection has been very widely adopted in a comparatively short time, and the need has now manifested itself for some suitable equipment for periodically testing the relays installed in networks. Figs. 54 and 55 show the portable testing apparatus for transmission-line distance relays ready for making a test.

A distance relay protection for cable mains with insulated neutral, or neutral earthed through a high resistance, has been developed on similar lines to the transmission-line distance relay. Fig. 56 shows the equipment of a cable main for the selective tripping of three-phase short circuits and two-pole short circuits between any phases. Current transformers in two phases and potential transformers connected in V are sufficient for feeding the relays. The operating current of the relays can be adjusted between once and twice the rated current. The short fundamental time of only 0.3 second is particularly noteworthy as this enables a short circuit to be isolated in about one second. For determining the direction of flow of energy, which as in the case of distance relays for transmission networks is accomplished by the ohmmeter itself, a resistance of 40 milliohms across the relay terminals is sufficient. The adjustment of the relay to the length of the cable section and to various transformation ratios of the current transformer is effected by means of a terminal plate in the relay casing.

(8) Switchgear.

The following important orders for switchgear were obtained during the past year:—

The complete switchgear for the extension to Geertruidenberg Power Station of the N. V. Provinciale Noordbrabantsche Electriciteits Maatschappij, Noord Brabant, Holland. The power station will be provided with three double bus-bar systems, as follows: a 10-kV main bus-bar system, a 10-kV auxiliary bus-bar system with thirteen outgoing cable mains and connecting lines to the existing power station, and the 500-V bus-bar system with eighteen outgoing cable mains. Provision is made for a fourth double bus-bar system of 110 kV to be erected in the open near the power station. The following apparatus is particularly worthy of note:—
4 three-pole oil circuit breaker sets of our reinforced design with solenoid contacts and motor control for a rated current of 2500 A and a rupturing capacity of 750,000 kVA at a rated pressure of 110 kV;

34 three-pole circuit breakers of similar design for various currents, single and three-pole isolating switches for 37 kV, 2500 A. In addition, the generators will be equipped entirely with our regulating and protective gear.

Orders have been received from quite a number of plants for our fault-proof switching supervisor with light diagram and block-signalling system which we described in our last report. The Pizançon Power Station of the Sté des Forces Motrices du Vercors, Valence, deserves particular attention. When completed the following will be represented on the light diagram in this plant:

- 4 generators, each of 12,500 kVA, which work on to a 10-kV double bus-bar system;
- 3 three-winding transformers, each of 20,000 kVA, 10/35 kV, with two outgoing lines of 150 kV;
- 1 transformer of 15,000 kVA, 10/70 kV, with one outgoing line;
- 17 35-kV transmission lines.

Another interesting order is that for the switchgear of Bösdernau Power Station of the Zillertaler Kraftwerke A.-G., Innsbruck.

One of the most important orders for switchgear which we have yet executed is that for Puerto Nuevo Power Station of the Cía. Italo-Argentina, Buenos Aires, and the corresponding substations. At the beginning of 1929 we received an order for three turbo-alternator sets of 37,500 kVA, 7000 V, 3000 r. p. m., 50 cycles (see the Brown Boveri Review 1930, No. 1, page 3). During the past year, the order was placed for all the other electrical equipment, which will be built according to the following general lines:

The three turbo-alternators mentioned for Puerto Nuevo Power Station supply the main distribution network, which is operated at a pressure of 27,500 V, directly through three transformers. The pressure in the secondary distribution network is 7000 V. Five transformers, each of 2000 kVA, are necessary for supplying the auxiliary services. These transformers step the pressure down from 27,500 to 2300 V. All the large motors are fed directly at this voltage while for the auxiliary circuits the pressure is further transformed to 440/225 V.

For connecting the power station with the substations, eight outgoing cable mains, operated at 27,500 V, are provided for at present. Four other cable mains connect up to the old power station of Pedro-Mendoza (BBC Mitteilungen 1918, June issue, page 107).

When complete, each substation (Tucuman and Estados Unidos) will contain six transformers of 10,000 kVA,
27,500 V, ± 6.5%/7150 V. At present only four such transformers are to be supplied for each substation. They have no high-tension bus-bars; the transformers are connected directly to the incoming lines from Puerto Nuevo Power Station. On the 7000-V side of the substation is a double bus-bar system from which, when the plant is complete, 45 outgoing lines will be led off. During the first stage of construction, Estados Unidos Substation will have 25 outgoing lines and Tucuman Substation 30. All the transformers are for a uniform rating of 10,000 kVA and are provided on the high-tension side with tapping switches for regulating the voltage by ± 6.5%. They are used for equalizing the voltage drops at the various active and reactive loads.

Perez-Galdos coupling Station is situated in the immediate neighbourhood of the old Pedro-Mendoza Power Station and is used for coupling the two generating stations. In all probability, the Pedro-Mendoza plant will be used merely as a stand-by later on, in which case Puerto Nuevo will supply all the power. When complete, the coupling station will contain five 10,000-kVA transformers. At present only four have been ordered. The control room for this coupling station will be in Pedro-Mendoza Power Station.

The control rooms of all four plants will be equipped with light diagrams, while those of Puerto Nuevo generating station and Perez-Galdos coupling station, i.e., where synchronizing and paralleling have to be effected, will also be equipped with fault-proof switching supervisors and block-signalling systems.

The generators will be provided with voltage and current-limiting regulators and protected by over-current relays and differential relays. In addition, all the main transformers of the network will be provided with differential protection. For protecting the network itself, distance relays will be used exclusively.

The Mundenheim Substation (Ludwigshafen) of the Pfalzwerke A. G., which was completely equipped by us, was put into service during the past year. The first complete installation incorporating the previously mentioned fault-proof switching supervisor with light diagram and block-signalling system was supplied for this plant (Figs. 57 and 58).

(9) Winding engines.

The increased activity in mining which became apparent two years ago induced us to re-design some of our equipment for winding engines. This work has been brought practically to a conclusion during the past year.

With regard to direct-current winding engines, the fundamental method of connections, as shown in Fig. 59, has been simplified. The new system is intended to replace the one used hitherto, in order to obtain that for a given load and with the control lever displaced by the maximum amount, the speed remains the same whether the load is being raised or lowered, i.e., whether the load torque is positive or negative. The possibility of correcting small variations in speed, despite variations in the load or with different positions of the control lever, during the period when the machine is running at full speed, has been given up. It is simply wished to ensure that the speed cannot exceed a certain value, but at the most can only fall below that value.

The new system of connections operates independently of auxiliary machines and auxiliary windings. Its principle consists in keeping short-circuited a portion (bcde) of the series resistance (ae) in the case of positive loads, and of switching in this resistance in steps for negative loads, according to the magnitude of the reverse current, i.e., according to the magnitude of the negative load. A more direct method of control is inconceivable, as this one depends on the position to which the control lever has been moved by hand.

The armature of a rotary electro-magnet R (Fig. 60), which is excited according to the magnitude and direction of the current flowing in the Ward Leonard circuit, carries a number of contact springs (1, 2, 3) depending on the number of different kinds of load—
in our case, full-load, half load and balanced load. When hoisting, these contact springs short-circuit the corresponding steps e-d-c-b according to the current in the Ward Leonard circuit, and put them into circuit according to the magnitude of the reverse current when the load is negative. This is brought about by the fact that the magnitude and direction of motion of the magnet depends on the magnitude and direction of the current in the Ward Leonard circuit. In order that this magnet will always rotate in the same direction for both directions of rotation of the winding engine, the field is changed over by the switch U coupled to the control lever.

Fig. 61 shows the new design of the operating mechanism for direct-current winding engines with our single lever operating stand and depth indicator. Fig. 62 illustrates the new depth indicator, in the base of which is arranged the electrical retarding gear. A separate cam is, however, also provided for each direction of travel, for mechanically returning the control lever (retarding curve), and a starting cam connected to this, the cam in use being for the next wind. A change-over gear ensures compulsorily that at the beginning and end of a wind the correct curves are always opposite the correct roller-ended levers by means of which the control lever is returned or interlocked. The curves are not, however, as is usually the case, designed as a wheel which rotates all the time the winding engine is running: they are only operated at the end of the wind. When the engine is decelerating, the rising nut lifts a vertical rod S which rotates the shaft W on which the cam segments K are keyed. When the winding engine is starting, the shaft W is turned back again by the descending nut allowing the rod S to sink. The whole cam gear is arranged in the basement of the engine house. The new design possesses the advantage that when winding from some other depth the radial position of the curves need not be changed.

Figs. 63 and 64 illustrate our well-known single-lever operating stand in its new design with widened slot for operating a variable-pressure brake (pneumatic braking-pressure regulator) mounted either on the operating stand itself (Fig. 63) or on the brake cylinder (Fig. 64). In the latter case a rod transmission system is necessary.

Some noteworthy improvements have been made to our emergency brake. Since we considered it essential for technical reasons and questions concerning the safety of the plant to keep this independent of the service brake, it had to be ensured that the engine cannot be braked by both brakes simultaneously. This was accomplished by a simple arrangement (Fig. 65) which, as soon as the control lever is moved into an operating position, causes either the service brake alone or the safety brake to operate on the machine. Only when the lever is in the neutral position is it possible — or rather essential — for both brakes to be applied before the emergency brake can be released. A three-way cock h is fitted in the
pipe from the braking-pressure regulator to the brake cylinder. Attached to the lever for operating this cock is a small weight g which, when the emergency brake is released, is supported on the crosshead of the piston rod and keeps the cock h open so that the brake cylinder is under pressure.

If the emergency brake were now to operate, the weight g would no longer be supported by the crosshead. It would not, however, fall, because with the control lever in its mid-position it has a second point of support on the slotted rod s. If the control lever is thrown over (Fig. 65b), the point of support of the weight g in the slot s is removed, and should the emergency brake now operate the weight g will fall (Fig. 65c) and turn the three-way cock h to "exhaust". If the service brake were to be operated in this position, the compressed air supplied by the braking-pressure regulator to the cylinder would simply escape through h into the open. When the control lever is returned to the mid-position, which is necessary

Fig. 63. — Brown Boveri single lever operating stand with built-on pressure regulator for the friction brake. Brake released. Front view.

Fig. 64. — Operating stand, compressed-air service brake, and rod mechanism between the operating stand and the regulator built on to the compressed-air service brake. Control lever in running position; service brake released.

Fig. 65. — Device for preventing dynamical braking with the service brake and emergency brake simultaneously.

Fig. 66. — Operating stand, emergency brake, compressed-air brake with built-on pressure regulator, by-pass valve for preventing simultaneous dynamical braking by means of the service and emergency brakes, and control and braking gear. Control lever in central position in the recess in the slot, with compressed air service brake applied.
in order to be able to operate the emergency brake, the weight \( g \) is again lifted by the slotted rod, and \( h \) thus turned to the braking position. During normal operation, i.e., with the emergency brake released, the slotted rod will merely be lifted up and down by the control lever without affecting the weight \( g \). Fig. 66 shows the arrangement of the control gear.

According to a new mining regulation the emergency brake must be capable of holding the machine with the greatest out of balance weight which occurs with a static factor of safety of at least three. This means that the brake weight must be dimensioned for the most unfavourable case, irrespective of what would happen if the emergency brake were applied while conveying men. It is highly probable that the brake weight would have to be made much too heavy, with the result that the retardation would be too rapid for the men in the cages to withstand without injury.

In order to meet these contradictory requirements we have combined our emergency brake, as shown by Fig. 67, with a shock absorber for the brake weight. We consider that, according to the prevailing conditions, entirely different brake weights should be used when conveying men or carrying material, but that it is essential that the brake weight necessary for the particular load be adjusted by means of the same lever used for changing over from conveying men to winding material, or vice-versa. The solution is extremely simple. The emergency brake remains completely unaltered, while a sleeve carrying additional weights is fitted over the brake weight.

The sleeve \( H \) rests on the shock absorber \( G \) and together with this makes up the brake weight necessary for the factor of safety of three. When the emergency brake falls while conveying material this total weight comes into operation. When, however, the machine is changed over for conveying men (Fig. 67c), an auxiliary resistance is put in series with the control resistance by means of the change-over switch, thus reducing the maximum speed. At the same time, however, compressed air is supplied to the cylinder \( C \), pushing the piston forwards. This movement is transmitted by a parallel motion to the two arms \( D \) which then move outwards under the projecting pins \( E \) on the sleeve \( H \), though without lifting them (Fig. 67d). If the emergency brake is now applied, the sleeve \( H \) remains suspended from the arms \( D \) while the shock absorber \( G \) underneath the sleeve falls, the weight it carries being sufficient for the maximum load when conveying men.

In the shock absorber there are now two springs instead of the one previously used. The two together give the characteristic for one kind of winding, and one alone gives that for the other kind.

This arrangement can be further developed by making the flow of compressed air to the cylinder \( C \) dependent on the position of the cages in the shaft or at the landing stage. It would then be possible to subdivide the brake weight further, or when the

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Fig. 67. — Brown Boveri emergency brake with device for adapting the brake weight for winding material or conveying men.
cage approaches the landing stage to change over automatically to the weight necessary when conveying men. The change-over can also be made according to the speed by regulating the supply of compressed air to the cylinder C.

When the air is allowed to escape from C, the spring F returns the arms D together with the parallel motion into the horizontal position.

The arms D are free to move upwards in case the change-over switch were operated while the brake weight is in the lowest position, in which case the stops E will strike against the arms D when rising. To prevent the sleeve rotating, i.e., in order to keep the stops E always in the same position, it fits like a stuffing box on the square shaft.

We have also developed a safety device for winding engines having cages with several decks, for preventing a new wind being started during the decking period. The greater the number of decks to be unloaded per wind, the greater is the danger that the driver may eventually make a mistake, in spite of optical and acoustic signals, and start a new wind when he should have stopped again at the last deck. There is then the danger that the men at the working or at the loading place, who as a rule perform their work quite mechanically, may push the tub into the empty shaft or perhaps fall down it themselves if the cage, instead of stopping, unexpectedly passes on.

Fig. 68 shows the connections of this safety device.

It is rendered impossible to start a new wind during the decking period, but within this distance the cage can travel at the usual decking speed even with the shaft doors open.

A robust switch a in the framework of the shaft is operated by the rising cage on reaching the landing stage. In parallel with this switch is another one b operated by the shaft doors. When the top deck reaches the loading place, it has already closed switch a and the cage travels slowly onwards until deck I is opposite the landing stage. On opening the shaft doors, switch b will be opened. The circuit of the holding magnet on the emergency brake is controlled only by the position of switch a, which is determined by that of the cage. The tubs can now be pushed into or out of the cage. If a new wind were now commenced without the shaft doors being closed, deck IV on passing the landing stage would open switch a, this in turn causing the emergency brake to operate. Now, in order to prevent the driving motor accelerating to such an extent during the decking period that it could not be stopped within a few centimetres on applying the emergency brake, the switch b puts a resistance g in the exciter circuit of the variable-pressure dynamo as long as the shaft door is open. This resistance is of such a size that it allows the machine to develop the high torque required during the decking period, but on the other hand does not allow the speed to increase to such an extent that the machine is not stopped practically instantaneously on the application of the emergency brake.

Our operating stand and mechanism for three-phase winding engines has also been re-designed. The simple manner of applying the service brake, as necessitated by the use of the single lever stand, is of particular interest. This enables the braking pressure regulator to be operated by the longitudinal and transverse movements of the control lever. Figs. 69 and 71 show the arrangement of the operating gear in combination with the mechanical parts of the retarding gear operated by the depth indicator (Fig. 70). By means of the gear R, the pressure regulator is always operated when the control lever is moved in the longitudinal direction either to the left or to the right. It is therefore also operated when the lever is thrown into the position for winding, though, in this case, the compressed-air connection between the pressure regulator and the brake cylinder is closed by an electric interlock. This interlock is released if the control lever is in a braking position.

The fulcrum of the lever XZ, which is connected to the piston rod by a die block Y designed as a crosshead, alters according to whether the control lever (which is at the same time the braking lever) is being moved in the longitudinal or transverse direction. In one case, for example, the lever XZ rotates about Z as the fixed point when the control lever is moved back along the braking edge of the slot to its mid-position.

Fig. 68. — Diagrammatic arrangement of the Brown Boveri safety device for winding engines with cages having several decks.
The various movements required for braking will be seen quite clearly on reference to Fig. 71.

Position a: Control lever in mid-position in the recess in the slot; service brake applied under full pressure.

Position b: Control lever in mid-position on the running edge (brake releasing edge); service brake released by the transverse movement, the lever xyz moving about x as fulcrum.

Position c: Control lever on running edge in furthermost longitudinal position; service brake applied at a pressure up to the maximum during the longitudinal movement of the control lever. Lever xyz moving about z as fulcrum.

Position d: Control lever on braking edge in furthermost longitudinal position, the spring F being compressed by v. Service brake under full pressure, also remaining thus when the control lever is moved back along the braking edge into position a. Lever xyz moving about y as fulcrum.

Fig. 72 illustrates the new operating stand for three-phase winding engines. Our new centrifugal switch, shown in Fig. 73, has the following features: The rotating part is borne by a strong cast-iron pedestal, and the contact fingers are controlled by cams. The contacts can be arranged inside an oil bath. When correctly set, the driving spindle of the switch has a maximum axial play of $\pm 3$ mm; the switch can be set to the required speeds at the works.

The new centrifugal switch is made with and without protective cover for the rotating weights.

Fig. 71. — Control of the service brake on three-phase winding engines, with single lever operating stands.

Fig. 72. — Control of the braking pressure regulator on three-phase winding engines for varying the braking pressure by means of the longitudinal and transverse movements of the control lever. The control lever is in the extreme longitudinal position and is moved transversely, thus putting the regulator under full pressure.
The design without protective cover allows of a maximum of four regulating ranges having the following relationship: 25%, 70%, 100%, 110%. The design without protective cover usually has only one regulating spring which spring used for adjusting the regulating range, namely, for about 70%, 100%, and 110%.

There may also be instances where the lowest contact should operate earlier than about 25%, e.g., at 10%. This occurs principally with three-phase winding engines fitted with a speed limiting device or with a retarding device. This regulating point must then be obtained by means of a special centrifugal switch designed for a higher speed. At 10% of the synchronous speed of the centrifugal switch for 3 or 4 ranges of regulation, its speed must already be such that at 100% synchronous speed it runs at 3000 r.p.m. The design with protective cover (Fig. 74 left) is used for this purpose. This cover is fitted in place of the regulating spring of the other design, the spring being arranged inside the hollow spindle of the centrifugal switch and the sliding sleeve dispensed with.

The switch may be driven by a belt (Fig. 73), gear wheels (Fig. 74), or a coupling.

Fig. 75 shows the test bed for winding engines in our works at Munchenstein, near Basle.

Of the winding engines for which we received orders during the past year, the following deserve particular mention:

A complete winding engine with cylindrical drum and all the auxiliary equipment for the Kaliwerke Kalusz. This machine is for a maximum depth of 260 metres, an effective load of 4800 kg and a winding speed of 5 m/sec. It has a three-phase winding motor with a continuous rating of 420 H.P., 750 r.p.m.

A large winding engine with Ward Leonard control was installed at the Mines de fer de Segré.
and for this we obtained the order for the apparatus and the converter set. These comprise a three-phase induction motor of 625 H.P., 1000 r. p. m., 3000 V, 50 cycles, direct coupled to a d.-c. generator of 510 kW, ± 455 V, and two exciters.

A complete winding engine with bicylindrical drum for a maximum depth of 460 metres, a maximum effective load of 2500 kg and a winding speed of 13-8 m/sec was ordered by the Mines de la Grand' Combe. This machine has Ward Leonard control and comprises a direct-current winding motor of 650 H.P. and a Ward Leonard converter with synchronous motor of 680 H.P., 5000 V, 1000 r. p. m., 50 cycles, direct coupled to a d.-c. generator of 610 kW.

We also received an order from the Graf von Ballestremschen Güterdirektion, Gleiwitz, to electrify an existing steam engine driven winding engine with rope pulley at the Tante Anna pit of the Castellengo Mine (effective load 6000 kg, depth 384 m, winding speed 16 m/sec). The material we supplied included the complete Ward Leonard winding equipment comprising a d.-c. winding motor of 1935 H.P., 43.7 r. p. m., 440 V, the converter set, and also the exciter set with all auxiliary equipment.

Finally, an order was placed with us for the complete winding engine equipment for the Amalie I pit of the Mines de Potasse d'Alsace. This consists of a direct-current winding engine of 970 H.P., 22-4 r. p. m., a Ward Leonard converter set with a synchronous motor of 920 kVA, the corresponding variable-pressure generator and all the apparatus. This plant is particularly noteworthy because it is the first skip hoisting plant to be installed in France. The capacity of the skip (13 tons) is also considerably greater than that of any other in Europe. Winding is effected by means of only one rope, however, the skip being balanced by a weight. The depth of the pit is 695 m and the winding speed 8-45 m/sec.

(10) Electric furnaces.

Of the electric furnaces which we supplied during the past year, two heat treatment furnaces and an electrode furnace plant are particularly noteworthy.

Fig. 76 shows a furnace in the Porzellanfabrik Langenthal for baking porcelain at a maximum temperature of 950° C. The furnace comprises a pre-heating chamber, the actual heating chamber, and a cooling chamber.

The charge of porcelain is placed in baskets on rollers and is pushed forwards into the furnace by a hydraulic ram. On emerging from the furnace, the

Fig. 76. — Furnace for burning the decorations on all kinds of porcelain ware. Power consumption 130 kW. Total length of furnace 14 m. Internal length of muffle 2 m. Capacity 3 to 4 tons of porcelain per 24 hours.

Fig. 77. — Electric furnace for heating brass bars to 729—890° C. Internal dimensions: length 8200 mm, width 760 mm, height 250 mm. Power consumption 425 kW. Hydraulically operated chain feeding mechanism, discharging device, and doors.
(11) Electric traction.

First of all we might mention some new designs of our pantograph current collectors which are characterized by particularly low weight. The reduction in weight by more than one half compared with the previous designs was achieved by avoiding as much as possible the use of cast steel and by employing welded iron, particularly for the movable parts. The fact that the electrical conductivity suffers if the cross-section of the tubes is reduced too much was overcome partly by using copper and also by suitably bridging over the hinges. Fig. 78 shows a current collector with a weight of only 125 kg for a tramcar, and Fig. 79 a locomotive current collector for 11,000 V designed on the same lines.

Some noteworthy orders for locomotives are as follows:

The Swiss Federal Railways again placed an order for twenty 2 D, 1 locomotives (series 10901) with our celebrated individual axle drive, and also for ten C-type shunting locomotives (series 16331) of the new design with central driver’s cab (mechanical part made by the Swiss Locomotive and Machine Works,
Winterthur). Fig. 80 shows one of the ten locomotives of this type ordered from us last year and which have since been delivered.

The German State Railway ordered two 1 D0 1 express locomotives with Brown Boveri individual axle drive to complete the series E1601, comprising seventeen locomotives, which have proved very satisfactory.

The Norwegian State Railways placed an order with our branch in Oslo for the electrical equipment for two standard-gauge four-axle motor coaches for 15,000 V, 16⅔ cycles. The axles of one of the bogies are driven by two axle motors, each with a continuous output of 140 kW at 1120 r. p. m., and a one-hour rating of 172 kW at 920 r. p. m. Electro-pneumatic contactor control is provided.

Two four-axle motor coaches with similar drive were supplied to the Reading Railroad Company (11,000 V, 25 cycles). In this case, each driving motor develops 238 H. P. at 870 r. p. m.

We also had the opportunity of equipping an old locomotive of the Ferrovia Valle Brembana with four single-phase axle motors, each with a one-hour rating of 63 kW at 1000 r. p. m.

As regards direct-current rolling stock, we obtained, among others, the order for two 3000-V motor coaches with control cars for the Ferrovia Nord-Milano, whereby the number of motor coaches and control cars supplied to this tramway company has been increased to 14; further, we are supplying for the Rome-Civitacastellana-Viterbo section of the Società Romana per le Ferrovie del Nord the electrical equipment for ten four-axle motor coaches for the same contact-wire pressure, comprising 10 × 4 axle-motors, each with a one-hour rating of 166 H. P. at 790 r. p. m.; also four B0 B0 locomotives, each with four motors similar to those of the motor coaches. We also supplied the forty Brill bogies for twenty trailer coaches (built by the locomotive department of the Vado Ligure works of the Tecnomasio Italiano Brown Boveri), the complete contact-wire equipment, the three-phase feeders, and the three rectifier substations which have already been mentioned in this article.

Four four-axle motor coaches were ordered for the Rimini-San Marino Railway (3000 V, 950-mm gauge). Each vehicle has four self-ventilated axle motors with one-hour ratings of 110 H. P. at 690 r. p. m. The motors are connected in pairs permanently in series.

The Office Chérifien des Phosphates in Morocco ordered three standard-gauge B0 B0 locomotives for a contact-wire pressure of 3000 V similar to the two locomotives ordered some time ago. Each locomotive is equipped with four axle-motors with a one-hour rating of 189 kW, 750 r. p. m. The same company also ordered two four-axle motor coaches for the same section (for hauling passenger and light mixed trains). Each has two bogies and is equipped with two similar motors and the same apparatus as the locomotives which, like the motor coaches, have electro-pneumatic contactor control.

Particular interest centres round the five motor coaches (1500-V contact-wire pressure) ordered during the past year for the Appenzell Tramway (St. Gall-Gais-Appenzell). These are for combined rack and adhesion operation; the mechanical parts were made by the Swiss Locomotive and Machine Works, Winterthur. Each of the motor coaches is equipped with two direct-current series-wound motors permanently connected in series. The one-hour and continuous ratings of each motor are 192 and 144 kW at 830 and 920 r. p. m. respectively. The motors are suspended by feet underneath the floor of the coach and drive the adhesion wheels and cog wheels through a safety slip coupling, a fixed reduction gear and a cardan shaft. The maximum running speed on the adhesion sections is 40 km/h and on the rack sections 20 km/h and 16-8 km/h when ascending and descending gradients respectively.

The motors are controlled by a centrally situated cam controller which is mechanically operated. In order to obtain enough economical running positions in spite of the elimination of the series-parallel position, the possibility exists of over-exciting the motors by means of the combined braking change-over switch and over-excitation switch, so that their speed is reduced. The coaches are heated and illuminated directly at the contact-wire pressure of 1500 V.

Messrs. Sulzer Brothers, Winterthur, placed an order with us for the electrical equipment for two Diesel-electric motor coaches. For each vehicle this comprises a generator direct coupled to the Diesel engine of 250 H. P., and two self-ventilated direct-current axle-motors with a one-hour rating of 70 kW at 673 r. p. m.

A B0 B0 Diesel-electric locomotive, which is of particular interest on account of the new method of control, was ordered from the Compagnie Electro-Mécanique, Paris, by the Paris-Lyons-Mediterranean Railway. The electrical equipment comprises the main generator of 340 kW, 700 r. p. m., an auxiliary generator, and four self-ventilated axle motors. The
M.A.N. Diesel engine has three economical running speeds of 300, 450 and 700 r.p.m., to which its normal output is approximately proportional. The speed of the vehicle must be controlled principally by regulating the speed of the Diesel engine. The makers of the engine, however, required that the number of operating speeds of the engine should be reduced to three; it was therefore inadequate to keep the torque of the engine permanently constant. Provision has consequently been made for varying this as well as the speed. When the speed has once been adjusted, it is kept constant by automatically influencing the excitation of the generator in an extremely simple manner directly from the Diesel engine governor. Since the driver has no means of varying the generator excitation at will, there is no danger of too great a torque being thrown on to the engine or of the latter being run at an unnecessarily high speed. Since only a single control lever is provided, the power of the locomotive can only be regulated as follows:

The torque of the Diesel engine is first brought to its full value. Then, by notching up, the engine speed is increased and the torque again brought up to the maximum value corresponding to that speed in a few steps. Thus, as far as possible the engine always develops its full torque and runs at the lowest speed at which it can develop the necessary power without being overloaded.

A rotary snow plough ordered from us by the Sociedad de Ferrocarriles de Montana a Grandes Pendientes for the Ribas-Nuria section is of particular interest. (During the past year, we delivered to this company the four rack locomotives (Fig. 81) mentioned in the January, 1929, number of this review). The snow plough is equipped with two direct-current compound-wound motors permanently connected in series and fed at the contact-wire pressure of 1500 V. Each motor drives a snow wheel of 1200 mm diameter through a reduction gear with a ratio of 5.22:1. Both wheels are coupled together through gears. The speed of the motors is regulated by a controller of our manufacture with individual switch elements. The machine is not propelled electrically but is pushed by a locomotive.

There was a noteworthy increase during the past year in the number of direct-current axle-motors ordered. These have been proving extremely satisfactory everywhere on account of their excellent design. For example, 80 self-ventilated motors having a one-hour rating of 31.5 kW at 900 r.p.m. and 500 V were ordered for the Turin Tramways (in addition to 50 controllers); 84 self-ventilated motors with a one-hour rating of 33.5 kW at 1040 r.p.m. and 550/2 V were ordered for the Lima Light, Power and Tramway Co., Lima; and 168 self-ventilated motors with a one-hour rating of 31.5 kW at 970 r.p.m. and 550/2 V for the Rotterdam Tramways.

Finally, brief mention might be made here of an event which took place during the past year and brought to a conclusion a memorable episode in the history of electric traction with which the name of our firm is very closely connected. At the beginning of the past year three-phase operation through the Simplon Tunnel was replaced by single-phase operation, almost exactly twenty-five years after the piercing of the tunnel on February 24th, 1905. In the middle of May, 1930, in accordance with an agreement made between the Swiss Federal Railways and the Italian State Railways, this single-phase electrification was extended downwards as far as Domodossola.

It is interesting to recall how the electrification of the Simplon Tunnel was accomplished as a result of our initiative, and particularly that of one of our directors, Mr. E. Thomann. Two 1 C 1 three-phase locomotives (Fig. 82) for a contact-wire pressure of 3000 V, 16 cycles, which we were building...
at the time in conjunction with the Swiss Locomotive and Machine Works, Winterthur, for the Valtellina section of the Strade Ferrate Meridionali (as it was then called) were quickly made available for operation on the Simplon line. In a few months we had projected and installed the overhead equipment, and with the aid of the two previously-mentioned locomotives undertook to maintain the service of trains through the tunnel practically from the day of its opening (June 1, 1906) for 60 centimes per locomotive kilometre travelled. The Swiss Federal Railways supplied the section with current.

Even the two first locomotives used (Fig. 82, service numbers 364 and 365) possessed many noteworthy improvements compared with the state of development at the time.

With the double type of current collector, consisting of two similar parts coupled together, which was introduced for the first time on these locomotives (it was afterwards adopted as standard by the Italian State Railways), the wind pressure was completely equalized. For varying the speed of the motors within a range of 1 : 2, pole-changing was employed, in contrast to the previous locomotives of the Valtellina Railway. The stators of the motors had normal three-phase coil windings, and in the rotors a six-phase d.-c. type winding with tappings and overlapped phases was employed, and the connections changed over by the Dahlander and Lindström method (German Patent No. 98417).

The two D-type locomotives (Fig. 83) with service numbers 366 and 367 supplied in the autumn of 1907 were designed according to quite new principles. The demand for four economical speeds was met in a very simple manner by using squirrel-cage motors, as it was then possible to confine the pole changing to each of the two mutually independent stator windings which could be changed in the ratios 16 : 8 and 12 : 6; the squirrel-cage rotor naturally runs on any number of poles induced by the stator. A. Aichele designed the rotors in a very ingenious manner to suit the requirements of railway service. To obtain better cooling, the individual conductors of the squirrel-cage rotor were made of copper tubes and connected at both ends with the short-circuiting rings of considerably smaller diameter by bronze bands of high specific resistance. The latter gave the rotors the ohmic resistance necessary for producing a sufficiently powerful torque. They also served as fans and drew cooling air axially through the rotor by way of the open end shields and corresponding openings in the locomotive frame; the air was forced either from left to right or vice-versa according to the direction of rotation. Transformers in V connection were used for starting the motors and adjusting them to intermediate speeds.

As regards the mechanical part, O. Kjelsberg, a former director of the Swiss Locomotive and Machine Works, Winterthur, employed a rectangular coupling frame divided into panels without sliding joints, in place of the flat triangular coupling frames with guide bars and die blocks of the 1 C 1 locomotives, series 364. With an even number of driving axles, the latter arrangement leads to an unsymmetrical disposition of the electrical equipment. The two outermost driving axles were given lateral movement and radial adjustment by making them as hollow axles according to the designs of C. R. Klien and R. Lindner (German Patent No. 68932).

After service had been maintained experimentally by us for nearly two years, whereby the suitability of the complete electrical equipment of the Simplon Tunnel was proved in every respect, this was taken over on May 31st, 1908, by the Swiss Federal Railways for the sum of 1-38 million francs.

The rolling stock of the Simplon line was increased in 1915 by the addition of the 1 D 1 locomotive, No. 371, shown in Fig. 84. This machine was exhibited at the Swiss Exhibition at Berne in the summer of
1914. In contrast to the 1 C 1 and D locomotives, both motors are here mounted high up in the frame and are connected by two inclined rods to the die block of a slide incorporated in the horizontal coupling rods (German Patents Nos. 275880, 286492). When the nature of the high-frequency oscillations was recognized, the open V-shaped system of driving rods was closed and made into a triangular frame by connecting together the motor cranks. The motors are arranged for pole changing in the ratio of 8 : 6 in the following manner:—The stator is provided with a d.c. type three-phase winding with the required number of tappings for each number of poles, and the rotor with a three-phase coil winding brought out to eight slip rings (Swiss Patent No. 88041). In addition, for each number of poles cascade connection is used so that four speeds in the ratio 16 : 12 : 8 : 6 are obtained.

In 1920, two more D-type locomotives (service numbers 368 and 369) were supplied, because, on account of the coal shortage during and immediately after the war, the three-phase traction through the Simplon was temporarily extended in 1919 along the Rhone Valley as far as Sitten.

The Simplon Tunnel was operated for nearly 24 years by means of three-phase current, service being maintained since 1920 by seven locomotives which handled without difficulty the greatly increased passenger and goods traffic after the war. Although three-phase traction has now been superseded by single-phase traction and is becoming a thing of the past, we may still claim the honour of having played a very big part in developing the idea of main line electrification—no matter of what system—and of having helped in paving the way for the subsequent electrification of our Federal Railways by successfully electrifying, nearly a quarter of a century ago, the longest tunnel in the world.

II. THE WORK OF THE TURBINE DEPARTMENT.

(1) Steam turbines.

During the past year the critical economic situation throughout the world had a marked influence on the sale of steam turbines, our Baden works in particular being affected since it cannot rely on a home market for turbines. In spite of the unfavourable conditions, however, turbines of an aggregate output of nearly 600,000 kW were ordered during the last twelve months, thus bringing the output of Brown Boveri turbines supplied or on order up to over 13 million kilowatts (Fig. 85). We naturally attribute this gratifying fact to the reliability and economy of our products, which fully hold their own even under critical market conditions.

The range of Brown Boveri single-cylinder steam turbines was increased within the past year by the addition of a further machine of 20,000 kW. For large turbines it was previously the practice to employ three to five impulse wheels, requiring diaphragms and packing glands in the high-pressure stage. It is significant, with regard to the respective merits of impulse and reaction turbines, that in order to increase further the reliability and economy, this design has been abandoned and the combined system reverted to which has been used since 1910 for small and medium-sized single-cylinder turbines, whereby practically all the power is developed by reaction blading (Fig. 86). In this turbine a pass-out is provided before the last stage, enabling part of the steam to escape without doing work in the last row of blades. The apparent loss of power is more than counter-balanced by the diminution of the leaving losses of the remainder of the steam and by the effective reduction in the amount of water present in the last stage. The turbine rotor, which previously consisted, as usual, of a shaft with keyed-on or shrunk-on wheels or drums (Fig. 86), is now built up—in the manner described by Dr. A. Stodola at the World Power Conference at Berlin in 1930—of separate discs and drums welded together and then annealed as a whole to eliminate stresses due to welding. There is no through shaft. The advantages of this design, known as a welded rotor, are very important. The rotor is very stiff and runs far below the critical speed. The distribution of the material is excellent, and by providing holes between the discs the whole rotor is heated uniformly and in the shortest possible time during starting or when the load varies. Wheels can no longer work loose and set up dangerous vibrations or cause wearing of the keys, wheels or shaft. The stress in the material is kept small due to the elimination of the central boring, and the weight of the shaft is low. That this new construction can be adopted without hesitation is clear from the fact that the stress in the material at the welds is only about 30 kg/cm², this giving a factor of safety with respect to the elastic limit of about 100 and completely eliminating any risk due to inexactitudes
in manufacture. Naturally these welded shafts were subjected to numerous very comprehensive tests before this design was adopted. The welds were stressed with the utmost severity, in tension by applying heavy hydraulic pressure between the discs; in shear by heating one disc and cooling the next; for resistance to shocks by a falling weight; and also by long duration bending tests. Finally, this new type of welded steam turbine rotor was tested under all conditions of loading and also by starting it up very quickly. Later on, in actual practice, it proved extremely satisfactory in numerous installations. The welded turbine rotor is protected by patent.

The largest — 20,000-kW — single-cylinder turbine built by us runs at 3000 r.p.m. and develops a coupling efficiency of 82% with an initial steam pressure of 20—25 kg/cm². It may also be supplied with steam at 30 kg/cm² if a slightly lower efficiency can be tolerated. It is used in cases where there is insufficient room for installing the more economical multi-cylinder machine, or where, on account of the short time during which it is run annually, its lower initial cost, and not the better fuel consumption of the multi-cylinder machine, is the decisive factor in determining the type of turbine.

During the past year, Brown, Boveri & Co. have again made important progress in the manufacture of high-pressure steam turbines. In 1930, three 25,000-kW, 3000-r. p. m. steam turbines for live steam at 55 kg/cm², 450° C, were erected and put into operation in Langerbrugge Power Station of the Centrales Electriques des Flandres (Fig. 88). Work was also begun on a three-cylinder steam turbine of 36,000 kW, 3000 r. p. m., 130 kg/cm², 480° C, with generator, for the Karoline Pit of the Witkowitz Bergbau und Eisenhüttengewerkschaft. The steam for this turbine is raised in a Loeffler boiler of Witkowitz design. After passing through the high-pressure cylinder, the steam will be reheated at 12 kg/cm² to 360° C in an intermediate superheater (also of Witkowitz design), heated by live steam. This will improve the thermal efficiency of the steam cycle and will prevent too much water from condensing out in the last stages of the low-pressure cylinder. Figs. 89 and 90 show photographs of this turbine during manufacture and on the test bed. It is interesting to note that with the works fully occupied, this new machine was designed and constructed in seven months.

After very careful investigations, a steam pressure of 130 kg/cm² was selected for the Karoline Pit plant by Dr. Havlicek, superintendent of the Witkowitz Works. We again call attention to the results of the investigations carried out by us on the choice of the most suitable steam conditions, published in the Brown Boveri Review 1930, No. 1.
and also to the paper presented by Messrs. Felix and Noack at the World Power Conference in Berlin, 1930, when they also agreed that the most economical live-steam pressure for large turbines is from 120 to 130 kg/cm². Investigations in America have also shown that a pressure of this order is the most economical, and that at higher pressures the increasing losses in the packing glands and at the blade clearances, and also the increased proportion of power required for driving the feed pumps, counter-balance the increased efficiency of the steam cycle. The facts laid bare during these investigations are so important and appear already to be playing such a big part in practical developments that we feel justified in reproducing once again the diagram Fig. 91.

A particular instance encountered in these considerations is that of a steam power plant with Benson boiler in which steam is raised near the critical pressure of 225 kg/cm² in order to prevent the formation of steam bubbles. A plant of this description was installed by Herry in Langerbrugge Power Station of the Centrales Electriques des Flandres for the express purpose of being free to select for the future extension of the power station that steam pressure

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**Fig. 87.** — Single-cylinder steam turbine of 20,000 kW, 3000 r.p.m., for pressures up to 30 kg/cm² and temperatures up to 450°C.

The shaft is built up of drums and discs welded together and afterwards annealed. The welded seams have a factor of safety of about 100 with respect to the ultimate strength of the material. Efficiency of turbine approx. 82%.

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**Fig. 88.** — Langerbrugge Power Station of the Centrales Electriques des Flandres et du Brabant.

(In the foreground are three Brown Boveri three-cylinder turbines, each of 25,000 kW, 55 kg/cm², 450°C; in the background are some Brown Boveri single-cylinder turbines of older design and high-pressure primary turbines.)
importance of this problem will be understood when it is realized that large power stations in America and Europe have, during full service, suddenly been shut down for hours at a time due to failure of the auxiliary machines.

Previously the simplest and most economical method of driving the auxiliary machines was by means of electric motors fed from the main network. With this system, however, the danger exists that if the current should fail, the auxiliary services, e.g., the condenser pumps and perhaps some separately mounted generator fans, would stop and thus interfere with the operation of the main machines. In low-pressure steam plants, the motors are often provided with stand-by

(2) Auxiliary machines.

When projecting a high-pressure steam power station, the choice of the kind of drive for the auxiliary machines is a very difficult task. The
steam turbines which normally run without load in a vacuum, but automatically take over the drive of the pumps should the current fail. In high-pressure plants, this method of guaranteeing continued operation of the auxiliary machines is not favoured because the high-pressure auxiliary turbines are heavy and expensive even if it is not wished to utilize the steam in the most economical manner.

In order to avoid failure of the electrically driven accessories due to occurrences in the external network, these machines are often run off a separate main, fed by a house generator either coupled directly to the main generator or driven by a special house turbine. However, disturbances can arise even in such a house network. If the house generator is coupled to the main generator, special measures must be taken when starting or paralleling the machines; if the house turbo-sets are independent units, they require separate auxiliary machines which again become potential sources of trouble.

For many years, Brown, Boveri & Co. have taken a leading part in all problems concerning high-pressure power plants and have not neglected the question of the most suitable drive for the auxiliary machines. In high-pressure plants it was also the practice at first to install special high-pressure auxiliary turbines, in addition to the driving motors for the condenser pumps and generator fans (Fig. 93). Since then, generator fans—in spite of the large volumes of air they must supply at low pressures—have been successfully built for a speed of 3000 r. p. m. This enables at least the generator fans to be driven in the most reliable manner, viz., directly by the main machine (Fig. 94).

Where the auxiliary machines are driven electrically or where local conditions require the use of a special motor-driven fan underneath the generator, as in Fig. 95, for example, the motors of the auxiliary machines can be connected up, according to a patented system, directly or through a transformer between the generator and generator circuit breaker. Thus if the breaker were tripped by a disturbance in the mains, the auxiliary services would

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**Fig. 92.** — High-pressure primary turbine of the Centrales Electriques des Flandres et du Brabant, for 4000 kW and a live-steam pressure of 200 kg/cm² at a temperature of 450° C. Turbine coupled to a Sulzer boiler feed pump for a water pressure of 300 kg/cm², an asynchronous generator, and a stand-by turbine for a pressure of 55 kg/cm².

**Fig. 93.** — Auxiliary machines for a high-pressure steam power station comprising condenser pump with motor drive and stand-by high-pressure turbine for 55 kg/cm².
Fig. 94. — Turbo-alternator for 36,000 kW, 3000 r. p. m. with separate fan driven directly by the generator.
The cooling air is forced downwards by the fan through the coolers and into the generator, and is drawn out again at the top.

not be interrupted. An arrangement of this description is illustrated in Fig. 96, from which can also be seen the means taken to protect the main generator from possible breakdowns in the auxiliary motors. These motors are not provided with separate switches, thereby avoiding another possible source of trouble. Instead, short-circuit proof over-current relays are incorporated in the motor circuits for tripping the main switch in the event of a short circuit in an auxiliary motor. Then, by switching off the excitation, the output of the generator is reduced to zero.

Maximum operating reliability of a steam power station is undoubtedly ensured by driving the auxiliary machines directly from the main machines. For reasons of safety, the most important auxiliaries, viz., the oil pumps, have always been driven directly from the main machines; to drive the condenser pumps and generator fans mechanically must therefore also be advantageous. In large sets such a drive is called upon to transmit quite large powers. On account of the diameter of the turbine and generator, the level of water in the circulating-water channel, and the position of the condensate pump underneath the condenser, it has to bridge over a certain distance between the shafts of the main and auxiliary machines. After bevel, worm and chain drives, etc., had been studied and found unsuitable, the method of driving the auxiliary machines by a train of gears was adopted. This is a new and unusual arrangement but provides a technically perfect solution of the problem. In order to keep the distance between the main and auxiliary shafts as small as possible, the condensers and the air coolers for the generator are built on to the side of the turbine and generator in an elevated position. The whole turbo-set is mounted on a foundation of steel and the pumps and generator fans arranged between the girders of the foundations near the main machines. The auxiliary shaft also drives the oil pump so that only the governor and safety

Fig. 95. — Turbo-alternator of 20,000 kW with motor driven fan between the foundations.
The fan runs at 1000 r. p. m. and can therefore be designed for a high efficiency. The air conduits are built into the foundations.

The motors of the auxiliary drives are connected up without switches between the generator terminals and the main switch. Thus even if the main switch trips they do not stop.

1. Generator.
2. Exciter.
3. Motors for condenser pumps, generator fans, etc.
4. Voltage regulator.
7. Over-current relay.
8. Intermediate relay.
10. Tripping coil of oil circuit breaker.
11. Stator field switch.
12. Double-core current transformer for differential protection, etc.
15. Change-over switch.
16. Field regulator.
17. Adjusting resistance.
18. Push-button switch.
19. Auxiliary current supply.
20. For connecting up instruments.

Before starting up the set, a quick-acting steam ejector produces a moderate vacuum in the condensers and primes the pumps. Such turbo-sets are completely assembled and tested in the works and the steam part, i.e., turbine, condenser, and pumps, is despatched as one unit, so that the erection on site can be carried out in a few days. The illustration shows the turbine group in running order being loaded on to a railway truck.

Another very important problem which has to be faced in steam power plants is the generation of peak loads such as occur every evening in large municipal generating stations. Some characteristic load diagrams taken in New York, Berlin and Parisian power stations on a December day are shown in Fig. 99. In addition to the daily basic load, of about 12 to 14 hours duration in winter, there is, for example, a peak during the morning — though this only occurs on the shortest days — of about two hours duration and equal to 15 to 20% of the basic load. There is also a peak in the evening of about five hours duration which may reach as much as 50% of the basic load. In every case, however, the load during the night is only a fraction of the average load during the day time. The question now arises as to how these load fluctuations can be dealt with.

In most large municipal generating stations, the machines and boilers not required are shut down during governor remain on the main shaft, the usual gearing being dispensed with. Finally, in order to reduce the length of piping, the feed water heaters, which are heated by steam extracted from the main turbine, are incorporated in the same block. By suitably designing the individual parts, it was possible, in this way, to combine all the machines and apparatus of the steam generating plant not pertaining to the boiler into a self-contained set which is readily accessible and occupies a minimum amount of space. The method of driving the auxiliary machines directly from the main machine, the short length of the piping, and the standardized manufacture and assembly of the whole machine, result in the increased reliability so greatly desired. Fig. 97 shows a combined set of this description (known as a “Turbloc”) with a three-cylinder steam turbine of 25,000 kW. The drawing is explained in the legend. A similar set for a smaller output (1500 kW) is shown in Fig. 98. In this case, the turbine runs at 7500 r. p. m. and drives the generator through gearing at 1500 r. p. m. The condensate pump is at the same height as the turbine shaft, but the condensate is supplied by an ejector pump mounted low down on the set. The air is drawn out of the condensers, placed lengthwise on each side of the turbine, by a steam jet air ejector. The exhaust steam from this air ejector is used in the usual manner for heating the boiler feed.
the night and started up again when the load increases. For reasons of reliability, however, as many machines are always kept running as can meet the demand for current, should one of the sets in operation break down, by utilizing their overload capacity at least until a stand-by machine has been started up. Reliable and economic operation demand that it should be possible to start up the machines in a few minutes without producing dangerous vibrations, no matter how long they have been standing idle. It should be mentioned here that Brown Boveri turbines are specially designed for this purpose and can be started without vibration from any temperature without a long period of warming up. During the day, the machines should be so loaded that they operate at the most economical point of their efficiency curve. During the short and not very big drop in load at mid-day they are usually kept running, being supplied with such partial loads that they can run with a few but fully opened sets of nozzles and with full steam pressure, i.e., with the best possible efficiency. Under the present system of operation, while the peak lasts (particularly during the evening) other
would be very undesirable, might be considered as exceptions. It should also be noted, however, that when a storage plant is added to an old power station, the latter must operate for longer periods and more intensively, and therefore also has a greater unpleasant effect on the neighbourhood. Steam storage might also be suitable for certain industrial purposes where there is a heavily fluctuating demand for heating steam, and where the boilers are of the old type and incapable of adoption to varying loads. Our investigations have also shown here that a modern boiler with adaptable and special automatically controlled firing is, in most cases, completely suitable for such conditions, whereas the employment of a thermal storage plant introduces big complications and not infrequently reduces the efficiency. In the following paragraphs the reasons are given why Brown, Boveri & Co. never took up the manufacture of thermal storage plants and why they considered the correct solution of the problem of supplying peak loads to lie in making the generating plant capable of being heavily overloaded.

A modern high-pressure boiler with large radiation heating surfaces and air preheaters operates over a wide range with only slightly varying efficiency. Fig. 100 shows the efficiencies of two American boilers and of a German boiler burning lignite. From one-quarter load to full-load the efficiency does not fall by more than a few per-cent below the maximum. For reasons of economy, and in order to prevent damage to the brickwork, a boiler of this kind is operated with a daily basic load corresponding to its highest efficiency, say, of about 30 kg/m² per hour, so that during the peak loads it can be brought up to one and a half to twice the full load without any appreciable reduction in the efficiency.

In the same illustration, some points B are indicated which show that if the load is taken off the boiler for five to ten hours during a 26-hour test, there is practically no diminution in the efficiency. Tests carried out by ourselves and others have shown, in agreement with this, that in a modern boiler with under-feed stokers if the air supply is completely cut off the pressure can be maintained for a period of 24 hours, and that of the glowing coal on the grate only 0·5 to 1·5 kg per sq. metre of evaporating surface is burned in 24 hours. This proves that the old idea about heavy losses in a boiler operated with a varying load is no longer true, and that there is no point in providing thermal storage

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1 See the Brown Boveri Review 1928, No. 1, 35.
For supplying the load peaks in large municipal power stations, Brown, Boveri & Co. have also developed a special peak-load turbine which operates at normal loads with the maximum efficiency of 84 to 86% attainable at the present day and can take peak loads of approximately 50% with only a very small drop in efficiency. Fig. 102 is a section of a peak-load turbine of patented design. To obtain the overload capacity of the otherwise standard turbine, the impulse stages and some of the reaction blading are by-passed, and live-steam supplied directly to a lower stage of the high-pressure cylinder. From Fig. 103 it will be seen that this turbine develops from 60 to 150% of its output at an efficiency of over 81%.

The generator driven by a peak-load turbine must be capable of developing a peak load continuously because it will be required for several hours at a time in winter. Compared with a smaller machine, the efficiency of this generator—as will be seen from Fig. 104—is somewhat higher at full load, almost equally good at normal load, and only at 50% normal load about 1% less.

The condenser will, if anything, be chosen rather large for the normal load so that a good vacuum can be maintained on overload. In addition, an overload circulating water pump will be used, this being stopped on normal load in order to reduce the power required by the pumps.

The heat consumption per kilowatt-hour of a peak load station, together with all auxiliary machines and boiler feed pumps, is shown in Fig. 105 as a function of the load. From full load to 50% overload it only increases by about 6%.

In contrast to this, the heat consumption per kilowatt-hour of a thermal storage plant is 50 to 70% higher than that of a good normal power station at full load due to the big loss in pressure when charging and discharging the accumulator,
The turbine can develop 16,000 kW with an efficiency of about 84\%, and a maximum output of 24,000 kW with an efficiency of about 82\%.

Fig. 103. — Efficiency of the Brown Boveri peak load turbine.
The coupling efficiency of this turbine from 60 to 150\% full load is over 81\%.

Fig. 104. — Generator efficiencies of the 30,000-kVA generator for a peak load turbine of 16,000/24,000 kW.
At 20,000 kVA both generators are almost equally efficient.

Fig. 105. — Heat consumption of a peak load power station with turbines and boilers capable of being heavily overloaded, including all auxiliary machines and boiler feed pumps.
From normal load to about 50\% overload the heat consumption only increases by about 6\%.

to the low efficiency of the turbine which operates on a continually falling pressure, and on account of the big loss of heat in the thermal storage plant. In such a power station, therefore, the peak loads are produced at a very low efficiency which it would only be possible to tolerate if a great saving in the capital expenditure were effected.

This, however, is not the case. According to our calculations, the initial cost of a peak load station, with boilers and peak load turbines capable of being heavily overloaded, is only some 5 to 7\% higher than that of a power station of previous design, this increased cost being due to the larger generator, the additional regulating valve for the turbine and the somewhat bigger boiler fans.
Now under normal conditions a power station can be built for Frs. 300. — per kilowatt; therefore a plant designed to supply a 50% peak load continuously would cost about Frs. 320. — per kilowatt. Thus the initial cost of a peak-load station for an average pressure, with boilers and turbines capable of being heavily overloads, is only Frs. 210. — per kilowatt referred to the peak load which it is capable of supplying continuously, and at any time. A thermal storage plant would, according to published building costs, be about 10 to 20 % more expensive, and at the same time suffers from the big disadvantage that it can only supply this peak load for a short time, e.g., for about two hours, and then only after previous charging for several hours. The higher costs of a thermal storage power station compared with a peak-load plant will be realized still more clearly on considering the initial costs of the whole power plant group required for furnishing the basic load and the peaks. Taking into account the storage capacity and the shape of the load diagram, a maximum load of say 100,000 kW would require a normal power plant of 80 — 90,000 kW and a thermal storage plant of 20,000 to 10,000 kW. According to the above estimate, this represents an initial cost of about Frs. 29,000,000. Compared with this, a peak load station with boilers and turbine capable of being heavily overloaded costs only Frs. 21,000,000.

Apart from the high cost and poor efficiency, the thermal storage plant has the further disadvantage that it cannot serve as a stand-by for the normal boilers. Should any boilers be shut down, there is insufficient boiler power for the peak loads and for charging up during off-peak periods. The peak-load turbines also cannot be regarded as effective reserves for the ordinary turbines as they can only run on throttled steam at a reduced temperature.

The investigations we have carried out also show that a steam power station with boilers and turbines capable of being heavily overloaded is much better suited than a thermal storage plant to serve as an instantaneous stand-by to a municipal generating station. From the very nature of the thermal storage plant, from the length of time during which it can be used, and from the shape of the peaks of the load diagram it is clear that the installed power of such a plant will be about 10 to 15 % of the maximum daily load. This power, which is intended for supplying the peak loads, is certainly available as an instantaneous reserve, provided the storage plant is charged. It is, however, incorrect to suppose that the thermal storage plant can be used at one and the same time for supplying peak loads and as an instantaneous stand-by. While supplying peak loads, i.e., at a time when disturbances are most likely to occur, and also during the charging period, the thermal storage plant can be used either not at all as an instantaneous reserve or only to a limited extent. The boilers and generating sets in operation must then immediately supply the shortage of power if any trouble arises in the plant. In direct contrast to this, a peak load power station with modern overload boilers and turbo-sets which, as described above, operate all day long at the best efficiency and about two-thirds the maximum possible output, is ready at any time to take over instantaneous overloads up to the limits of its capacity. Peak-load generating stations of this kind occasion no special losses during ordinary service, whereas a thermal storage plant kept as an instantaneous stand-by continuously requires about 4 % of the maximum output to compensate the losses of the turbine, which is kept running idle, and of the condenser plant.

In order to emphasize the reasons given, some of which are very serious, we repeat that in our opinion boilers and turbines capable of taking heavy overloads, and not thermal storage plants, should be provided in steam power stations for supplying peak loads and furnishing an instantaneous stand-by in the event of individual sets having to be shut down. We also consider it unwise, with a view to the future development of a generating station, to spend the usually limited money available for extensions or new stations on equipment which, though able to meet the present peak load demand, makes it necessary to employ old plant, with an efficiency far below that of modern machinery, for supplying the basic load. It is undeniably the better policy to buy modern boilers and turbo-sets for generating the basic load and to use the old, existing equipment, as far as necessary, for the brief peak loads.

The feed-water accumulator as made by the Kraftanlagen A.-G., Heidelberg, a firm in close touch with Brown, Boveri & Co., provides a noteworthy means of increasing the peak load capacity of an ordinary power station. In contrast to the thermal storage plants considered, this does not store working steam but hot boiler feed water which is heated to 180—200° C by steam tapped from the turbines during periods when the load on the boilers is light. The feed-water
reservoir is charged by heating both condensate and cold water from the storage tank in the feed heaters, these being heated by steam extracted from the turbine. The cold water is drawn out of the lower, cold part of the reservoir and, after heating, is accumulated in the top part. While the peak lasts, the large quantity of feed water required is taken from the top part of the accumulator, and at the same time the preheating of condensate and storage water is suspended. As a result, the steam consumption and the load on the boiler for a given turbine output are increased during off-peak periods compared with operation without the feed-water accumulator, but are reduced during load peaks due to the elimination of feed heating by extraction steam. By suspending the feed heating, the output of the turbine can be increased with the same steam consumption by 10 to 15 %, according to the size of the feed heating plant, a corresponding peak load and instantaneous reserve then being available. Fig. 106 shows diagrammatically a power plant with hot water accumulator. It will be seen that when the steam pressure falls, the valve in the pipe line through which the storage water flows is throttled, and thus the feed heating reduced. In a

plant of this type, equipped with feed water accumulator, the boilers and turbines may be quite normal or capable of being heavily overloaded in the sense already described. Thus all the enumerated advantages of a pure power station over a thermal storage plant remain unchanged. However, even the feed water accumulator is not cheap and is only capable of storing a limited amount of energy. For a given volume, its storage capacity is nevertheless several times greater than that of a steam storage plant, so that it is correspondingly less expensive. Each case must be investigated separately, taking into consideration the load conditions and the existing equipment, in order to determine whether the installation of a hot water accumulator is economically justified.

During the past year, a process for quickly and safely starting large turbines without special previous heating was developed; it is therefore of interest in the present connection. According to this process, which was proposed and described by Mr. Eric Brown at the World Power Conference in Berlin, 1930, the steam turbine is kept at a temperature above or near the saturation temperature of the steam supply, for example by means of hot air which is circulated round or through the turbine; thus when starting the machine, condensation of steam is prevented and excessive temperature differences and heat stresses in the turbine cannot occur. This renders it possible to start even the largest machines in about one minute and to shut them down temporarily when not required without any misgivings. The process will be followed more clearly on reference to Fig. 107. The heating air is drawn by a fan through either a steam or electric heater and then circulated round the turbine underneath the lagging. This process increases to a great extent the freedom with which the units in a power station can be chosen, and also the possibility of starting stand-by machines. In our opinion, it will be very widely employed in future in large generating stations.

A new feed water evaporator was developed by our condenser department during the past year. In order to prevent incrustation of the boiler, all the sediment is deposited in the evaporator, which is therefore designed so that it can be opened up and cleaned with a minimum of trouble. The tube nests are formed of layers of tubes which can be removed separately without the use of a crane and then readily freed from chalk deposits by beating, brushing, or by means of acids. Fig. 108 illustrates the new Brown Boveri evaporator; the practical arrangement and ready accessibility will be clearly seen.

A new condenser pump set comprising circulating water pump, ejector pump and condensate pump has been designed for large steam turbines up to 40,000 kW (Fig. 109). If used in a peak load power station, an additional circulating water pump as shown in Fig. 110 would be provided. This would not be used for normal loads. The ejector and condensate pumps of the combined set can be designed for the highest outputs necessary.
(3) Turbo-compressors.

According to the experience of our blower department, a definite reversion is now taking place in the construction of blast-furnace blower plants from the gas engine driven blower. It has been realized that reliability is as equally important as a high efficiency and therefore the more reliable turbo-machine is being used to an increasing extent, particularly as the efficiencies now attained by steam power plants are no longer inferior to those of gas engines. Since turbo-blowers are also more economical than large reciprocating compressors, gas-fired steam boilers with turbines and turbo-blowers are now preferred in Europe and America to gas-engine driven compressors. Fig. 111 shows two large modern blast-furnace blowers for Rheinhausen Colliery, each for a delivery volume of 2800 m³/min, and Fig. 112 the blower plant of the Mannesmannröhren-Werke, Huckingen, containing two steel-works blowers, each for 600 m³/min, 2·8 kg/cm², 2900 r. p. m., and three blast-furnace blowers, each for 1800 m³/min, 2·5 kg/cm², 2930 r. p. m. These blast furnace and steel-works blowers are preferably provided with movable diffuser blades, as in Fig. 113, which enable the delivery volume to be varied within wide limits at the best efficiency. Fig. 116 shows the pressure-volume and efficiency curves of such a blower with movable movable diffuser blades.

Fig. 107. — Equipment for enabling large steam turbines to be rapidly started up.

By this method the turbines are kept at a temperature above the saturation temperature of the working steam by means of hot air so that even large machines can be started at any time in about one minute.

1. Fan.
2. Heating apparatus.
3. Lagged covering of turbine.
4. Sheets for guiding the hot air round the turbine.

Fig. 108. — Brown Boveri feed water evaporator.

The tube nest is subdivided. Each layer of tubes can be readily removed and easily cleaned.
been adopted more recently according to which the blower and other auxiliary machinery are driven through step-up gearing by, for example, an auxiliary Diesel engine. A blower of this description with gearing, on to which the other auxiliary machines are also built, is shown in Fig. 109. The blower runs diffusers for various settings. The envelope of the curves shows what excellent regulation can be obtained by this method. By closing the diffusers, the stable operating range of the blower can be extended almost as far as desired towards the no-delivery point. The regulating equipment of a large blower for a Russian blast-furnace plant is illustrated in Fig. 115. In this instance, a special condition had to be fulfilled that it should be possible to regulate the blower to constant delivery pressure or, by simply changing over a valve, to constant suction volume. This called for considerably more regulating apparatus than normally required. The plant will enable practical experience to be gained as to the relative advantages of pressure and volume regulation, a question concerning which great differences of opinion always exist between engineers and works chemists. The movable diffusers are adjusted by hand to the most favourable conditions. Pumping of the blower is prevented by a blow-off valve which is automatically adjusted to the smallest blow-off volume for each diffuser position by the closing of the diffusers.

Up to the present time, Brown, Boveri & Co. have supplied about 230 scavenging blowers, all driven by electric motors or steam turbines, for two-stroke cycle Diesel engines. In contrast to this kind of drive, another method has...
Fig. 112. — Blower plant of the Mannesmannröhren-Werke, Huckingen.
Two steel-works blowers, each for 600 m³/min, 2-8 kg/cm² abs, 2900 r.p.m.; three blast-furnace blowers each for 1800 m³/min, 2-5 kg/cm² abs, 2950 r.p.m.

Fig. 113. — Movable diffuser for a turbo-blower for adjusting the delivery volume to widely varying operating conditions.

Fig. 114. — Diagrammatic arrangement of the regulating apparatus of a blast furnace turbo-blower equipped for constant-volume regulation and designed for changing over to constant-pressure regulation.

Fig. 115. — Control apparatus for regulating to constant delivery volume and for operating the automatic blow-off valve.

Fig. 116. — Pressure-volume curve of a turbo-blower with movable diffusers.
The envelope gives the maximum pressure attainable with various delivery quantities.
at 4600 r. p. m. Since it is accelerated up to full speed in a few seconds by the Diesel engine, the blower and also the gear must be specially designed for the high acceleration torque.

The Büchi system of charging four-stroke cycle Diesel engines by means of Brown Boveri exhaust-gas turbo-driven blowers has made noteworthy progress during the past year. Up to the present, orders have been received for 110 of these sets for Diesel engines with a total supercharged output of about 250,000 H.P. About 50 sets are already running and giving excellent service. This method of charging has also proved extremely satisfactory for high-speed heavy-duty Diesel engines as built, for example, for submarines. Fig. 119 shows a charging blower with exhaust-gas turbine drive for a submarine. In view of the space available, the set was made with vertical shaft. The results of tests carried out on the high-speed M.A.N. Diesel engine to which this blower was fitted (see Fig. 118) show that, in spite of the increase in power, the exhaust-gas temperature of the engine and the fuel consumption per horse-power decreased very considerably. In comparison, still better results are obtained on slow-speed Diesel engines with charging blowers. A photograph is reproduced in Fig. 120 of a 1150 H. P. Diesel engine made by
in them, and then only with great difficulty. Since vapour compression machines using ammonia, sulphurdioxide, etc., as refrigerants cannot be employed in these mines, Brown, Boveri & Co. developed an air dehumidifying plant in which the air to be cooled is used as the refrigerating agent. The air is compressed in a turbo-blower and then cooled in an intercooler where a large proportion of the water is separated out. Afterwards it expands to a temperature of about $-5^\circ$ C in a turbine directly coupled to the blower and driving motor, further moisture being deposited as ice. The ice is removed in a water separator of special design so that the air is cooled and, at the same time, its humidity reduced to about 10% of the original value. This cold air machine certainly requires a somewhat greater power than a vapour compression machine using ammonia or sulphur-dioxide; danger due to the escape of poisonous gases is, however, completely eliminated, which renders this plant the really only suitable kind for installing in a mine. Fig.123 shows the preliminary trials being carried out on a refrigerating machine of this type.

With regard to high-pressure compressors, Fig. 122 shows the pressure-volume and efficiency curves obtained during the trials on the air compressor supplied to the Victoria Falls and Transvaal Power Co., Transvaal. This is the largest compressor that has ever been built. Fig. 124 illustrates the

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Fig. 120. — Four-stroke Diesel engine for 1150 H.P., 215 r.p.m., built by the Swiss Locomotive and Machine Works, Winterthur, with Brown Boveri charging blower and exhaust-gas turbine.

Fig. 121. — Four-stroke Diesel engine built by Messrs. Harland & Wolff for the Silver Line (M.S. "Silver Walnut"), with Brown Boveri charging blower and exhaust-gas turbine.

The charging blower increases the output of the engine from 2000 H.P. at 90 r.p.m. to 3350 H.P. at 110 r.p.m.
mounted on two shafts and driven at 8400 r. p. m. by a motor through step-up gearing.

(4) Marine drives.

Our marine department has taken up the construction of exhaust-steam turbine plants for vessels propelled by reciprocating steam engines, as already proposed by Parsons 25 years ago but which only recently attracted the attention of ship-owners. In these plants the exhaust steam from the reciprocating engine performs further work in a turbine, the power of which is transmitted to the pro-
Vessel | Displacement Tons | Previous performance | New performance |
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<td>SS &quot;Amasis&quot; HAPAG</td>
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One of these plants is illustrated in Fig. 125 on the test bed. Fig. 126 shows the wheels of the reduction gears, and Fig. 127 the coupling provided between the gearing and propeller shaft. The characteristic feature of the Brown Boveri exhaust-steam turbine plant is that the turbine is always coupled to the propeller shaft through the gearing. There is no clutch, and thus all danger of the turbine running away while manoeuvring, due to a leaking change-over valve, is completely eliminated. When manoeuvring, live steam is supplied to the turbine in such a way that the whole engine is decelerated and accelerated again in the required direction, thus rendering the manoeuvring time as short as possible. The manipulation and control of the machine is made extremely simple and convenient for the engineer by means of oil relays, this also serving to reduce the manoeuvring time.

On steam vessels, the auxiliary machines are driven by the main engine, by auxiliary steam engines or small steam turbines. Figs. 128 and 129 show the condenser pump sets and boiler fan for a torpedo boat. They are driven by high-speed geared steam turbines. By building the turbines for a high speed their weight was kept low and their efficiency high.

The first requirement placed on marine lighting sets is reliability, and for this reason the independent drive already described for the auxiliary machines of...
stationary plants has recently been adopted for these sets. In Fig. 130 is shown a marine lighting set of 850 kW. The turbine runs at 8000 r.p.m. and drives the generator through a reduction gear at 850 r.p.m. The pumps of the condenser plant are driven from the same gearing.

(5) Gear drives.

As regards the construction of gears, further progress has been made by improving the methods of checking and also the gear cutting machines and cutters. It is interesting to note that with the methods of measuring we now use it is possible, by measuring the teeth, to determine in advance the various tones of the noise produced by a gear when running. This obviously provides further possibilities of discovering and removing sources of trouble, thus increasing the field of application of gears for larger powers and higher speeds. Fig. 131 illustrates a reduction gear for 140 kW, 1225/350 r.p.m., which can be run in either direction. It will be seen that a thrust collar, of the well-known Brown Boveri type, is provided at each end of the pinion for taking the axial thrust of the single-helical teeth.

(6) Steam boilers.

Some time ago a description was given of the Brown Boveri cascade injection boiler. It resembles the Loeffler boiler in that it has no heating sur-

faces in contact with the water but only superheater surfaces; in contrast to the Loeffler boiler, however, it requires no steam circulating pump. We will again describe the new principle on which this boiler works.
For a boiler with a working pressure of say 130 kg/cm², about 5% of the required weight of steam is raised at a pressure of approximately 150 kg/cm² in the first so-called "exciter" stage which comprises a small boiler of any convenient design. This exciting steam is superheated in coils of tubes heated by direct radiation from the furnace, and then flows to an evaporator (a small cylinder fitted with baffle pieces) situated at some convenient point outside the furnace.

In this evaporator an excess quantity of hot feed water, corresponding to the maximum output of the boiler, is sprayed into the superheated steam from a water reservoir lying outside the boiler but under the full steam pressure. Due to the superheat of the steam a corresponding amount of the feed water is evaporated, while the remainder flows back to the water reservoir. The quantity of steam, which has been increased by about 40% in this first stage, now passes to a second superheater stage, then to a second evaporator stage where it again evaporates a quantity of feed water equal to about 40% of the quantity of steam flowing into the evaporator. After at most 10 of these stages the required quantity of steam, i.e., 20 times the original quantity of excitation steam, is obtained, which is then finally superheated to the live-steam temperature required in the turbine. The steam leaves the exciter boiler at about 150 kg/cm², flows through the various superheaters and evaporators under a natural pressure drop, and passes to the turbine at 130 kg/cm². The number of stages is smaller the higher the steam pressure, the greater the superheating in each stage and the higher the temperature to which the feed water is heated. For example, steam at 20 kg/cm² abs with a temperature of 480°C in the superheaters can be produced in 10 stages, while steam at 130 kg/cm² abs can be raised in 8 stages. The number of stages, however, has practically no influence on the design and cost of the boiler as its size is determined essentially by the heating surfaces in contact with the hot gases. In the first example, the steam is driven through the boiler with a pressure difference of about 3 kg/cm² and in the second with a difference of 20 kg/cm². In contrast to the Loeffler boiler, no pump having to circulate three to four times the working steam through the evaporators is required. Thus this technically undesired auxiliary machine, which involves a loss of power of 3 to 4% and is of complicated design, is avoided. It might be mentioned here that the Brown Boveri cascade boiler can be operated with an "exciter" pump instead of the exciter stage for supplying the excitation steam, this pump raising about 5% of the final quantity of steam required to the initial pressure. It should be noted that the capacity of this pump is only slightly more than 1% of that of the Loeffler circulating pump; the pump is therefore much cheaper, causes only negligible losses and is much less liable to faults in design and failure when running. In this steam boiler, there is, apart from the small exciter stage, a complete absence of water tubes and drums with their difficulty of circulation and danger of incrustation. The steam is forced through the superheater tubes at a high velocity, thus rendering it possible to use small diameter tubes with thin walls and therefore of light weight. In contrast to the drums of water tube boilers, the water drum outside the boiler is not weakened by numerous holes for the tubes and is not subject to the heat of the fire. It can therefore be of light construction. It is, in fact, nothing more than a hot water reservoir, the pressure inside which, in our case, can vary between 150 and 130 kg/cm² according to the quantity of steam raised. The capacity of the water drum is chosen according to the operating conditions and enables any desired flexibility to be given to the boiler. Altering the fire has a direct effect on the steam flowing through the boiler, it being unnecessary to heat up large quantities of boiler water. Since the design of the boiler avoids as much as possible all brickwork in which heat is stored, the output of the
heater in which the temperature of the condensate—usually already heated by steam extracted from the turbine—is raised to that of saturation.

Messrs. Humboldt have had an experimental boiler working on the cascade evaporation system in continuous use in their own works for a considerable time. An existing boiler of somewhat large size was used for raising the excitation steam, the quantity being approximately doubled in three superheating and evaporating stages. The test, which it was intended should provide information regarding the superheaters and evaporators, proved these parts, and indeed the whole system, to be entirely suitable. In Fig. 133 will be seen the three evaporators in which the feed water is evaporated by spraying it into the superheated steam. The plant appears somewhat complicated due to the use of existing equipment, though it will be realized how small the evaporators are compared with the furnace of the boiler.

We also intend, very shortly, to install a cascade boiler of this type for

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Fig. 132. — Brown Boveri cascade injection boiler as projected by the Maschinenbau-Anstalt Humboldt, Köln-Kalk.

The characteristic feature of this boiler is that the heat from the fire is transmitted to steam flowing through superheater coils and not through heating surfaces in contact with water. The flow of steam is produced by a natural pressure drop and not by a circulating pump.

1. Pulverized coal burner. 5. Superheaters.
3. Air preheater. 7. Economizer.

boiler can be immediately adapted to the new steam requirements by regulating the fire. This ease with which it can be varied renders the cascade injection steam boiler particularly suitable for use as an instantaneous reserve and as a peak load boiler.

A drawing is reproduced in Fig. 132 of a cascade injection boiler as designed by our German licencees, the Maschinenbau-Anstalt Humboldt, Köln-Kalk. The superheater coils lining the furnace all consist of exactly similar elements built up of tubes about 30/44 mm diameter. The evaporator units in all the stages are of the same size, but in the later stages two and three units are connected in parallel. After the superheaters, the flue gases pass over a feed

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Fig. 133. — Experimental plant with a Brown Boveri cascade injection boiler built by, and in operation at, the Maschinenbau-Anstalt Humboldt, Köln-Kalk.

Note the three evaporators.
about 20,000 kg of steam per hour in our own works for the steam turbine test beds.

(7) Scientific investigations.

A large number of scientific investigations have been carried out in our turbine testing department, some of which are as follows:

Continuation of tests on impulse and reaction turbine blading in order to increase our knowledge of the effects of blade length, clearance, blade angle and amount of admission; tests on the flow of steam through turbine blades and nozzles; tests on labyrinth, carbonring, and fluid packing glands for turbines in order to determine the losses due to leakage and the behaviour of the various materials; tests on double-beat valves to determine their stability; tests on thrust bearings; tests to determine the resistance to erosion of various materials used for turbine blades; tests on pressure regulators and pressure reducing valves for pressures up to 200 kg/cm²; tests on welded steam-turbine drums and their behaviour when stressed in various ways and under different operating conditions; tests on roller and ball bearings at high speeds and high temperatures; tests on steam stop valves with double packing for preventing steam leakage to the turbine; investigations on the draining of steam turbine blading; tests on propeller-type fans; tests with blower and compressor impellers; tests regarding the loss of pressure in the bends of air pipes; investigations on the dehumidification of air by means of cold air refrigerating machines.

The tests on the elements of gas turbines have been completed so that it was possible to commence the construction of a gas turbine. Experiments were also conducted on measuring-nozzles of various forms and sizes. Different apparatus for the transmission of heat, with various shapes and arrangements of cooling tubes for various cooling agents, were tested in order to determine the coefficient of heat transmission. In conclusion, a sectional drawing is reproduced in Fig. 134 of the axial experimental compressor with wind tunnel and measuring nozzle.

III. THE WORK OF THE RESEARCH DEPARTMENTS.

First of all the field of physical research will be considered, in which important work has been done on the investigation of the cathode spot. It was attempted to fix this in a conical funnel of tungsten and then to determine the current density with the cathode spot completely covering the mercury. It was also wished to ascertain whether the cathode spot distended to any measurable extent in the direction of the current. The apparatus shown diagrammatically in Fig. 135 was used for these investigations.

The cross-sectional area of the free mercury could be conveniently varied and measured in the conical tungsten funnel. In each case the current was increased until the cathode spot just covered the surface of the free mercury. Under these circumstances the current density was measured: it varied between 17 and 19 A/mm².

In order to measure its depth, the cathode spot had to be magnified at least 30 times. The binocular magnifying glass used for this purpose had a focal length of only about 7 cm, and the apparatus in which the arc was produced had therefore to be designed so that the objective could be placed at this short distance from the fixed cathode spot. This was accomplished by means of the apparatus shown diagrammatically in Fig. 135. Vertically above the conical
funnel of tungsten is the observation glass, which is cemented on the outside and cooled with water. Mercury which condensed on the inside of this glass was continually removed by a window wiper operated from the outside. Where the operating rod passed through the casing it was ground to an accurate fit and greased (to prevent air leaking into the apparatus). The observations were made when the cathode spot enveloped part of the line of contact of the mercury and funnel. When magnified 30 times, the cathode spot appeared as an oval-shaped, brightly illuminated, and rapidly vibrating cloud of gas with a very definite elongation perpendicular to the side of the funnel in the direction of the current. The line of vision was tangential to the side of the funnel. It was thus possible to calculate the thickness of the cloud to within a few hundredths of a millimetre.

Following on the measurement of the thickness it was endeavoured to record particulars of the rapidly vibrating fixed cathode spot by means of an ultra-rapid camera (Fig. 137, below). The exposure frequency, however, was only 200 pictures per second, and due to the minuteness of the component parts of the cathode spot, it was impossible to draw any useful conclusions from the pictures.

Interesting experiments were also carried out to determine the variation and magnitude of residual charging currents during a short circuit on a single anode in mercury arc rectifiers, with current peaks up to 4600 A per anode. Fig. 136 shows diagrammatically the apparatus used. The single-phase transformer 9, with a transformation ratio of 8000/440 V,
supplies the short-circuit current for the circuit containing the anode, cathode, and limiting resistance, this current being recorded by the oscillograph element 6. During the period when the current is not flowing, the oscillograph element 7 records the residual charging current on the sleeve. The exciting anode 4 is connected to a battery, the current being limited by the resistance R to 5 A. While the oscillographic record was being taken, the switch 12 was closed; it was opened again immediately afterwards.

The oscillogram Fig. 138 shows the variations of the arc current and the dependent residual charging current in the sleeve during the time when the arc passes no current. The part of the residual charging current passing to the anode is smaller, and it was impossible to record it with this arrangement. Even though the residual charging current in the sleeve actually has a larger value than the current flowing to the anode, both must nevertheless be of the same order of magnitude. What is also of interest here, however, is the magnitude of the residual charging current for various arc currents and various cylinder temperatures, i.e., for various mean densities of the mercury vapour. The part which diffuses out of the continuously-burning ignition arc is specially shaded in the oscillogram. The oscillogram Fig. 138 shows the current variation of an anode with a maximum value of 4600 A. During the period when the arc passes no current, only the residual charging current in the sleeve is recorded. Shortly after interrupting the anode current, this suddenly increases, attains a value of 57.5 mA after 1.4 x 10⁻³ second, and falls to zero when the arc begins to pass current. The current in the sleeve does not fall steadily: pronounced steps can be clearly seen.

In the oscillogram Fig. 138 the probable current variation of this part is shown dotted. It is to be assumed that this is a saturation current, i.e., a constant, dependent current. This variation can only be produced by the constant ignition current and must be independent of the arc current. In Fig. 139, saturation values of this part of the current, as derived from a number of oscillograms, are reproduced (curve 5). Their mean value is 15 mA.

The maximum values of the residual charging currents flowing in the sleeve are shown in the diagram as a function of the arc current for cylinder temperatures of 20°, 40°, and 60° C. The increase is not as rapid as if the function were linear.

Finally, experiments were carried out on controlling the mercury arc by influencing both the negative and positive charge carriers. The research was carried out with various control tubes and connections. In one of the tubes, electrons were drawn out of a mercury arc through a well-cooled anode with holes drilled in it. These electrons then acted as charge carriers for a pure, dependent stream of electrons, which was controlled by means of a grid in the same way as in electron tubes. The large amount of cooling required by the anode prevents
the practical development of this tube. In another control tube (Fig. 140), the vapour density in front of the grid and anode is artificially kept small by superheating; the anode drop is kept high by enlarging the discharge space in front of the grid and anode into a spherical shape. By varying the grid potential with respect to that of the anode, the anode current can be influenced. The curves in Fig. 141 and the oscillograms Fig. 142 show the effect of controlling the anode.

With regard to Fig. 141, it should be mentioned that both the anode and grid currents are electron currents. As long as the grid is at a potential which is positive with respect to that of the cathode, it will collect, principally, electrons. If the grid potential is reduced to zero or made negative, then both the arc to the anode and also the glow discharge to the grid are extinguished.

The stream of electrons to the grid increases rapidly as the positive grid potential increases. Grid current and anode current are of the same magnitude when the grid is at a negative potential of about 9 V with respect to the anode arranged behind the grid. It appears here that the preference with which this stream of electrons passes to the grid, on account of the position of the latter, is counterbalanced by the fact that the grid is at a negative potential of 9 V with respect to the anode.
In that part of the characteristic curve where the grid has a positive potential with respect to the anode, we are concerned with a pure, dependent stream of electrons. This is determined by the number of electrons passing through the holes in the grid and also by the velocity with which these enter the space between the grid and anode. Since the grid and anode are very hot (about 600 to 800° C), the vapour density in this space appears to be low, so that collisions between electrons and neutral vapour molecules, and therefore ionization, are extremely rare. With regard to the physical problem of the rectifier, this velocity of dispersion of the electrons in front of the anode is of great importance, particularly with respect to the independent discharge which takes place in the mercury vapour during the period when the arc passes no current. Even at pressures of 2000 V (about 20,000 V/cm) it was never possible to detect an independent discharge in the space between the grid and the anode.

In our materials testing department tests have been carried out to determine the behaviour of mild-steel plates at high temperatures with a view to solving the question of the strength of welded steam pipes. The same 10-mm thick mild-steel plates were employed for the tests as those used for standard fittings for steam pipes. The welding was carried out in the workshops in exactly the same manner (e.g., as regards seams and electrodes) as that usual for steam pipes. The following specimens were also made:

- 8 bars of welding material—4 produced by autogenous welding and 4 by electric welding. These were made by building up "ropes" exclusively of welding material of such a size that it was possible to produce test specimens from them.
- 8 sheet-metal plates with V seams—4 produced by autogenous welding and 4 by electric welding—each plate being sufficient for 5 flat bars, i.e., 3 x 3 bars for determining the permanent strength at 300, 400, and 500° C, and 1 bar for a tensile test at room temperature.

The tests showed that at 300° C the permanent strength of the welded bars is less than that of the unwelded bars, though greater than that of the specimens consisting of welding material only. At 400° C the permanent strength of the electrically welded bar is the same as that of the unwelded bar, though the strength of the latter is also less than at the lower temperature. In the case of the autogenously welded bars the ratio of the permanent strengths is about the same as at 300° C. The permanent strengths of welded and unwelded bars at 500° C were equal, but greater than that of the welding material. In general, electric welding shows the greater strength, one reason being, presumably, that the heating produced by the welding in this case is confined to a much narrower region as shown by the sections in Fig. 143. Fig. 143 (below) shows a section through an electrically welded joint, and above through an autogenously welded joint. The autogenously welded seam has a heavy deposit of metal, the surface is coarse, and the heating effect on both sides of the weld is very pronounced. As a result, the grains are coarse. The seam was hammered. The deposit in the case of the electrically-welded seam is small, the surface is much smoother, and the heating effect less extensive. The cross-sections through the solid bars of welding material (Fig. 144) have the same typical characteristics; the difference in the size of the grains and in the number of pores, in particular, is very pronounced.
Extensive research was carried out regarding the softening temperature of the copper used for commutators as it was wished to ascertain whether the temperatures occurring during the manufacture of commutators are liable to damage the copper laminations. Laminations of copper obtained from two different sources (here referred to as F and S) were used for the tests. The F laminations had numerous surface faults, while those designated by S were absolutely smooth. The copper oxide content of the former and the impurities due to arsenic were also greater. The specific resistance was accordingly also somewhat higher. An advantage of the F-laminations is their absolutely uniform and fairly fine structure, and also the constant hardness of 82 to 84 Brinell over the whole cross-section. With the S-laminations the grains at the centre are very coarse and towards the circumference very fine. As a result the hardness at the middle is lower (76) than at the outside, or contact surface (95). Thus if segments made of this material are reduced in diameter by stamping or turning, the softer interior becomes the contact surface. Annealing tests of various durations at temperatures of 140—320 °C showed that when the copper was annealed for half an hour it became softer than when annealed for a quarter of an hour at the same temperature (Fig. 145). It was further observed that the more the copper is worked in a cold state, i.e., the harder it is, the sooner the softening begins. This explains why a very hard-drawn copper wire begins to soften at 150 °C (see the Brown Boveri Review, 1930, p. 54). In the case of the commutators, softening begins first at the rubbing surface, with the S-copper at about 200 °C, and with the F-copper at about 250 °C. During all the other measurements and tensile tests (Fig. 146), and with regard to the specific resistance, the annealing effect only becomes evident at 260 and 290 °C in the case of the S-copper and F-copper respectively.

The high temperatures and pressures at which modern steam turbine plants work place very exacting requirements on the lubricating oil used, particularly with respect to the resistance to oxidation. The products formed by the oxidation of such oils are very favourable to emulsification, and when in an advanced state of decomposition become deposited as a hard crust in the oil coolers. Comprehensive tests have shown how steam turbine oils must be refined in order to render them oxidation-proof. Various kinds of oil were tested.

The tests proved conclusively that with normal acid-refined oils, more pronounced ageing phenomena occur with increasing degree of refinement (acid content). These manifest themselves by an increase in the viscosity, a big increase in the acidity, and a comparatively strong tendency to emulsify with alkaline solutions. The behaviour of specially refined oils is fundamentally different. The rate of increase of the viscosity decreases with increasing degree of refining, as also does the acidification. These oils are therefore considerably more oxidation-resisting and suffer comparatively little due to ageing. In confirmation of previous tests it was found that the chemical values determined in the normal way, such as acid number and saponification number, are no criterion of the emulsification properties of a turbine oil that has aged. The surface tension also provided no direct
relationship between these properties. This phenomenon can also be understood because in the case of emulsions between mineral oils and neutral or alkaline solutions, a system of equilibrium is formed between the various emulsions. Our tests also showed that the old theory that saponification is a basis for the formation of emulsions must be rejected.

In connection with our research departments, we finally mention that our high-power testing plant, which was put into operation during June of the past year, was made two years ago, was put into operation during June of the past year. Fig. 147 shows the building in which the permanent test plant is housed. It is 42 m long and 23 m wide, and has a structural framework of steel with roof and walls of corrugated iron. Fig. 148 shows, in the foreground, the 10-metre long short-circuit generator set comprising the 12-pole generator for a closing and opening capacity of 800,000 and 500,000 kVA respectively, and the 2200-kW driving motor with liquid starter. The generator alone weighs 300 tons. In the background, on the left, the transformer can be seen. This is designed for a rated output of 85,000 kVA and is connected between the generator and breaker to be tested when a higher voltage than 11,000 V is required. Corresponding to the purpose for which it is used, the transformer has a short-circuit voltage of only 2.21%.

In Fig. 149 the oil circuit breaker test-beds can be seen between the machine house and the hill, and with the cable cabins of reinforced concrete on either side.

This plant, which has been built at no small expense, has proved exceedingly satisfactory during the few months it has been in use, and is now regarded as an indispensable addition to our research plant, particularly for testing oil circuit breakers. It will be described in detail in a future number of this review.
IV. THE DEVELOPMENT OF BROWN BOVERI SYNCHRONOUS MACHINES.

The development of single and polyphase-synchronous machines, which we have carried on ever since our firm was founded, does not, curiously enough, depend directly on the 32-pole three-phase alternators designed by C. E. L. Brown (when still associated with the Maschinenfabrik Oerlikon) for the famous Lauffen Transmission, the success of which induced C. E. L. Brown and W. Boveri to establish their own manufacturing concern. The two-phase alternators (Fig. 150) supplied in 1892 for the Kappelerhof power station of the Elektrizitätsgesellschaft Baden, as it was then called, were the first machines to be despatched from the Baden works. Each machine consisted of two 24-pole single-phase alternators built directly together, each set having a total output of 175 kVA. In contrast to the Lauffen generators, these had stationary fields and rotating armature windings, the halves of the machines having a relative displacement of 90 electrical degrees. Two-phase current at a line voltage of 1100 V was led off from the four slip rings, two of which were connected together to form the neutral point.

For the relatively low outputs of that time, the design with fixed field frame and rotating armature as developed from the direct-current machine was employed with success until the middle nineties as long as voltages hardly greater than 3000 V were used, the collection of which from slip rings appeared to be quite admissible, particularly when the number of rings was reduced to two as in the single-phase alternators largely built at that time. Fig. 151 shows one of the single-phase alternators for 165 kVA, 480 r. p. m., 2200 V, 40 cycles, built in 1894 for the Società d'Elettricità, Sondrio. The design of this machine was based directly on that of the multi-pole direct-current machines. A noteworthy feature is the slotless rotor, on the circumference of which the armature coils were secured by means of rings and wooden packing pieces. Polyphase field windings were built up of single-phase coils shortened successively and, as in the armature shown in Fig. 152, laid in slots. The reason for the departure from the design with internal rotating pole-wheel used for the Lauffen generators was the realization of the extraordinarily large leakage with this design, which, even when the excitation was increased, produced no notable diminution in the voltage drop. Thus machines with this design of pole wheel only
too frequently “did not give their voltage” and then, when subjected to a heavier inductive load, almost completely ceased to supply any voltage due to the effect of the demagnetizing component of the ampere turns. The modification of this design shown in Fig. 153 is noteworthy. Here the concentric field coil arranged between the oppositely-magnetized halves of the pole wheel is rigidly secured inside the armature, thus enabling exciter slip rings to be avoided.

We built the first machines with internal rotating pole wheel from 1893 onwards. These were the so-called umbrella-type generators developed by C. E. L. Brown to suit the vertical-shaft Francis turbines in low-head power stations, the construction of which was proceeding rapidly at that time in Switzerland and other countries. The one-piece open generator frame containing the armature laminations and windings was mounted on a supporting ring secured to the floor of the machine house, the arm spiders of this ring carrying the generator shaft in two collar bearings. The practice at that time was to excite all the generators of a power station from one separate exciter set. It was therefore possible to key the pole wheel directly on to the shaft-end projecting from the upper collar bearing, the spokes being inclined so as to avoid the bearing, thus giving to the machine the typical conical shape from which it derived its name. The poles were screwed on to the rim, which is cast in one piece with the pole wheel. Still under the influence of the design of the Lauffen generators, only every other pole was wound, the unwound ones serving as so-called consequent poles. Fig. 154* illustrates one of the generators of this type for 230 kVA, 180 r. p. m., 4000 V, 42 cycles, built by us in 1893 for Vonwiler & Co., Romagnano.

Some machines of essentially similar design are shown in Figs. 155 and 156. In the two-phase alternator of Fig. 155, which was built in 1894 for the Elektrizitätswerk Aarau and has a rating of 230 kVA, 48 r. p. m., 2000 V, it is interesting to note that the frame and bearing spider are constructed as one assembly split along a diameter. The exciter is driven from the generator shaft through bevel gearing. The stator winding is here already a two-phase coil winding with one slot per pole per phase.

* See plate facing page 80.
Fig. 156 illustrates a three-phase alternator of the umbrella type for 1165 kVA, 120 r. p. m., 3500 V, constructed in 1896 for the Société Lyonnaise des Forces Motrices du Rhône. The frame is split both diametrically and circumferentially and thus consists of two symmetrical parts, each again split into halves, the two lower ones of which are bolted to the bearing spider. It is worthy of note that, for example, in the last-mentioned machine, at the rated speed the circumferential velocity of the pole wheel was 31.4 m/sec—a very high value at that time. Thus if the load were suddenly thrown off and the turbine governor were to fail, a sudden increase in this velocity up to 60 m/sec would have to be reckoned with. Such instances occurred more than once without the slightest damage being caused to the pole wheels, in spite of the fact that their design was purely empirical (e.g., in a two-phase umbrella-type alternator of 200 kVA, 5200 V, 420 r. p. m., built in 1897 and installed in the Sihl power station).

The principles of design which had proved correct in the case of umbrella-type generators were also applied to the horizontal-shaft generators introduced at that time for coupling to Pelton-wheel turbines in mountainous countries, and to the flywheel-type generators used in conjunction with Sulzer horizontal drop-valve steam engines in the generating stations of large towns. To the latter class belong the single-phase alternators of 630 kVA, 85 r. p. m., 3000 V, 45-3 cycles (Figs. 157 and 158) delivered in 1894 to the Frankfurt a. M. Municipal Power Station. The stator frame is divided radially into 16 segments, and is again split round the circumference, the two halves, which are bolted together, enclosing the laminations. To stiffen and support the stator frame, which has an outside diameter of more than 6 metres, a plate split diametrically and provided with eight spokes is flanged on to it at each side. The plates have a large number of barring holes round their circumference so that after the holding-down bolts have been removed from the stator, this can be rotated for the purpose of inspecting the lower half. The stator winding is a single-slot, single-phase coil winding. The pole wheel, which is mounted in pedestal bearings, is made in two parts, held together at the hub by bolts and two shrink rings, and at the rim by keys. The poles are screwed on to the wheel rim, through which pass the insulated leads from the individual built-on exciter.

The typical design of the Frankfurt generators was repeated at this time and in the following years in quite a number of similar machines. Among these may be mentioned the 420-kVA, 105-r. p. m. three-phase alternators delivered—also in 1894—to the Hölriegelskreuth power station of the Isarwerke (Fig. 159) in which a terminal pressure of 5000 V was already attained. The frames of the machines were again constructed without feet and were supported on the foundations at both sides by two screws operated by hand wheels. Further, mention may also be made of the single-phase alternators of 200 kVA, 200 r. p. m., 2100 V, for Kaiserslautern, and the three-phase alternators of 1050 kVA, 105 r. p. m., 3600 V, for the Porta-Volta power station of the Società Edison, Milan (Fig. 160), all delivered in 1894; then the three-phase alternators of 700 kVA, 75 r. p. m. delivered in 1896 to the Manufactur Prochoroff, Moscow (Figs. 161 and 162), and the three-phase alternators delivered in 1898 to the Paderno-on-the-Adda power station (Fig. 163). The last-named alternators created a general sensation because of their large output, for that time, of 1800 kVA at 180 r. p. m., but still more because of their terminal pressure of 13,500 V, when only a year previously (1897), in the horizontal-shaft three-phase alternators of 460 kVA, 400 r. p. m., for the Elektrizitätswerk Schwyz (Fig. 164) a pressure of 8000 V was the maximum attained.

The Frankfurt type of machine, the most important repetitions of which were the four 1300-kVA, 85-r. p. m. single-phase alternators (Fig. 165) built...
between 1897 and 1899 for the Frankfurt am Main power station itself, proved so satisfactory, that it was also used in 1897 coupled to vertical-shaft turbines with bevel wheel drive, e.g., for the Elektrizitätswerk Ölten-Aarburg (Fig. 166).

The flywheel type of generator in which the pole wheel rotated outside the stationary armature in order to increase the flywheel effect was built for the first time in 1894. Figs. 167 and 168 show the design of this machine. The armature body, which is again divided circumferentially and diametrically and stiffened by spokes, is secured, together with its "hub" to a drum cast in one piece with the foot of the bearing at the exciter end. The poles are bolted on to the two-piece pole wheel rim from outside.

During the following years the development of generators for water turbine drive was characterized by a rapid increase in the ratings. In low-head power stations the vertical type began to be used exclusively, while for high-head power stations horizontal or vertical-shaft generators have been built side by side up to the present day according to local conditions. Notable steps in the development are provided essentially by those generators built in connection with the schemes for utilizing the large sources of water power in Switzerland, which were being carried out by the company "Motor A. G. für angewandte Elektrizität", as it was called at that time.

In 1898, some 1150-kVA three-phase vertical-shaft alternators for 100 r. p. m. and a terminal pressure of 8000 V, as shown in Figs. 169 and 170, were built for the Hagneck power station on the Lake of Bienne. The umbrella type appears modified here in so far as the bearing spider is built up of two separate parts. The outer part consists of a ring with radially projecting feet on which the generator frame rests, while the inner part is constructed with radial arms, which, in contrast to earlier designs, support only one collar bearing. This was the first type of ventilated machine, cooling air being led up from below between the above-mentioned radial feet of the bearing spider and over the pole coils and rotor windings. The well-known three-phase alternators built in 1902 for the Beznau-on-the-Aare power station for 885 kVA, 8000 V and 66⅔ r. p. m. (Figs. 171 and 172) are of the same type.

The two three-phase alternators of 675 kVA, 84 r. p. m., 10,000 V, 42 cycles (Fig. 173) built in 1903 for the San Giovanni Lupatoto (Verona) power station of the Manifattura Festi e Rasini, introduced the modern type of vertical-shaft generator, fundamentally different from the umbrella type. This came into existence through the necessity of avoiding the inaccessible turbine footstep bearing, which frequently ran hot and caused vibrations, substituting for it, according to L. Zodel's proposal, a bearing arranged at the generator end, and conveniently accessible from the machine room. This was accomplished in the following manner. On, or better, above the generator frame, a bearing spider with six arms of strong section was constructed; this supports a collar bearing and carries the above-mentioned thrust bearing, covered by a cast-
In 1909 the three-phase alternators (Fig. 174) of 8600 kVA, 300 r. p. m., 8000 V, delivered to Biaschina power station, were, as regards output, the largest machines of this type. Here the stator laminations are already secured by teeth screwed to the stator frame. This, together with the separate arrangement of casing and end plates as against the previous design with symmetrically split casing provided with flanges, made it possible to avoid bolts through the laminations. In the case of the pole wheel, considerations of manufacture and especially the necessity of using material of great strength for the rim, which is subjected to severe strain, led to the adoption of the later built-up type. A large number of discs of boiler plate are pressed on to the one-piece cast steel hub. The poles are dovetailed into these discs and the pole shoes are laminated. In these machines the circumferential speed of the pole wheel is as high as 59 m/sec at the rated speed. The exciter is mounted above the thrust bearing. From about this time onwards the exciters even of slow-speed vertical-

![Image of stator](image1)

**Fig. 162. — Stator of the machine shown in section in Fig. 161.**

![Image of three-phase alternator](image2)

**Fig. 163. — 1800-kVA three-phase alternator, 180 r. p. m., 13,500 V, for Paderno-on-the-Adda Power Station. (1898.)**

![Image of 460-kVA alternator](image3)

**Fig. 164. — 460-kVA, 400-r. p. m. three-phase alternator for the Elektrizitätswerk Schwyz (1897.)**

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1 It is noteworthy that for large vertical-shaft alternators a return to a kind of umbrella-type is now beginning to take place in America. In the case of the new type introduced by the large American firms (the so-called "overhung type") the upper bearing spider is avoided. The thrust bearing carrying the pole wheel is built on to the lower bearing spider.
vertical-shaft alternator of 7050 kVA, 83.8 r.p.m., 8400 V, 50 cycles, built in 1916 for the Ollen-Gösgen power station. The four-piece stator frame is here mounted in an elevated position on eight cast-iron columns. The spider carrying the collar and thrust bearings rests on the stator frame; its eight arms form, as it were, a continuation of the columns supporting the stator. There is no lower bearing spider with a second collar bearing. The body of the pole wheel is entirely of cast steel and comprises

shaft generators have always been direct coupled.

The Biaschina machines mark the change over to the modern "flexible" design of generator with a comparatively high reactance, small permanent short-circuit current and wide voltage range, the regulation of which is entrusted to automatic voltage regulators.

A machine of approximately twice this output (15,600 kVA) and correspondingly greater width of iron, was supplied to the same power station in 1916. The arm spider of grey cast iron is shrunk on to the shaft (as shown by Fig. 175) and consists of two symmetrical parts bolted together. The drum of the pole wheel is built up of six discs of forged steel in which the poles are again dovetailed. A noteworthy feature is the compressed-air brake, later on adopted as standard, which works directly on the hub. The brake is supplied from the central compressed-air plant and can bring the set to rest in a few minutes. The regulating pump is driven from the generator shaft through bevel gearing and a belt.

For very slow speed generators the design was somewhat modified. Fig. 176 shows a section of the three-phase
the two-piece arm spider and the four-piece rim. The rim is bolted to each spoke by six bolts and each pole is secured to the rim by four bolts. The whole machine is mounted above the level of the machine room floor, thus making the control gear of the turbine and the slip rings readily accessible. The compressed-air brake operates on a brake rim integral with the spokes of the pole wheel.

The three-phase vertical-shaft alternators of 8000 kVA, 166.6 r. p. m., 17,600 V, 50 cycles, built in 1919 for Mühleberg power station of the Bernische Kraftwerke are of similar design (Fig. 177). As in the Biaschina machines, the generator housing rests directly on the foundation frame; there is no lower bearing spider and the upper spider has six arms. The pressure-lubricated thrust bearing is water cooled by means of coils built into the bearing. The hub, spokes and rim of the pole wheel form one cast-steel piece split diametrically. The poles are secured to the rim of section by four bolts.

The most interesting slow-speed vertical-shaft machines of this design are those supplied in 1930 to Ryburg-Schwörstadt power station. Each generator is of 32,500 kVA, 75 r. p. m., 10,500 V (Fig. 178). The eight-piece stator frame rests on the turbine pit lining of grey cast iron in which there is an eight-arm spider carrying the lower collar bearing. The pole wheel is made throughout of cast-steel, and to facilitate manufacture and transport was subdivided into a large number of parts. It is built up of two wheels mounted one above the other, each being divided into a four-piece
lifting the rotor and for dismantling the thrust bearing. The direct-coupled main exciter has a rating of 400 kW. The auxiliary exciter for exciting the main exciter is built on to it.

The design of high-speed vertical-shaft generators is based on that of the previously mentioned Biaschina machines. A further stage in the development was provided by the three-phase alternators of 16,500 kVA, 500 r. p. m., 8800 V, 50 cycles, supplied in 1924 for Rempen power station of the A. G. Kraftwerk Wäggital (Fig. 179). Since, due to the local conditions, the height of the machines is great compared with the diameter, the pole wheel is built up of eight steel discs pressed directly on to the shaft without a boss. The poles, which are fitted with laminated pole shoes, are dovetailed into this. As regards the stationary part, there is no essential difference compared with the design of the Biaschina generators except that the thrust bearing was here designed for the first time with self-aligning thrust segments mounted on balls, the use of pressure oil being completely avoided.

The large axial dimensions of the three-phase alternators of 35,000 kVA, 337/375 r. p. m., 10,100/10,800 V, 45/50 cycles, supplied in 1927 to Galleto power station of the Società Terni per l’Industria e l’Elettricità (Fig. 180) led to the construction of the rotor as a double pole-wheel, the general design of the machines remaining otherwise unchanged. Each pole wheel consists of five cast-steel spoked wheels to both rims. The shaft, which is about 9 m long and weighs some 30 tons, is bored along its entire length to take the pressure oil pipes for operating the servo-motor for adjusting the turbine runner blades (Kaplan type). The upper bearing spider comprises a central portion about 3.5 m diameter to which the eight arms are bolted. The thrust bearing is sunk into this central portion; it is designed for a total load of 900 tons. A number of brake cylinders are mounted on the arms of the lower bearing spider; these are operated by oil under pressure and can be used for.
Fig. 154. — 250-kVA, 180 r.p.m. two-phase umbrella-type alternator with consequent poles, Vonwiller & Cie., Romagnano. (1893.)

Fig. 155. — 230-kVA two-phase umbrella-type alternator, 2000 V, 48 r.p.m., for the Elektrizitätswerk Aarau. (1894.)

Fig. 156. — 1165-kVA three-phase umbrella-type alternator of 120 r.p.m., 350 V, for the Société Lyonnaise des Forces Motrices du Rhône. (1895.)

Fig. 157. — 230-kVA two-phase alternator, 85 r.p.m., 3000 V, 45-3 cycles, for the Frankfurt a.M. Municipal Power Station. (1894.)

Fig. 158. — 630-kVA single-phase alternator, 85 r.p.m., 3000 V, 45-3 cycles, for the Elektrizitätswerk Olten-Aarburg. (1895.)

Fig. 159. — 700-kVA, 75 r.p.m. three-phase alternator for the Manufacturer Prochoroff, Moscow. (1896.)

Fig. 160. — 1300-kVA single-phase alternator, 85 r.p.m., 3000 V, 45-3 cycles, for the Frankfurt a.M. Municipal Power Station. (1897–1899.)

Fig. 161. — 550-kVA two-phase alternator, 120 r.p.m., 5300 V, for the Elektrizitätswerk Olten-Aarburg. (1897.)
Fig. 168. — 270-kVA three-phase flywheel alternator, 91 r. p. m., 240 V.
Duménil, Jäggle & Cie., Thann (Alsace). (1899.)

Fig. 170. — 1150-kVA three-phase umbrella-type alternator, 100 r. p. m., for the Manifattura Festi e Rasini, Milan. (1898.)

Fig. 172. — 885-kVA three-phase alternator, 800 V, 66.6 r. p. m., for the Beznaa Power Station on the river Aare. (1902.)

Fig. 173. — 675-kVA three-phase alternator, 84 r. p. m., 10,000 V, 42 cycles, for the Manifattura Festi e Rasini, Milan. The first generator with thrust bearing at the top. (1903.)

Fig. 174. — 8600-kVA three-phase alternator, 300 r. p. m., 8000 V, in Biaschina Power Station of the Officine Elettriche Ticinesi. (1909.)
Fig. 181. — 790-kVA three-phase alternator, 4000 V, 300 r.p.m., for the Elektrizitätswerk an der Kander, near Spiez. (1898.)

Fig. 182. — 5250-kVA three-phase alternator, 8000 V, 375 r.p.m., for the Löntschwerk. (1907.)

Fig. 183. — 790-kVA three-phase alternator, 4000 V, 300 r.p.m., for the Elektrizitätswerk an der Kander, near Spiez. (1898.)

Fig. 184. — 5250-kVA single-phase alternator, 16,000 V, 375 r.p.m., for the Löntschwerk. (1897.)

Fig. 185. — 2500-kVA single-phase alternator, 16,000 V, 300 r.p.m., 15 cycles, for Spiez Power Station of the Bernische Kraftwerke A.-G. (1909.)

Fig. 186. — 250-kVA three-phase turbo-alternator, 3900 r.p.m., 2000 V, 65 cycles, for the Municipal Light and Water Supply of Coire. (1901.)

Fig. 187. — 450-kVA three-phase turbo-alternator, 3000 r.p.m., 2000 V, 50 cycles, for Messrs. Schlieper & Baum, Elberfeld. (1901.)

Fig. 189. — 250-kVA three-phase turbo-alternator, 3900 r.p.m., 2000 V, 65 cycles, for the Municipal Light and Water Supply of Coire. (1901.)

Fig. 190. — 650-kVA three-phase turbo-alternator, 3000 r.p.m., 3800 V, 42 cycles, for the Porta-Volta Power Station, Milan. (1904.)
Fig. 194. — Two-pole turbo-rotor of the disc type with parallel slots. (1910.)

Fig. 195. — 5000-kVA three-phase turbo-alternator, 450 r. p. m., 6600 V, 25 cycles, with salient poles, for Deptford Power Station of the London Electric Supply Co. Ltd. (1911.)

Fig. 196. — 7700-kVA three-phase turbo-alternator, 3000 r. p. m., 3500—3800 V, 50 cycles, for the Soc. Lyonnaise des Forces Motrices du Rhône. (1914.)
pressed on to the shaft; each pole carrier consists of two separate adjacent poles of rectangular cross section. The pole shoes are screwed on to these in the usual manner. According to the old practice, the generator housing had again to be split circumferentially into two parts. The whole machine is let into the floor of the machine room, only the thrust bearing and exciter projecting above the floor. This arrangement enables the cooling air to be drawn through the pole wheel from above and below by the fans on both sides of the wheel and to be discharged readily into the warm-air ducts surrounding the generator frame. The main and auxiliary exciters, between which the slip rings are situated, are mounted on top of the generator.

The alternators of 36,000 kVA, 252/300 r. p. m., 10,000 V, 42/50 cycles, supplied in 1929 for Cardanoni power station are of similar design (Fig. 181). As regards the rating, these are the largest machines which we have built for water turbine drive. The rotor is built up of four cast-steel pole wheels on each of which two cast-steel rims with pole carriers are pressed. Each pole shoe spans the four pole carriers of two adjacent discs. The two axially adjacent poles have one common field coil.

The development of the various designs of modern horizontal-shaft machines is based on the period opened up by the Frankfurt generators; the first steps in this development are illustrated by the machines shown in Figs. 182 and 183, 184 and 185. In the type of machine illustrated in Figs. 182 and 183 (three-phase alternators of 790 kVA,
Fig. 181. — 36,000-kVA three-phase alternator, 252/300 r.p.m., 10,000 V, 42/50 cycles, for Cardanoni Power Station of the Soc. Generale Elettrica Tridentina. (1929.)

4000 V, 300 r.p.m., built in 1898 for the Elektrizitätswerk a. d. Kander near Spiez) the housing is still divided circumferentially, but the stiffening on both sides by means of the heavy spoked rims is absent as these were unnecessary due to the frame being split along a horizontal diameter. The lower half of the frame has feet bolted on, these being secured directly to the foundation. The end connections are enclosed by light cast-iron covers. The generator shown in Fig. 184 (three-phase alternator of 5250 kVA, 8000 V, 375 r.p.m., built in 1907 for the Löntschwerk) has a frame of the well-known box section and is not split circumferentially. Bolts passing through the stator laminations are avoided (see above). The pole wheel, which at the rated speed has a peripheral velocity of 49 m/sec, is split circumferentially into two parts. The two halves fit together and are secured with bolts.

The pole shoes are formed of packets of laminations riveted together. Each is secured to the pole carriers, which are cast on to the pole wheel, by two dovetail-section bars and a key.

As regards the mechanical features, the single-phase alternator of 2500 kVA, 16,000 V, 300 r.p.m., 15 cycles, supplied in 1909...
to Spiez power station of the Bernische Kraftwerke is of essentially similar design (Fig. 185). The feet are bolted to the lower half of the generator frame which rests on four rollers so that it can be rotated for purposes of inspection. The pole wheel consists of a one-piece hub of grey cast iron on which the rim comprising a large number of discs of boiler plate is pressed, and in which each of the poles is secured by means of two dovetailed projections. The pole shoes have holes in an axial direction for the damper windings. These machines, which have one pole earthed, were the first to be built directly for 16,000 V. Together with the larger alternators supplied later to the power station at Kandergrund of the Bernische Kraftwerke these machines feed the contact wire of the Lötschberg line directly. They have proved extremely satisfactory and led the Swiss Federal Railways to have all their single-phase alternators designed directly for the contact-wire pressure.

The first of these were the alternators of 9000 to 11,500 kVA, 333.3 r.p.m., 15,000 V, 16.7/3 cycles, delivered in 1919 for Ritom Power Station. These were followed in 1922 to 1928 by the more powerful machines (10,000—12,700 kVA) of similar design for Barberine Power Station (Fig. 186). In these alternators the six-pole
rotor is built up of two adjacent six-arm wheels each of which carries two cast-steel rims. The pole carriers are so shaped that they fit together and form cylindrical poles. The pole shoes are made as muffs and are screwed on to the poles like cap nuts. They have dovetailed slots for holding the laminations. The damper windings consist of round copper bars which pass through the pole shoes in a direction parallel to the axis of the generator and are connected at each end by copper bars to the short-circuiting rings, made in six segments of massive sheet copper. The single-plane stator winding is distributed among 144 slots; there are twelve different coils per pole. The coils themselves were impregnated twice under pressure, then encased in mica, and tested in their finished condition at 55,000 V for one minute. A test voltage of 45,000 V, i.e., three times the normal voltage, was prescribed for the whole machine. In order to satisfy this condition, it had to be ensured that the layer of air left between the coils and the sides of the slots was not too heavily stressed dielectrically and ionized. The exterior of all the coils was therefore provided with a conducting coating for a distance somewhat greater than the length of the iron. In this way the air gap between the coil insulation and stator iron was bridged over. At this high test voltage and operating voltage, if the field distribution at the edges and corners of the teeth and pressing fingers is unfavourable, it is possible that glow and brush discharges, which would damage the coil insulation, might occur where the windings leave the iron. In order to avoid such an occurrence, the coils were here provided for the first time with a closely fitting covering of tin foil where they leave the iron, a sleeve of conductive material being pushed over this covering. By means of this conductive connection between the stator and sleeve, the surface of the coil where it leaves the iron is artificially brought to the same potential as the stator iron, i.e., to the earth potential. Thus all discharges from the coil are led to the edge of the conductive casing, where they are then easily suppressed by enclosing this roll-shaped edge in a layer of insulation. The machine is totally enclosed. The ventilation vanes on the rotor draw in the cooling air at both ends of the generator from special conduits in the foundations, and discharge the warm air radially at the middle of the machine through the lower openings in the stator frame.

The single-phase alternators of 11,000—14,000 kVA, 333-3 r. p. m., 15,000 V, 16½ cycles, supplied in 1926 for Vernayaz power station of the Swiss Federal Railways had such large dimensions that the design of pole wheel used on the Ritom and Barberine generators could no longer be used here. Four steel rims are pressed on to each half of the two-piece
hub, which is provided with six arms. The poles are
let into the rims and each is secured by two dovel-
alled projections with saw-toothed profiles (Figs. 187a
and 187b).

The highest powered horizontal-shaft generators
which we have yet built are those supplied in 1930
for Mese power station of the Società Elettrica
Interregionale Cisalpina (Fig. 188). The machines,
which are designed for 33,300 kVA, 420/500 r. p. m.,
8000 V, 42/50 cycles, were ordered in 1930, and as
regards the design of pole wheel closely resemble the
generator shown in Fig. 180. As in all large modern
generators of the totally-enclosed type, the cooling
air is drawn in from both sides and expelled through
the lower openings of the frame, which, on account
of the large axial dimensions, is made in two parts.

In conclusion, it might be said with regard to
the present state of development of generators with
salient poles, that there hardly appears to be an
upper limit to the output because, on account of
transport difficulties and reasons connected with the
production and manufacture, the rotor and stator
have already to be subdivided into a more or less
large number of parts. With the materials available
at the present time, generators of 100,000 kVA and
over, at speeds of 300 r. p. m. and less, can be
built—outputs which still lie far above present
requirements. The stresses produced in the rim of
the pole wheel and in the pole shoes at the high
runaway speeds, which it is still considered necessary
to take into consideration in turbine design, are very
high and scarcely lower than those encountered in
the rotors of turbo-alternators. It is possible that the
design used for turbo-alternators may also become
standard for water-turbine driven alternators if, as has
already occurred in the case of low-head machines due
to the advent of the Kaplan turbine, the speeds at
present corresponding approximately to the various
ranges of power should be subjected to a further
increase, that is, if turbines should be designed, which,
who evolved the design which became the basis of turbo-generator construction throughout the world, namely, the drum-type rotor with excitation windings laid in slots (German Patent No. 138253). In Fig. 189 a sectional drawing is reproduced of the first turbo-generator of this type which he built; Fig. 190 shows the rotor. This was a two-pole three-phase alternator of 250 kVA, 3900 r.p.m., 2000 V, 65 cycles supplied in 1901 to the Municipal Light and Water Supply of Coire. The rotor, which had already a peripheral speed of 76 m/sec, was then built exactly like those of direct-current machines and three-phase motors, i.e., of slotted laminations pressed directly on to the shaft. Exactly as in present-day practice, the end connections were secured by cylindrical caps pressed on to the hub-like projections of the end plates holding the laminations together; they were also built together with ventilation fans.

Like the rotors, the stator frames of turbo-generators were also developed in a manner suitable for this type of machine. The most important step was the attainment of an intensive cooling of the machine, though at first this was only applied to any great extent to the stator laminations and stator windings. In the first turbo-generator built by us (Fig. 189) the fans mounted directly on each end of the rotor drum drew cooling air into the machine from both sides, according to a proposal of A. Aichele (German Patent No. 148966). This air collected mostly in the bottom of the frame, passed from here through the slots in the stator laminations, and left the machine at the top through the openings in the stator. This method of cooling and the design of frame which it necessitates have become standard practice for all turbo-alternator design.

Fig. 188. – 33,300-kVA three-phase alternator, 420/500 r.p.m., 8000 V, 42/50 cycles, for Mese Power Station of the Soc. Elettrica Interregionale Cisalpina. (1930.)

for outputs of say 40,000 to 50,000 kW, have rated speeds of 750 to 1000 r.p.m., and corresponding runaway speeds of double these values. The vertical-shaft eight-pole three-phase alternators of 23,000 kVA, 8200 V, 42/50 cycles, 630/750 r.p.m., ordered from us during 1930 for Piottino power Station of the Officine Elettriche Ticinesi, and described elsewhere in this number, may be regarded as fore-runners of this development. As in the case of turbo-alternators, the rotors are made as cylindrical drums with the excitation windings laid in slots.

The development of the turbo-generator has been directly connected with the acquisition of the Parsons steam turbine patents in 1900. It was C. E. L. Brown who evolved the design which became the basis of turbo-generator construction throughout the world, namely, the drum-type rotor with excitation windings laid in slots (German Patent No. 138253). In Fig. 189 a sectional drawing is reproduced of the first turbo-generator of this type which he built; Fig. 190 shows the rotor. This was a two-pole three-phase alternator of 250 kVA, 3900 r.p.m., 2000 V, 65 cycles supplied in 1901 to the Municipal Light and Water Supply of Coire. The rotor, which had already a peripheral speed of 76 m/sec, was then built exactly like those of direct-current machines and three-phase motors, i.e., of slotted laminations pressed directly on to the shaft. Exactly as in present-day practice, the end connections were secured by cylindrical caps pressed on to the hub-like projections of the end plates holding the laminations together; they were also built together with ventilation fans.

Like the rotors, the stator frames of turbo-generators were also developed in a manner suitable for this type of machine. The most important step was the attainment of an intensive cooling of the machine, though at first this was only applied to any great extent to the stator laminations and stator windings. In the first turbo-generator built by us (Fig. 189) the fans mounted directly on each end of the rotor drum drew cooling air into the machine from both sides, according to a proposal of A. Aichele (German Patent No. 148966). This air collected mostly in the bottom of the frame, passed from here through the slots in the stator laminations, and left the machine at the top through the openings in the stator. This method of cooling and the design of frame which it necessitates have become standard practice for all turbo-alternator design.

1 The first turbo-generator built by us had a rotating armature winding, a rating of 315 kVA, 3000 r.p.m., 500 V, 50 cycles, and was supplied in 1901 to the spinning mill of Messrs. Wild & Abegg, Turin.
In the same year (1901) a three-phase alternator of 450 kVA, 3000 r.p.m., 2000 V, 50 cycles, was supplied to Messrs. Schlieper Baum, Elberfeld (Fig. 191). The rotor has a peripheral speed of nearly 78 m/sec and consists of a hub, to which the slotted laminations are keyed, and shaft stubs fitted at each end. The rotor caps are made of bronze and the fans are mounted on the bosses of the press rings.

The method of cooling is the same, only more efficacious; the rotor, which is still laminated, has distancing slots and thus the cooling air not only passes over it but also through it.

The first four-pole turbo-alternator, for 3250 kVA, 1360 r.p.m., 3000 V, 45-3 cycles, was also built in 1901. This was a single-phase alternator for the Frankfurt Municipal Power Station. On account of the large dimensions, the stator is split circumferentially into two and diametrically into four parts. The stator laminations are secured in the frame by means of keys, and the stator winding is a single-phase bar winding (Fig. 192). The design of the rotor is otherwise similar to the two-pole turbo-alternators built at that time. The end caps of Delta metal are, however, screwed to the press rings of the rotor laminations. To increase the cooling effect, axial holes are provided in the laminated rotor underneath the slots for the windings, these holes communicating with the radial rotor ventilation ducts. In this way, parallel cooling of the rotor with fresh air as far as the air gap was obtained for the first time.

The turbo-alternator of 6670 kVA, 1260 r.p.m., 3800 V, 42 cycles, shown in Fig. 193, was supplied in 1904 to the Porta Volta power station, Milan, and corresponds essentially to the design of four-pole machine still built at the present time. A large number of mild-steel plates are pressed on to the hub, which is slotted for the purpose of axially cooling the rotor and fitted at the ends with shaft stubs. The plates form a cylindrical body out of which the slots for the excitation windings are milled.

Two years later (1906), eight-pole and four-pole turbo-alternators of this design were built for 10,600 kVA, 750 r. p. m., 12,500 V, 50 and 25 cycles.

Already in 1902 the solid forged rotor began to replace the laminated rotor in two-pole turbo-alternators, though due to the metallurgical difficulties encountered in those days with very large forgings it temporarily gave place to the disc rotor in 1905. In the last-mentioned type the slots were milled radially, or sometimes, as shown by Fig. 194, also axially. In four-pole machines, this arrangement of the slots led to the design with salient poles adopted temporarily between 1909 and 1911 because it was easier to machine. A steel boss with four pole carriers is pressed on to the shaft (Fig. 195), and the pole shoes pushed over the carriers and secured by a ring of sunk screws. In machines of greater length, several of these four-pole "wheels" were fitted next to each other and the pole shoes either screwed into the pole carriers or over them like cap nuts as on the previously-mentioned generators for Ritom and Barberine power stations.
From 1910 onwards, the rotors of two-pole turbo-alternators were again made as solid forgings of open-hearth steel with radial milled slots. The end caps were of rings of Delta metal and were pressed against the rotor body by plates of steel or manganese-bronze. Fans for cooling the stator end connections and the circumference of the rotor were fitted to the pressing plates. Cooling air was drawn into the rotor at both ends from underneath these plates, passed over the rotor end connections from below, and flowed through holes bored in an axial direction in the rotor body. These holes communicated with the radial ducts in the rotor through which the air passed outwards towards the stator. The stator frame and distancing pieces were so arranged that the air circulated spirally through the stator laminations, being finally discharged downwards through the openings in the stator frame.

This method of guiding the cooling air, based on the German Patent No. 148966 due to A. Aichele, cools both the rotor and stator very effectively. With two-pole 3000-r.p.m. turbo-alternators designed with this special cooling, a maximum output of 3000 kVA at a peripheral speed of 105 m/sec was attained in 1910, and an output of 7700 kVA at 120 m/sec peripheral speed in 1914 (Fig. 196). At that time, i.e., before the War, the maximum attainable outputs were always determined—that is, limited—by the strength of the material of which the end caps were made. Thus the question of the design of the end caps was of foremost importance. With the annealed open-hearth steel available at that time, it was possible to overcome effectively the stresses in the body of the rotor itself, provided the diameter of the forging did not exceed about 800 mm. However, at that time the only non-magnetic material available for making the caps was forged bronze which, at best, had an elastic limit of 30—35 kg/mm². In spite of a considerably greater permanent strength, caps made of magnetic nickel steel were out of the question because even when separated from the rotor body by an intermediate packing piece of non-magnetic material, they caused considerable stray flux in the rotor which required a 10—15% greater excitation current and therefore increased the temperature rise of the rotor. It also increased the losses in the winding supports and end plates. Based on the experience acquired in metallurgy during the War, end caps of non-magnetic steel were then made by the cold forging process. These had an elastic limit of 50 kg/mm² and over, an ultimate tensile strength of 70—80 kg/mm² and had not the same excessive elasticity of earlier designs. By means of this material the problem of the end caps was solved once and for all, so that in 1921 it was possible to increase the output of two-pole turbo-alternators with open-hearth steel rotors 860 mm in diameter and 2000 mm long to 15,600 kVA.

The rapid increase in the output of two-pole turbo-alternators, which has characterized the development of the last few years, as described elsewhere in this number, was rendered possible by the employment of heat-treated nickle-chrome crucible steel for the rotor with an elastic limit of 45 kg/mm², an ultimate tensile strength of 65 kg/mm², a percentage elongation of 15—20% and a strength determined by the notch test of 10 kg/mm². In 1925, an output of 25,000 kVA was attained with a forging diameter of 920 mm (peripheral speed 144 m/sec) and a length of 2500 mm; in 1928, 40,000 kVA with a diameter and a length of forging of 940 and 3500 mm respectively; and in 1930, 48,000 kVA with the same dimensions. Fig. 197 shows a section of the generator.

As pointed out elsewhere in this number, there is no reason why the output of two-pole turbo-alternators should not be greatly increased provided metallurgical knowledge advances sufficiently to enable homogeneous forged rotors to be produced, having the previously mentioned strength and with larger dimensions corresponding to the higher outputs.

The further development of four and six-pole turbo-alternators has proceeded along similar lines, though, in general, the disc-type rotor has been adhered to. Figs. 198 and 199 show sections of the largest machines of this type which we have yet built. The rotor of the six-pole machine illustrated in Fig. 198 (three-phase turbo-alternator of 100,000 kVA, 1200 r. p. m., 60 cycles, built in 1928 for Hell Gate Power Station of the United Electric Light and Power Co., New York), consists of a two-piece hollow shaft with milled longitudinal slots for the cooling air. 36 discs of forged nickel steel, out of which the slots for the winding are milled in the usual
manner, are shrunk on to this shaft. The four-pole machine of similar output supplied to Zschornewitz power station of the Elektrowerke A. G. (Fig. 199) is of similar design except that there are $16 \times 250$ mm wide nickel steel plates mounted on the shaft without intermediate distancing pieces. The material of these plates has an elastic limit of $55 \text{ kg/mm}^2$ and an ultimate tensile strength of $75-85 \text{ kg/mm}^2$. At the runaway speed of $125\%$ normal speed, the maximum stress at the internal circumference of the plates is about $50\%$ of the elastic limit taking into account the shrinkage stress.

At times the two-pole design of machine has been used for four-pole alternators, though altered in so far as the central cylindrical part is made of tubular form with milled slots for the windings and has the end pieces flanged on (Fig. 200). The middle and end pieces are made of nickel steel with an elastic limit of $40-45 \text{ kg/mm}^2$ and an ultimate tensile strength of $65-75 \text{ kg/mm}^2$.

In addition to the use of high-quality material for the rotor forgings and end caps, the tremendous increase in the output of turbo-alternators during the last ten years must also be attributed to a series of measures which have

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**Fig. 197.** General design of modern two-pole turbo-alternators for 3000 r. p. m. Output attained in 1930: 48,000 kVA.

**Fig. 198.** 100,000-kVA three-phase turbo-alternator, 1200 r. p. m., 60 cycles, for Hell Gate Power Station of the United Electric Light and Power Co., New York. (1928.)

**Fig. 199.** 100,000-kVA three-phase turbo-alternator, 1500 r. p. m., 50 cycles, for Zschornewitz Power Station of the Elektrowerke A.-G. (1929.)
enabled the losses in the machines to be gradually reduced by a large amount, viz: the use of high-alloy steel for the stator laminations; using sheet brass for the distancing pieces welded to the laminations; providing the cast-steel pressing plates with deep radial slots and bronze fingers, at their internal circumference, for supporting the teeth of the stator laminations; designing the short-circuit proof supports of the stator end connections with as little metal as possible; making the stator covers of non-magnetic material (cast aluminium); and last, but not least, by designing the conductors of the stator winding according to the method introduced by L. Roebel (German Patent No. 277012). The individual strands in each slot are bent and interwoven in such a manner that each strand has twice as many bends as the number of times it is transposed. Each strand thus passes through every position of the cross-sectional area of the slot, so that in all parallel strands in a slot approximately equal electromotive forces are produced by the influence of the leakage field of the slot, and thus Eddy currents practically eliminated.

Fans built directly on to the rotors of turbo-alternators usually have a low efficiency and also increase the temperature of the cooling air flowing through them by $6-7^\circ$ C. Therefore, wherever possible, and particularly on large turbo-alternators, these fans are replaced by a separate fan mounted on the shaft between the slip rings and exciter. The size of this fan can be made independent of the dimensions of the rotor. It draws the warm air out of the generator at the top through a special conduit, forces it through a cooler, and back again in a closed circuit into the generator from underneath. Thus pre-heated cooling air is no longer passed through the machine (see Figs. 198, 199 and 200).

In all the large turbo-alternators illustrated, part of the cooling air flows into the stator from each end by way of the air gap, but principally in a radial direction. For this purpose there are a number of inlet and outlet ducts in the stator housing so that a large number of parallel paths for the air are provided. The cooling air enters at the outer circumference of the laminations, flows radially inwards through the ventilation ducts formed by the distancing bars, passes for a short distance along the air gap between stator and rotor, and escapes radially through other ventilation ducts in the laminations. This method of ventilation ensures uniform cooling.
of the laminations independently of the length of the stator.

Up to the present, at least in turbo-alternators, the terminal pressure has in general been limited to about 10,000 to 12,000 V. However, a development towards the use of appreciably higher terminal voltages now appears to be taking place which takes into account the rapid increase in the output of generators by enabling excessive currents, the controlling of which presents almost insurmountable difficulties, to be avoided. In 1929, as a result of careful analytical investigations on various combinations of insulating materials (mica, paper and binding agent), and by improving manufacturing methods, we produced an insulating material whose dielectric losses are only a fraction of those of the previous insulating material used, while at the same time the breakdown strength is increased (see the Brown Boveri Review 1930, No. 1, page 4; and page 5 of this number). This made it possible to build a high-voltage turbo-alternator for a terminal pressure of 36,000 V, and for a test voltage to earth of 72,000 V; the individual conductors are also designed for this high test voltage against each other. The stator of this machine is illustrated in Fig. 1.

The latest development in turbo-alternator design is to fabricate the stator frame of welded iron (Fig. 201), whereby a noteworthy reduction in weight and a simplification of the machining are achieved. The new design is now standard practice for the frames of turbo-alternators, but has also been adopted in certain cases for the frames of generators with salient poles.

Finally, mention should be made here of the generators as built within recent years for the testing departments of manufacturing concerns for determining the rupturing capacity of oil circuit breakers. Generators of this type, which are required to furnish peak loads only, of several hundred thousand kVA, may be considered in an extreme sense as a return to the old design of generator with low reactance, correspondingly high short-circuit current, large amount of copper in the exciter windings, and therefore small weight of stator copper. Fig. 148 illustrates the 12-pole generator of our high-power electrical testing department. Its design is essentially similar to that of a turbo-alternator. It weighs about 300 tons and as regards its dimensions corresponds to a machine of about 80,000 kVA. (MS 650)

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