Bienne Outdoor Substation of the Swiss Federal Railways.
(Type of substation without overhead steel construction.)

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BROWN, BOVERI & COMPANY, LIMITED
MANUFACTURERS OF

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PROGRESS IN BROWN BOVERI DESIGN DURING 1928.

INTRODUCTION.

In preparing a report on the development in our designs during the short space of twelve months, and in repeating every year the surprising statement that progress has again been made in all branches, though naturally not to the same extent in every one, it is obvious that some explanation must be given of this continuous and seemingly unbounded development. There is no doubt that this is largely due to the growth and increasing diversity of the requirements of industry. To meet these requirements as completely as possible, and on a competitive basis, is the aim and object of every manufacturer, in much the same way that the aspirations of the individual are directed towards the attainment of position and influence.

These purely economic principles would, at the most, only necessitate a development of designs to correspond to the fluctuations of market conditions; in which case both continuity of progress and the epoch-making inventions frequently based on newly discovered fundamental knowledge would be lacking. It is these, and these only, which constitute true progress, and which, quite apart from the demands of industry, owe their existence entirely to the creative zeal of the designer. This again is, for him, a moral obligation, a mission of the highest ethical significance which, by his endeavours in the field of technical advancement, he is called upon to fulfil.

I. ELECTRICAL MACHINERY AND APPARATUS.

1. Synchronous machines.

In our last report mention was made of two turbo-alternator sets each for an output of 40,000 kVA at a power factor of 0-7 and a speed of 3000 r. p. m. ordered by the Zaklady Elektro Laziska-Gorne, Poland. During the past year we received the order for a third similar set, for the Schelle Power Station of the Société Inter-Escaut, Belgium. The output of these machines, however, has been surpassed by that of a turbo-alternator set for 45,000 kVA, a power factor of 0-8, and a speed of 3000 r. p. m. which we have built for the Geertruidenberg Power Station of the N.V. Provinziale Noordbrabantsche Elektriciteits Maatschappij, Holland. This is the largest two-pole turbo-alternator in the world running at 3000 r. p. m.; as regards its electrical features it follows our standard designs very closely.

The Elektrowerke A.G., Berlin, ordered a turbo-alternator set (see p. 35) for 100,000 kVA at a power factor of 0·85 and 1500 r.p.m. from Brown, Boveri & Co., Mannheim, for their power station at Zschornewitz. This is the largest generator that has ever been ordered for a European power station and the largest four-pole turbo-alternator built in Europe.

The same power supply company also placed an order for a 37,500-kVA four-pole turbo-alternator, with turbine.

Like all the large turbo-alternators which we have built during recent years, these machines are also cooled on the closed-circuit system, by a fan arranged between the alternator and the exciter.

In plants where there is insufficient room for coupling the exciter direct to the alternator, the fan and exciter are mounted below it and driven by a separate electric motor (patented arrangement). In certain cases this auxiliary set has also been provided.
Fig. 1. — Turbo-generator frame of welded cast-steel plates.

with a steam turbine which automatically starts up and drives the set if the current supply to the electric motor fails.

To reduce their weight, large alternators are now made with welded cast-steel frames instead of cast-iron frames (Fig. 1).

In addition to the two 36,000-kVA 20-pole vertical-shaft alternators for hydro-electric power stations mentioned in our last report, we received an order for a third exactly similar alternator during the year. A section through this machine — the largest hydro-electric generator in Europe — is reproduced in Fig. 2.

A fourth single-phase alternator, for 10,000 kVA, 15,000 V, 16\(\frac{2}{3}\) cycles, has been installed in the Barberine Power Station of the Swiss Federal Railways. This machine is of similar design to those supplied at the time the power station was built.

From among numerous other interesting machines, particular attention might be drawn to three vertical-shaft three-phase alternators for the Sembrancher Power Station of the Société Romande d'Electricité, Territet, and three vertical-shaft three-phase alternators for the Uppenborn Power Station of

the Munich Municipal Power Supply. The first-mentioned alternators are each for 5000 kVA, 5500—6500 V, 50 cycles, 300 r. p. m., and a power factor of 0·7, and are coupled to two-jet Pelton turbines. The last-mentioned alternators are each for 9200/11,000 kVA, 4600/5500 V, 50 cycles, 125 r. p. m., and will be driven by Kaplan turbines made by Messrs. Escher, Wyss & Co.

The two 30,000-kVA, 600-r. p. m. synchronous condensers mentioned in our last report have been delivered to the purchases, the Showa Denryoku K.K. (Japan). One of these machines, with exciter and induction motor for starting, is shown in Fig. 3. The starting motor is capable of driving the condenser for an hour at full speed in order to keep the transmission line under pressure.

The Montcherand coupling and regulating substation of the Cie Vaudoise des Forces Motrices des Lacs de Joux et de l'Orbe was put into service during 1928. In this substation there are two three-winding transformers each for 5000 kVA, 110/39/13·5 kV, 50 cycles; a synchronous condenser for 5000 kVA, 13,000 V, 50 cycles (Fig. 4); and two induction regulators and the requisite apparatus for all these machines.

A large number of smaller generators have been built for semi or fully automatic power stations.

In connection with automatic power stations we have developed a remote control and signalling system in which it has been possible to reduce the number of control and signal wires to four by using selecting switches working in synchronism. The desired circuits at the sending and receiving points are first connected up by brushes rotating synchronously on both selector discs and then the requisite operations or measurements are carried out. The synchronism of the selecting switches is ensured because they are started up by means of selective relays connected in series by means of auxiliary contacts on the selecting switches; the relays start up the motors of the selecting switches by producing a momentary current rush. The motors move the selectors by one contact,
whereupon the selective relays cause another current rush, this procedure continuing until the desired position is reached. The whole apparatus is normally at rest and only moves when a service operation is made or when signalling an alteration in the position of the switches in the controlled station. When operating a control, a selecting switch is closed in order to bring the selector to the correct position. When this is reached, and the apparatus is therefore ready for carrying out the operation, a lamp lights up. When a signal is being transmitted the attendant is notified by optical and acoustic signals. The acoustic signal stops itself, but the optical signal can be kept illuminated, so that, for instance, when switches are tripped, the extent of the disturbance can be ascertained. The movements of the switches are also indicated on a moving diagram of connections.

This system enables all control operations to be carried out in a very simple manner, as, for example: the operation of switches and the signalling of their movements; the control of regulators such as induction regulators, voltage and speed regulators, etc., with signals indicating when they reach their limit positions; also transmission of any measurements. Measurements are made simultaneously with the corresponding control operation, as, for example, the adjustment of the power of a machine with simultaneous signalling of the power. Thus for about 32 control and measuring operations only four control wires are necessary. A signalling system of this type for an automatic rectifier substation is at present under construction.

2. Induction machines.

An important order which we executed during the past year was one for 5000 specially designed three-phase squirrel-cage motors of 0·8 H.P. for the Michelin Tyre Company, Clermont-Ferrand. These motors have a compressor built on to one end shield and are to be used for pumping up motor-car tyres. It was required that the motor should constitute the frame of the whole transportable set. The motor casing rests on an axle with two wheels and can be fitted with a couple of handles for moving the set about. A leg is fixed below the reciprocating compressor.

A large number of voltage-regulating sets were
constructed during the past year, some for controlling the speed of large induction motors, others to be used in combination with converter sets for connecting different networks.

Two regulating sets have been installed in the Mannheim Power Station for the sub-synchronous regulation, within a range of 11%, of two 720-H.P. induction motors driving the feed pumps of the high-pressure boilers. The speed regulation is accomplished automatically in the first place by shifting the rocker arm of the small frequency changer built on to the pump motor. The brushes are shifted by means of an Askania pressure-oil regulator.

Three sets for regulating the speeds of the three 1000-H.P. pump motors are being installed in the first of the four pumping stations for pumping out the Zuider Zee. The delivery height of the pumps varies between 4.55 and 7.45 metres and the regulating sets enable the speed of the motors to be correspondingly reduced by 12% or increased by 18% (super-synchronous regulation).

The 2000-H.P. twelve-pole motor ordered by the Klöcknerwerke A.G., Haspe, for driving a billet rolling mill, is provided with a set for regulating the speed between 600 and 448 r.p.m. The set comprises a three-phase commutator machine with 300-kW starting motor, two three-phase exciters with starting motor, and a frequency changer. The set is mounted overhung on the shaft of the rolling-mill motor.

A frequency changer set is now being installed for the Sté Métallurgique des Terres Rouges, Esch (Luxembourg), for connecting their 50-cycle network with the 42.5-cycle network of the Aciéries Réunies Burbach-Esch-Dudelange. The set comprises a 4250-kVA synchronous machine connected to the 42.5 cycle network, a 4750-kVA asynchronous machine, and a regulating set consisting of a three-phase commutator machine with separate double exciter set and directly built on frequency changer.

The set can transmit a constant load adjustable from 0 to 4000 kVA in both directions independently of frequency variations in either network; transmit power in one direction or the other according to the frequency variation in either network; adjust the output to zero when a certain ratio prevails between the two frequencies, and regulate the power transmitted by the set according to the variation of either frequency from this ratio.

Fig. 5 shows an asynchronous condenser for 10,000 kVA, 11,000 V, 60 cycles, 900 r.p.m. with directly built on exciter, which works as a pure wattless-current machine. It was delivered, together...
with all apparatus, including two regulating sets with common driving motor, to the purchasers, the Nippon Denrioku K. K., Japan, during the past year.

3. Direct-current machines.

Considerable progress has been made during the past year in the development of main propelling motors type E for submarines. Two such motors for driving a submarine were built as double rotor machines with rotatable frames; when run as a motor each develops 600 H. P. at the one-hour rating at 360 r.p.m. and, as a generator, 1200 A. Six main propelling motors of similar design (for three submarines) were supplied to another navy. The one-hour rating of each motor is 360 H.P. at 395 r.p.m., and, when run as a generator, 1200 A at 260 to 310 V. We are also building, for the same government, a double commutator main propelling motor which develops 120 H.P. at 370 r.p.m. when the submarine is submerged, and 165 H.P. at 450 r.p.m. on the surface. In the same order is also included the direct-current shunt-wound generator for supplying the propelling motor when operating on the surface (Diesel-electric propulsion). The generator is of a special design with end shield bearings and flanged shaft for rigidly coupling to the Diesel engine; it develops 135 kW at 900 r. p. m. and the pressure can be varied between + 170 V and — 170 V.

Fig. 6 shows a Ward Leonard converter set installed at the Simon Pit of the firm Les Petits-Fils de François de Wendel & Cie, Petite-Rosselle Colliery, Forbach. The two variable-pressure generators, each for 2000 kW, 880 V, 500 r. p. m., driven through reduction gearing, are particularly interesting.

In this connection the conversion of the main shaft winding engine at the “Mauveschacht” should be mentioned. This installation was famous as the first turbine-driven winding engine. It was in continual use for 20 years, without any stand-by. In 1927, however, the colliery management decided to install a reserve for the turbine, and, on account of price and other considerations, did not propose to purchase a second turbine but a Ward Leonard converter; this has now been installed and is connected up to the network of a power supply company. It comprises an 820-kW variable-pressure
generator coupled to an induction motor for 850 kW, 6000 V, 50 cycles, 1000 r. p. m.

The opportunity was also taken of replacing the control apparatus, which had been installed with the original winding engine, by one satisfying modern requirements with regard to safety and ease of operation.

The excitation system was improved by the addition of an exciter set with separate exciters for the winding motor and variable-pressure generator. This made it possible to obtain greater precision of control by compounding the voltage drop in the Ward Leonard circuit by means of a quick-acting regulator, and to enable the field to be switched off during the intervals between the winds in the case of the winding motor.

Instead of the drop brake with the usual damping and unsatisfactory retarded operation, which is, nevertheless, not free from shock, our free-fall quick-acting brake was installed. In this brake the drop-weight falls suddenly but the braking pressure is gradually applied without producing any oscillation of the masses; by suitably setting the damping mechanism, the braking force can be adjusted so that it does not exceed the limit fixed by rope slip.

The depth indicator with mechanical device for bringing the machine to rest was replaced by one of Brown Boveri design with mechanical and electrical retarding devices. Normally the two retarding devices work in combination with each other, but in case one should fail the other operates as a reserve. As accident statistics show, this is a point of very great importance as regards the safe working of the plant.

A Brown Boveri single-lever operating stand was installed in place of the operating and braking stand for two-handed control. With this type of stand the winding engine is controlled and braked with one lever, moved by the right hand. As is well known, we equip all our winding engines with single-lever operating stands. From the point of view of safety these are greatly to be preferred to all other operating stands worked by both hands, on account of their greater precision of control and the logical manner in which the lever has to be moved.

The winding plant was also provided with auxiliary gear of the most modern design, such as: a safety switch for de-exciting the variable-pressure generator so that the electrical braking effect can be utilized in case of emergency; a centrifugal switch as a protection against the engine running away and against approaching the landing stage at too high a speed, and double protection gear against overwinding and restarting in the wrong direction.

By means of simple change-over gear mounted in the basement containing the machines, instead of
the old turbine-driven generator, the d.c. side of the motor converter can be connected up to the winding motor. Thus in future it will be possible to work the winding engine off either the colliery power plant or the mains of the power supply company. The motor converter is designed to supply sufficient power to raise the maximum load; if found necessary later on, it will be possible to equip it with a phase advancer on the three-phase side.

It is perhaps worth mentioning that the entire reconstruction was carried out during the Whitsuntide holidays last year without interrupting normal work in any way. Fig. 7 shows the rebuilt plant.

During 1927, the Compagnie des Chemins de fer du Midi ordered two synchronous converters from us, each for 750 kW and 1650 V on the d.c. side, for their experimental automatic substation at Hourat, in which an entirely new design of control gear has been installed. The plant is now in service.

The automatic gear, that is, the apparatus and relays which operate the main switch and a converter set, is built into a special, readily accessible desk (Fig. 8) arranged in a different room from the main switchgear. There is one of these desks for each converter set. The automatic gear common to both units is mounted on a small marble panel or in a small switch desk.

After equipping the substation at Hourat, we received the order for 36 synchronous converters for 16 other substations of the same railway company. On account of the satisfactory experience obtained with the experimental substation, the others are also being equipped for full automatic control.

A particularly interesting machine is the a.c./d.c. converter set for supplying 10,000-V direct current, ordered by the Latvian Postal and Telegraph Authorities in Riga for a wireless transmitting station. The set comprises a three-phase induction motor direct coupled to two 5000-V direct-current
high-tension generators connected in series. This is the highest d.-c. pressure ever generated by rotary machines. It is an achievement which opens up a wide field as regards railway electrification, because it is obvious that it will also be possible to construct rotors of locomotive motors suitable for terminal pressures of 5000 V, thus enabling direct-current contact-wire pressures of 10,000 V to be used. To obtain this direct current from three-phase current at the usual commercial frequencies it will be preferable to use mercury-arc rectifiers, rather than synchronous converters or motor generators, on account of their greater simplicity and higher efficiency.

Finally, during the past year the heavy-current synchronous converter for 3550/4200 kW, 240/300 V, 25 cycles and 167 r. p. m. ordered by the New York Edison Co. was shipped to America. This very noteworthy machine, described in our last report, is illustrated again in Fig. 9.

Fig. 10 shows a heavy-current synchronous converter for 5000 kW, 500 V, 50 cycles, 300 r. p. m. built during the past year.

4. Industrial drives.

We have recently developed a series of universal three-phase motors suitable for driving the most diversified industrial machines. The distinguishing feature of these motors is the standardized shape of the casing with machined flat which enables the motors to be mounted in a belt cradle, on a pedestal with reduction gear, in a loom frame, etc., or on a base.

Fig. 11 illustrates the standard design of this series of motors without base for building directly into the machine. Fig. 12 shows the same motor mounted in an adjustable belt cradle which enables the belt tension to be varied within wide limits simply by loosening a readily accessible bolt. The spring suspension is arranged in the base of the belt cradle and can also be adjusted.

Fig. 13 illustrates a loom drive incorporating a motor of this series and friction clutch. This drive can be adapted to any loom with driving shaft from 650 to 750 mm above the floor. The engagement of the motor pinion with the teeth of the gear wheel carrying the friction clutch can be adjusted with perfect accuracy by sideways movement of the motor support and the bearing of the driving shaft in the motor pedestal.

A protected motor of this series, with base bolted on, is shown in Fig. 14. In this form the motors are specially suitable for driving preparing machines in the textile industry. They are made with six poles for ratings of 0.55 to 3.7 kW, and with four poles for 0.75 to 4.5 kW.

The type of motor shown in Fig. 15, with reduction gear built into the end shield, can be used advantageously to replace the less efficient motors with a large number of poles. It can drive the machine directly although the speed of the machine is very different from...
that of the squirrel-cage motor.

Fig. 16 shows a motor with flanged end shield for building directly on to the machine. This type of motor can be used for driving almost every kind of machine, particularly small machine tools, wood grinders, etc., as it can run in any position without any alterations being necessary. According to the way the rotor is mounted in the stator, the free end of the shaft projects through either the flanged end shield (Fig. 16) or the normal end shield.

Armature stampings wound and fitted in a casing as shown in Fig. 17 can be used for building directly into the machine, for so-called built-in motor drives.

We have recently built some very interesting drives with complete control gear for large machine tools, the extensive alterations and additions made to our workshops during the last two years (see p. 57) having offered excellent opportunities for developing this type of drive. Fig. 18 shows the diagram of connections for the combined planing and milling machine, with a table 9.5 metres long and 3.7 metres wide, illustrated in Fig. 89.

The size of the machine, the double purpose for which it is used, and questions of economy, demanded that the various operations should be carried out by separate motors mounted as near as possible to the driven part. All the motors which must have speed regulation or electrical braking are driven by direct current, whereas other motors are supplied with three-phase current.

There are, altogether, eleven different motors on the machine, as follows:

(a) Motor 1 for driving the table. — This requires the most power and is controlled by a Ward Leonard
converter. The motor is started in either direction or stopped by means of push-buttons. When planing, it is automatically reversed by a switch, thrown over by the motion of the table, which reverses the excitation of the variable-pressure generator. No other apparatus is used for reversing the main motor, and thus the control of this, the most important drive, is as reliable as possible. The cutting and return speeds can be adjusted independently of each other. In addition, the speed can be altered automatically during the cut according to requirements. When the tool passes over long sections which are not to be planed, its speed can be increased to that of the return stroke by means of an acceleration switch. A retarding switch enables the speed to be reduced at the beginning and end of a cut to spare the tool and prevent the work from chipping.

(b) *Two milling motors* 15. — These are mounted directly on the spindle carriages and are controlled by automatic starting contactors and push-buttons. Their speeds can be varied in the ratio of 1:2 by means of field regulators mounted on the same carriage as the motor. The drives for the cutter and feed, also taken from the main motor, are interlocked so that the feed is automatically stopped should one or both cutters cease to revolve.

(c) *Three feed motors* 32 *for planing.* — These are controlled automatically by the movement of the table, i.e., on every return stroke of the table the motors are switched in and advance the tool by a certain adjustable amount. When the right amount of feed has been given, the motors are automatically tripped and rapidly brought to rest by rheostatic braking. These motors can also be controlled by push-buttons, used chiefly for rapidly traversing the tool boxes.

(d) *Two motors* MK *for lifting the tool holder when planing.* — To prevent damaging the work and to spare the tool, the tool holder is lifted before the return stroke and lowered again into the cutting position at the commencement of the cutting stroke. This also follows automatically from the movement.
of the table and is accomplished by means of separate contact makers.

(e) One three-phase motor 25 for moving the cross-slide. — This motor is mounted on the cross-slide itself and is also operated by means of contactors and push-button control.

(f) One three-phase motor 30 for the oil pumps. — This motor is also started by means of a contactor. Its chief use is to supply a copious quantity of oil to the table and gears. It is interlocked with the main drive so that this cannot be started up before the lubricating pumps are running. Should the pumps be stopped, the main drive is again tripped. The pumps can, however, be started up alone.

(g) One motor 4a for operating the control switch. — This motor throws over the control switch for the particular movement of the table required.

All the control apparatus for the motors just described is assembled in switchboxes mounted as near as possible to the motors. There are thus four switchboxes on the machine, viz.: two switchboxes, mounted on the cross-slide, for the two milling motors and the cross-slide elevating motor; one switchbox arranged behind the cross-slide, for the two feed motors; one main switchbox fixed on the right-hand upright, containing all other apparatus such as ammeters, tachometers, field regulators, etc.

The various motors are controlled by push-buttons arranged on the machine within convenient reach of the operator when working the machine from various positions. There are two operating platforms on the cross-slide and one operating position on the floor at each side of the planing machine.

The drives are completely protected by limit switches or interlocks so that a false switching operation or any danger of over-running an end position is impossible.

Fig. 19 shows the diagram of connections for the electrical equipment of the radial drilling machine, (see Fig. 86), which is driven by five motors.

The drilling spindle is driven by a vertical-shaft flange motor mounted on the saddle. The motor is started in either direction or stopped by means of contactors operated by push-buttons. This motor had also to be suitable for tapping, i.e., it must rotate at the correct tapping speed when cutting the thread, and run reversed at an increased speed. This is achieved by the automatic changing over of a second field regulator when reversing, which can be adjusted quite independently of the first field regulator. Thus the motor is reversed directly without it being necessary to operate the “out” push-button.

Fig. 19. — Diagram of connections for the electrical equipment of the radial drilling machine shown in Fig. 86.
The motor can also be reversed directly when using only one field regulator; in this case it will run at the same speed in both directions.

The arm is elevated and lowered by a direct-current vertical-shaft motor secured by the flange to the top of the column. The motor is operated for elevating or lowering by means of an ordinary reversing controller.

The d.-c. motor for locking the sleeve is operated by a contactor interlocked with the drive for the feed. The sleeve can, however, be locked independently of the feed.

The lubricant pump is driven by a d.-c. motor operated by a rotary switch.

The horizontal movement of the column is accomplished by a three-phase motor which is started, in either direction of motion, by an ordinary reversing switch.

All the control apparatus for the d.-c. motors is assembled in a box mounted on the column of the machine. The current for the d.-c. motors is led from a motor generator set to two contact rails from which it is picked up by slip rings. This arrangement was adopted because the motors and control gear
rotate about the column of the drilling machine, and by this means the number of wires could be reduced to the minimum.

The push-buttons, the two field regulators for the motor driving the drilling spindle, the two rotary switches and the oil pump, are all mounted on the saddle. Thus the whole machine can be controlled from the operator’s position.

In Fig. 20 the diagram of connections is reproduced for the slide lathe shown in Fig. 85; the machine has a height to centres of 1500 mm and a distance between centres of ten metres. It is driven by a 50-kW d.-c. compound-wound motor with speed variable between 320 and 960 r.p.m.

The following switching operations can be made by means of push-button control:

1. Starting in either direction of rotation;
2. Increasing or decreasing the speed;
3. Tripping and electrically braking the motor;
4. Reversing the motor directly.

Three push-button stations, each containing four push-buttons, are provided; there is one station on each saddle while the third is on the fast headstock. Each of the four push-buttons in a station operates a separate relay by means of which the desired switching operations are carried out. The relays operate only while the push-buttons are depressed. When these are released, the relays are short-circuited by auxiliary contacts on the contactors.

Starting in either direction of rotation. — On depressing the push-button — say 12 VS in the diagram of connections — the corresponding relay 26 VS operates. The short-circuiting contacts of the field contactor 5 then open and the reversing contactors 4a and 4b close immediately. The resistance is cut out in the usual manner by the starting contactors, which are controlled by the overload relays. The same series of operations takes place if the push-button RS is depressed. The two main contactor pairs are interlocked with each other and also with the braking and starting contactors, thus preventing false switching operations. The motor is always started with full field, independently of the position of the field regulator.

Increasing or decreasing the speed. — If, when the motor is running, the push-button 12 VS or RS (faster) or 12 L (slower) is depressed, the auxiliary motor for controlling the field regulator starts up and moves the regulator in the required direction.

Tripping and electrically braking the motor. By pressing the button 12 HB the relay 26 HB is operated; this causes the reversing contactor to trip, though the field contactor remains closed. The braking contactor closes and completes the rotor circuit through the starting resistance, which is then cut out in steps by the starting contactors as when starting up. It is thus ensured that the braking current remains practically constant during the entire braking period, with the result that the motor is powerfully braked almost until the moment when it stops.

Reversing the motor. — If the motor is running, say, forwards, it can be directly reversed by pressing the reversing push-button without having to be stopped first. This is achieved by suddenly reversing the rotor current by throwing in series the whole starting resistance, which is then gradually cut out in steps by the overload relays and contactors. This manoeuvre can be used when screw-cutting and results in a very appreciable reduction in the time required for operating the machine.

5. Transformers.

Many of the transformers ordered during the past year are particularly interesting on account of their high ratings and pressures.

In our last report we mentioned two 36,000-kVA three-phase transformers for 252,000 V on the high-tension side. During the past year we received the order for a third transformer of the same output.

As regards rating, however, these transformers have already been surpassed by a three-phase outdoor transformer for 40,000 kVA, and 220 kV high tension. The 110-kV low-tension winding can be connected in star or delta, or in two or four parallel groups, and a delta-connected tertiary winding is provided for 12,000 kVA at 10 kV. The transformer was ordered from Brown, Boveri & Co., Mannheim, by the Rheinisch-Westfälisches Elektrizitätswerk. It will be installed in one of this power supply company’s substations on the 220-kV transmission line for interconnecting the large steam power stations of the Ruhr with the “Ill River” hydro-electric power stations in Vorarlberg.
The following large power transformers ordered during the past year are also very noteworthy. Three three-phase, three-winding outdoor transformers for 2500/2500/2500 kVA and 125/5-5/2-9 kV for the Consorzio Industriale della Città di Rovereto e Riva; two three-phase transformers for 10,000 and 17,500 kVA and a transformation ratio of 118,000 to 4200 V, ordered by the Soc. Alluminio Veneto Anonima, Porto Marghera, with oil cooling in a separately-mounted natural-cooled radiator (we first introduced this cooling arrangement in the transformers for the Puidoux Substation of the Swiss Federal Railways); two three-phase transformers for 40,000 kVA and 63 kV high tension for the Silesian Electricity and Gas Supply Company, Chorzow; five three-phase transformers for 20,000 kVA, and 64 kV high tension for the Zaklady Elektro Laziska-Gorne, Poland; one three-phase three-winding transformer for 15,000 kVA and 69,500 V high tension for the Kraftanlagen A. G., Heidelberg; one three-phase transformer for 23,000 kVA and 23,000 V high tension for the Witkowitz Collieries; two three-phase transformers, each for 24,000 kVA and 150 kV high tension, for the Stà. Forze idrauliche dello Abruzzo; one three-phase three-winding transformer for the Erftwerke A.G., Grevenbroich, for 32,000 kVA, high tension of 110 kV, and low tension of $5 \times 5200 = 26,000$ V, the switch for changing-over the connections from 5200 to 26,000 V being mounted on the cover.

Two three-phase transformers for 30,000 kVA, and 144 kV high tension, ordered by the Stà. Meridionale di Elettricità, Naples, and three three-phase, three-winding transformers each for 15,000 kVA and 30,600 V high tension are of outstanding interest on account of their cooling arrangements. All these transformers are for outdoor erection, and their tanks are provided with the usual type radiators, each consisting of a separate nest of tubes. To ensure a uniform and efficient flow of air through these tubes, the air is not blown on to them from the sides in the manner previously employed, but from underneath by means of special nozzles. Due to the jet action of these nozzles, so much free air is drawn into the radiators that the amount which has to be forced through the nozzles is only a relatively small proportion of the total volume of cooling air.
Perhaps the most interesting transformer which we have supplied during the past year is a three-phase transformer (Fig. 21) for the Aschaffenburg Substation of the Bayernwerk A. G. It has a rating of 20,000 kVA and couples the two 100-kV networks of the Bayernwerk and Preussenwerk. In spite of both network pressures being the same, the transformer was not made with auto-transformer connections because, if the transmission of disturbances from one network to the other is to be avoided, only a magnetic coupling can be used.

The great distance between the two power stations and the coupling station at Aschaffenburg, and the possible variation in the direction in which power is transmitted, result in very wide variations in the incoming and outgoing pressures. It was therefore required that it should be possible to regulate the pressure within wide limits without interrupting the supply. As will be seen from Fig. 21, this problem was solved by providing a special 15,000-V auxiliary winding which can be connected to or disconnected from the 100-kV winding in six steps by a 100-kV tapping switch.

On account of the large number of tappings (12) in this case, the usual arrangement of a special regulating switch near the transformer would have required a correspondingly large number of 100-kV terminals both on the transformer and on the tapping switch. The switch was therefore mounted directly on the oil tank of the transformer, thus avoiding the necessity for leads from the transformer to the switch. This construction results in very simple and inexpensive connections to the switch, and increases the safety of the transformer to a great extent. A further advantage of this arrangement in which the regulating apparatus forms one unit with the transformer is the ease with which the whole plant can be supervised, and the large economy in space. As seen from Fig. 21, the tapping switch is so designed that the oil-immersed tapping contacts are opened and closed without current, this actually being interrupted by arcing switches.

The arrangement of the windings is also seen from Fig. 21. A compensating winding with delta connections, dimensioned for 30% of the output of the transformer, lies next to the iron core. This winding transmits symmetrically to the three phases of the one network any unsymmetrical loads in the individual phases of the other network, such as can be caused by shorts to earth, etc. Over this tertiary winding lies the 100-kV winding with the separate regulation winding, and, wound concentrically above this, the second 100-kV winding. The adjustable part of the central winding is mounted directly above the main winding and, to maintain the correct balance between the ampere-turns of this winding, is opposed by a compensating winding. For simplicity this is tapped off from the previously-mentioned delta-connected compensating winding.

This regulating transformer proved so very satisfactory, that the Bayernwerk A. G. ordered a second transformer of similar design, but for the increased rating of 35,000 kVA. The primary and secondary windings are dimensioned for 110 and 104 kV, respectively, and the latter pressure can be regulated in six steps by ± 15% by means of a regulating switch. The tertiary winding is for 13,500 kVA and 22 kV. The RheinischWestfälische Elektrizitätswerk A. G., Essen, ordered three outdoor transformers of this design, each for an output of 30,000 kVA. Two of the transformers are for 25 kV on both sides and one is for 35·1 kV on both sides. In all three the voltage can be increased in eight steps or decreased in eight steps by 12 1/2% on one side by means of a built-on regulating switch. The Pfalzwerke A. G., Ludwigshafen, also placed an order with us for two 20,000-kVA three-winding regulating transformers for 105 kV high tension and 22·3 kV low tension and with a 5·25-kV delta-connected tertiary winding. The low tension can be regulated by 8% in four steps by means of a regulating switch.

In this connection the three-phase four-winding outdoor transformer ordered during the past year by the Badische Landeselektrizitäts-Versorgung A. G., Karlsruhe, should be mentioned. In addition to a 105-kV high-tension winding, designed for 8000 kVA, there are two low-tension windings, for 6500 and 5500 kVA. One of these windings is dimensioned for 22·2 kV and the other for 11 kV. By means of a built-on regulating switch, the former can be regulated by ± 5% and the latter by ± 22%, each in eight steps. There is also a 3600-kVA, 6·6-kV compensating winding. This transformer was also equipped with the individual radiator cooling system already mentioned.

The 30,000-kVA three-phase three-winding transformer, for 110 kV high tension, ordered by the
Württembergische Landeselektrizitäts-A.G., Stuttgart, during the past year is particularly noteworthy. To reduce the magnetic stress, and therefore the iron losses, in the upper yoke, which lies in the hottest part of the oil, the transformer was made with five cores, i.e., with two auxiliary unwound cores. This is a design which we introduced no less than 15 years ago.

Finally, towards the end of 1928 the Milan Municipal Electricity Supply ordered two 65,000-kVA three-winding transformers from the Tecnomasia Italiano Brown Boveri, Milan. These are the largest transformers which Brown Boveri have yet built, and are amongst the largest in the world. The star-connected high-tension winding, with neutral point brought out, is designed for 55,000 kVA and 128 kV, and the star-connected low-tension winding for 65,000 kVA and 23 kV. The 25,000-kVA, 9-kV tertiary winding with delta connections is for connecting up to a synchronous condenser. Including oil, each transformer weighs about 140 tons.

During the past year we have standardized our dissonance extinguishing coils for ratings up to 2500 kVA and up to 50,000 V between phases. The coils have been made as simple as possible, chiefly by reducing the number of tappings, which can be replaced in a very simple and inexpensive manner by an auxiliary coil. If this auxiliary coil has one tapping, as shown in Fig. 22a, and the main coil none, three different connections can be obtained. To obtain these with only one coil, it would be necessary to have two tappings. If main and auxiliary coils are each provided with one tapping (Fig. 22b), six different connections can be obtained; these would otherwise only be possible with a single coil having five tappings.

It is not necessary to design the auxiliary coil for the full test voltage, because the main coil functions as a series choke coil and thus the auxiliary coil has to withstand only part of the full phase pressure.


In our last report we spoke of the steady development of our mercury-arc rectifiers up to those for rated currents of 16,000 A. Our new heavy-current rectifiers are now meeting a very urgent need. For example, ten 4000-A rectifier sets were ordered from us by the Vienna Municipal Council who are now installing rectifiers for supplying the extensive suburban tramway system in addition to the tramways in the town itself. This brings the total number of rectifiers ordered from us by the Vienna Municipal Council up to 32.

A fully automatic trial substation of the New South Wales Government Railways & Tramways, Sydney, in which two of our rectifier sets, each for 1500 kW, 1500 V, had been installed, proved so very satisfactory that after the plant had been in service only a few months the same administration ordered another ten rectifier sets from us for four new substations.

In connection with the increasing use of contact-wire pressures of 3000 V direct current for interurban railways, the order placed with us by the Soc. Tranvie Vicentine, Vicenza, for equipping their Vicenza and Valdagno substations, which supply the Recoaro-Chiamo section of railway, is of considerable interest.

Vicenza Substation is being equipped with two rectifier sets, each comprising one 1100-kW rectifier for a full-load pressure of 3000 V, an overload capacity of 25% for half an hour, 100% for three minutes, and 200% momentarily. Closed-circuit cooling sets with forced air draught are provided for the rectifiers. Two rectifier sets will also be installed in Valdagno Substation, which will be equipped for
automatic operation. Each set is designed for 750 \text{kW} at a full-load pressure of 3000 \text{V} and will also have a closed circuit cooling system with forced air draught. The automatic control gear is so arranged that the rectifiers are started up or shut down by means of a time switch. One set serves as a stand-by, the time switch putting the sets in service alternately, the one on one day and the other on the next. In the event of a disturbance in one set, the reserve set starts up automatically. Both rectifier sets can be operated from a control point, where apparatus is provided for signalling any disturbance occurring in the substation. The two feeder switches are provided with reclosing devices. Both substations are supplied with three-phase current at 10,000 \text{V}, 42 cycles.

Finally, during the past year the \textit{Consolidated Smelting Company, British Columbia}, ordered six 5000-A rectifiers from us, with a total output of 15,000 \text{kW}. These rectifiers are for supplying direct current at 510 \text{V} to batteries for zinc electrolysis.

Attention is again called to the electrification of the \textit{Rotterdam-Amsterdam} section of the Dutch Railways in 1927. The 1500-V direct current for this section is supplied exclusively by seven substations containing, in all, 19 Brown Boveri rectifiers. Six of the seven substations work completely automatically.

7. \textit{Apparatus.}

On account of the success with which they have been used under the severest climatic conditions, our single-pole type AF oil circuit breakers are finding a very wide field of application. One of the most interesting orders for circuit breakers which we received during the past year was one for nine groups of switches, each for a rated pressure of 220 \text{kV}, from the Rheinisch-Westfälische Elektrizitätswerk. The first 220-kV oil circuit breaker built by us, together with control pedestal, is illustrated in Fig. 23.

A special type of oil circuit breaker with high rupturing capacity has been developed for large power stations, particularly for those in large towns where the network is supplied directly at the pressure at which the current is consumed. These breakers (Fig. 24a), three of which are combined to form a three-pole group (Fig. 24b), have particularly strong tanks, capable of withstanding high internal pressures. This is achieved by using a cylindrical oil tank, reinforced outside at the top by a forged-steel ring of rectangular cross-

![Fig. 23. — 220-kV outdoor oil circuit breaker.](image-url)
with side control (the three breakers mounted side by side) motor drive with strengthened chain trans-
mission is used for currents up to 1600 A. For currents of 2500 A and over two motor drives are necessary.

The tank of the circuit breaker has the usual exterior insulating covering and wooden partitions between the different breaks. The secondary relays which operate the over-current relays are connected up by bushing current transformers.

The use of outdoor-type switchgear also appears to be finding increasing use for medium pressures (11,000 to 37,000 V). To meet this demand we have produced a special type of three-pole oil circuit breaker for outdoor erection (Fig. 25). It is made in three sizes to cover a range of currents from 400 to 1600 A, on the same lines as our other outdoor type switchgear, and is combined in the usual way with control pedestal.
On account of the rapid development in the size of our rectifiers it became necessary to build a high-speed circuit breaker for heavy currents. Such a breaker is illustrated in Figs. 26 a (control side) and 26 b (non-control side). The breaker has a current range of 4000 to 6400 A. Its electrical design is based on the fact discovered by A. Aichele that, in order to achieve a rapid extinction of the arc at break, the switch contacts should be so constructed that the ends of the arc move in a practically uniform magnetic blow-out field. This is accomplished most satisfactorily by means of circular contacts. In the breaker under consideration these contacts are supplemented by special main brushes on account of the heavy current which has to be broken. The increase in the total tripping time which these cause is more than compensated by the precision with which the special individual blow-out field extinguishes the arc and by the purely mechanical interlock. As will be seen from Fig. 26 b, this interlock is arranged outside the breaker and is readily accessible.

The breaker is closed either by hand or by a motor with remote control. Tripping is always effected electrically by tripping solenoids. Over-current, reverse-current or outgoing-current releases can be used for emergency trips. In all three cases the relays are practically the same and are mounted on the main bus-bars to the switch, thus rendering a special shunt unnecessary. Ready adjustment is provided for on all automatic releases.

Tapping switches are being used to an increasing extent for voltage regulation. Although regulation by tapping switches is not so smooth as when induction regulators are employed, it is preferred to use this method because it is less expensive. These tapping switches appear to be particularly suitable for rectifier plants where they can be used either for regulating the direct-current pressure within wide limits from the alternating-current side, or, for example, in d.-c. lighting networks, to prevent the pressure fluctuations in the a.-c. network having an effect on the direct current.

Fig. 27 shows a tapping switch with the exceptionally large number of 48 tappings for regulating the direct-current pressure of a rectifier from 515 V down to 193 V. The transformer which is regulated by the tapping switch has an auxiliary winding on each core, divided into 12 sections by tappings,
Fig. 27. — Three-pole air-break tapping switch, 6400 V, 900 A, 48 taps.

and having the same number of turns as the two sections of the main winding formed by a total of three tappings. The switch, comprising a separate tapping switch and change-over switch per phase, works as follows:—

For the maximum pressure of 6500 V the auxiliary winding is connected in series with the main winding. On giving the tapping switch a complete revolution, the first 12 tappings (12 × 83.3 V) are passed through, and the pressure is then 5500 V. If now the switch spindle is rotated further, the auxiliary winding is connected in parallel with the first section of the main winding by the change-over switch. Another complete rotation of the switch through 12 steps in the same direction reduces the pressure by 1000 V to 4500 V. The change-over switch then connects up the auxiliary winding in parallel with the second section of the main winding, the sequence of operations is repeated, and, by another complete rotation of the tapping switch, the pressure is reduced in 12 steps to 3500 V. The auxiliary winding is now connected in opposition to the lower section of the main winding and by rotating the switch spindle a fourth time the pressure of 2500 V is reached, again in 12 steps.

The change-over switch is made to operate at the correct time after 12 steps have been passed through by a single-tooth drive which comes into action on the completion of every revolution of the tapping switch. As in all tapping switches, the sections of the auxiliary winding are short-circuited by a step resistance while the change-over is being made. An arcing switch is also provided for actually interrupting the current, the brushes of the tapping switch and change-over switch gliding over the contacts without sparking.

Some switches of this type were built for the Vienna Municipal Council, for a rectifier feeding the lighting network of the town, and for an artificial fertiliser factory in Cologne.

Fig. 28a. — Switchbox type LC 2e; closed.

Fig. 28b. — Switchbox type LC 2e with no-volt release; open.
Our switchboxes types LC and M with thermal releases were designed for protecting induction motors of small and medium ratings against overheating, while not tripping under overloads of short duration. They have already been described in detail in a previous number of The Brown Boveri Review. Figs. 28 a and 28 b illustrate a switchbox type LC for a rated current of 64 A, with air-break contacts, thermal releases in series with the full motor current, and additional no-volt release. The switchbox type M with oil-immersed contacts is made in two sizes. In the smaller type, for rated currents up to and including 250 A (Fig. 29), the thermal releases are traversed by the full motor current, whereas in the larger type, for rated currents up to 640 A (Figs. 30 a and 30 b), they are connected to the motor leads through current transformers. Otherwise all the switchboxes of this series are of similar design. The switch-operating mechanism, with free-return clutch on which the thermal releases operate by means of a lever, is mounted in a cast-iron casing together with an ammeter and the terminals for the leads to and from the circuit breaker, which is fixed to the underside of this casing. The different types can all be provided with terminal protection covers (Figs. 29 and 30 a) or with trifurcating boxes (Fig. 30 b). No-volt release, instantaneous-acting over-current and under-current...
Fig. 31. — Regulating switch type G 1 for train lighting.

releases, and the usual auxiliary leads for remote tripping, etc., can also be fitted.

The current transformers used with the switchboxes for higher current ratings form a kind of selective protection, because, on account of the saturation of the core, the secondary current does not increase in direct proportion to the primary current when a short circuit occurs, but lags behind. Thus heavy short circuits calculated to damage the switchbox are tripped by the nearest network breaker, which has a higher rupturing capacity.

The regulating switch (Fig. 31) for our train-lighting system is also very interesting. Contrary to the previous design, only one contact sector is now used (instead of two), though there is the same number of subdivisions of the resistance as before.

We have also developed a number of connections for providing complete selective protection for three-phase networks, particularly those with insulated and earthed neutral points, by means of our distance relays. The tests carried out on networks protected with our distance relays¹ show that these satisfy completely the most exacting requirements of an efficient selective protection.


Fig. 32 shows a model representing three interconnected networks fed from three power stations. It enables the absolutely selective protection afforded by our distance relays built into the various branches to be demonstrated very clearly.

8. Switchgear.

In this connection the reader is referred back to The Brown Boveri Review 1928, No. 1, in which a description of the Bienne Outdoor Substation was given. In this substation (see frontispiece) the use of overhead steel construction has been practically eliminated. The difference between the normal type of outdoor substation, which cannot, however, be avoided where ground is expensive, and this latest type will be seen from Figs. 33 and 34.


When bright-annealing copper and brass wire, hoop iron, etc., it was previously necessary to place the charge in bundles in metal pots which, to prevent the charge oxidizing, were connected up for the whole duration of the process to a gas exhauster.
To avoid the necessity for using this gas exhauster, we have decided to provide all our furnaces in the future with annealing pots of the “Grünewald” type.

Constructionally, the Grünewald pot, shown diagrammatically in Fig. 35, differs from all previously used forms in that it does not stand in the furnace but is suspended inside it. Also, the charge is not laid directly in the pot but on a special tray which is suspended from the cover by means of rods. These new features allow of the following:

(1) The weight of the annealing pot can be reduced considerably. Instead of walls made of cast steel or boiler plate 20 to 30 mm thick, they need only 6 to 8 mm thick; the pots can be used until they are no longer air-tight due to burning, i. e., until their walls are reduced to a thickness of only 2 to 3 mm. This reduction in the thickness of the walls results in an important saving in current of 15—35 % due to the large decrease in weight and the reduction in the resistance to the passage of heat between the source of heat and the charge.

(2) The seal of the annealing pot is not in contact with the source of heat, and therefore an absolutely air-tight joint can be made in the simplest manner.

(3) The heat stored in the charge and in the pots can be easily regained by using it for pre-heating cold pots.
The individual parts of the annealing pot can be seen from Fig. 35. The operation of bright-annealing wire and hoop iron is as follows:

The charge for the furnace is laid on the supporting tray IX in the wire-drawing or rolling department, or in the annealing shop itself. The cover and the suspension rods X are held by a crane and are moved over to the supporting tray where the rods are fitted into the tray; the whole charge is then ready for lifting and can be moved to the annealing pot I and lowered into it. When transporting the annealing pot, the cover is held down by a safety device, not shown in Fig. 35; the water channel IV is filled with water for cooling the rubber joint V. The pot, ready charged, can now be lowered into the furnace by means of the lifting rings VI and heated up. A large part of the air is expelled through the valve VIII due to expansion caused by the rise in temperature, and also due to the vaporization of oil and grease which has adhered to the charge. The oxygen in the remaining air is used up for burning part of the oil vapour, so that the annealing pot becomes free of oxygen long before the oxidation temperature of the charge is reached. The pressure in the pot I drops towards the end of the process, and the valve closes automatically. The valve VIII can be screwed down tight for safety, when moving the pot. After the desired annealing temperature has been reached the pot is drawn out of the furnace by means of the crane, and is hung in a cooling pit where it cools in 20 to 30 hours. Due to the good fit of the cover and the valve, no air whatever can enter during the cooling process, so that a vacuum up to 400 mm of mercury is formed in the pot. The valve is only opened during the cooling process when the temperature has dropped to the value required for bright-annealing, blue, or black dull annealing, whichever is desired, and the charge, suspended from the cover, is withdrawn from the annealing pot. The supporting tray IX is placed on the floor and the suspension rods removed and immediately fitted to another supporting tray which is loaded with a fresh charge. This new process, combined with the electric reheating furnace, offers the following eminent advantages as compared with the old processes of annealing, still used to a very great extent, where the annealing pots are filled with cast-iron chips:
(a) The ratio between the weight of the charge and the pot, at present often 1:2, can be improved to 2:1 with the Grünewald pot.

(b) The expenditure for the filling of iron chips is entirely avoided.

(c) The annealing process is absolutely clean and dust-free, and enables the reheating furnace to be erected in the same shop where the wire-drawing or rolling is done, thus simplifying the handling of the material and reducing the transport costs.

We have supplied many melting furnaces during the past year with automatic electro-hydraulic electrode control, and of these perhaps the most interesting is that shown in Fig. 36. This furnace has a capacity of eight tons; it was delivered to a firm in Göteborg (Sweden) and will be used for the production of pearlitic cast iron. In addition to the mechanism for tilting the whole furnace, the door-opening mechanism is also operated hydraulically.

10. Electric traction.

The most important event in this connection which took place during the past year was the completion of the accelerated programme of electrification of the Swiss Federal Railways, i.e., the termination of the programme first laid down in 1918. According to this, the whole railway network was divided into three groups: the first, of 1128 route-kilometres, had to be electrified by the end of 1928; the second, of 601 kilometres, at the end of another 10 years; and the remainder by the end of 1948.

Electric traction, however, proved so very satisfactory as soon as it was introduced, and as it was urgently necessary to utilize the large sums of money to be spent on the electrification for relieving unemployment which was very serious about that time, the administration of the Swiss Federal Railways resolved to accelerate the programme of electrification in 1923. It was decided to electrify by the end of 1928 not only all the lines in the first group but also those sections of the second group which, according to the programme of 1918, were not to be electrified until 1933. By extending, in the meantime, the electrification of the Zollikofen-Bienne-Münster-Delsberg section and the Rapperswil-Wattwil and Sargans-Buchs sections, the total length of railway electrified under this programme is 1589 km. Thus, including the previously electrified Simplon Tunnel (Brig-Isele) and the Seethal Railway, which was taken over by the State in 1922, the total length of railway electrified at the present time is 1666 route-kilometres, i.e., 60% of the whole network of the Swiss Federal Railways, handling 80% of the total traffic (Fig. 37).

The electrification of the main lines of the Swiss Federal Railways is one of the most interesting parts of Swiss railway history and affords the first instance of the greater part of a railway being electrified within a few years. The solutions found to the numerous technical and economic questions which arose have now come to be regarded as representative practice and have given a great impulse to the development of electric traction throughout the world.

It will therefore be appropriate here if we indicate briefly to what extent our manufactures have been used in this electrification scheme.

Of the 21 alternators for supplying traction current installed in the Swiss Federal Railways' power stations at Ritom, Amsteg, Göschenen, Barberine, Vernayaz, Trient and Massaboden, we have supplied twelve, with an aggregate output of over 100,000 kVA, and, of the 96 transformers (excluding auxiliary station transformers) in the various power stations and substations, no less than 40, with an aggregate rating of 206,000 kVA. We have also supplied all the switchgear in the Barberine and Vernayaz power stations, in addition to that for the outdoor substations at Brugg, Puidoux, Fribourg and Bienne, and the 60-kV switchgear for the Giornico and Melide substations.

At the conclusion of their programme of electrification, the Swiss Federal Railways now have 391 electric locomotives, of which, in co-operation with the Swiss Locomotive and Machine Works, Winterthur, who built the mechanical parts, we have supplied 181, namely:—41 1B-B1 locomotives (series 12302), 86 2C₁ locomotives (series 10601), 23 2D₁ locomotives (series 10901), 18 C₁ and C type shunting locomotives (series 16301 and 16311), three C-C locomotives (series 15301), one 1 C-C₁ locomotive.
During the autumn of 1928, the Swiss Federal Railways put out contracts for 18 more 2D₀₁ locomotives (series 10901) which, like the other machines in this series, are again being equipped with our patent individual axle drive. We received the order to supply the electrical equipment for seven of these locomotives. Thus on the Swiss Federal Railways alone there are 150 locomotives fitted with our individual axle drive.

The following are some other important orders received during the past year:

From the Cia. Paulista de Estradas de Ferro, Brazil, one 1D₀₁ express locomotive (Fig. 39) for a d.c. contact-wire pressure of 3000 V and a gauge of 1600 mm; weight in working order approximately 115 tons, continuous tractive effort 10,200 kg at 65·8 km/h, maximum speed 105 km/h. Each of the four driving axles is driven by two motors permanently connected in series. The torque is transmitted from the motors to the axle, on one side only,
through reduction gearing and our patent individual axle drive.\footnote{The Brown Boveri Review 1928, p. 273.}

Two Bₐ-Bₐ standard-gauge goods locomotives for a d.-c. contact-wire pressure of 3000 V, with nose-suspended tram-type motors; weight in working order 58 tons, continuous tractive effort 7360 kg at a speed of 26·8 km/h. The locomotives were ordered by the Office Chérifien des Phosphates, Morocco.

Four combined rack and adhesion locomotives ordered by the Sociedad de Ferrocarriles de Montana a Grandes Pendientes for service on the Ribas-Nuria Railway. The locomotives are each equipped with two direct-current shunt-wound motors for a mean contact-wire pressure of 1500 V, a one-hour rating of 180 H. P. per motor at a speed of 500 r. p. m., with a corresponding speed of 11·6 km/h (Fig. 40). The maximum speeds on the rack and adhesion sections are 13 and 30 km/h, respectively.

Three single-phase C-C locomotives (series 401) for the Rhätischen Railway, for developing a continuous tractive effort of 8100 kg at 30 km/h. This railway now has 15 locomotives of this type.

In addition to the nine three-phase E-type locomotives (group E.554) for a tractive effort of 12,000 kg at 25 and 50 km/h, mentioned in our last report, the Italian State Railways have ordered 30 more similar machines from us (Fig. 41).

The Norwegian State Railways ordered a fifth 1C-Cl locomotive (series 2033) from the Aktieselskabet Norsk Elektrisk and Brown Boveri, Oslo. These locomotives are particularly noteworthy on account of the fact that they use regenerative braking when descending towards the Norwegian port of Narwik.

With the connections which we have used here, the motors are separately excited from the main transformer through a phase changer. Thus during the descent the electromotive force generated has opposed phase relationship to that in the network, which is the necessary condition for regenerative braking. It is very important that the motors be changed over to separate

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Fig. 38. — Distance in kilometres travelled by the electric locomotives and motor coaches of the Swiss Federal Railways.

A. Total distance in km covered by all the single-phase locomotives.
B. Total distance in km covered by the single-phase locomotives supplied by Brown, Boveri & Co.
C. Total distance in km covered by the 2 Cₐ1 locomotives Nos. 10601 to 10606.
D. Total distance in km covered by the 2 Dₐ1 locomotives, series 10901.
E. Total distance in km covered by the 1 C-C₁ locomotive No. 14201, the 1 D₂ locomotive No. 11001, the 1 C and C locomotives series 16301 and 16311 and the 1 B₀⁻1 B₀₁ locomotive No. 11000.
F. Total distance in km covered by the 1 C-C₁ locomotive series 15001.
G. Total distance in km covered by the motor coaches series 4801 and 18701.
H. Total distance in km covered by the three-phase locomotives of the Swiss Federal Railways.
   Type I C₁ (series 364).
   = D (series 366).
   = 1D₁ (No. 371).

Fig. 39. — 1D₁ express locomotive of the Cia. Paulista de Estradas de Ferro, São Paulo (Brazil).
excitation and the phase changer started at the correct time. This can be achieved with absolute reliability only if the regenerative braking connections are made automatically immediately the main controller is moved to the zero position and the reversing controller into the braking position.

A simplified diagram of connections for the regenerative braking as used on these locomotives is reproduced in Fig. 42. Referring to this diagram, the current flows from the tapping switch 5, through a special switch 6, with no-volt release, and through the rotor windings 7 of the motor to earth. The motor-operated change-over switch for making the various connections is not shown, but only its interlocking
contacts 71 to 74. The switch 27 is operated according to the position of the contact brush 5 of the tapping switch and is provided with a recall spring; 8 is a paralleling relay, and 9 a contact device for 8 operated by the sliding contact of the tapping switch. 11 is the phase changer provided with a centrifugal switch 12. Number 13 is a no-volt relay and 14 the combined starting and change-over switch for the phase changer; this switch is operated by the auxiliary motor 15. The switch 14 is furnished with cams for closing the switches 51 to 54. Number 16 is a push-button switch.

For braking, the main controller is moved to the zero position and the reversing controller to the braking position, though by means of the usual interlocking arrangement the latter is prevented from taking up the braking position until the tapping switch is at zero. By these movements, the no-volt relay 13 is put under tension over the contacts 62 on the reversing drum 14. The relay then closes its upper contacts, and the servo-motor receives current through the exciting winding 15a and the contact 63 of the change-over switch 14. The servo-motor rotates the switch 14 into the position I and the phase changer is then ready to start. In the position I, the switches 52, 53, and 54 are closed by the cams on the switch 14. Current now passes from the 220-V tapping of the main transformer 4 over the contacts 53 and 54 and the ohmic resistances 21, or over the contacts 53 and 52 and the choke coils 31, to the stator of the phase changer 11. By supplying the stator at two points 90° apart, a rotating field is produced and the phase changer runs as a single-phase motor. When a certain speed is attained, the centrifugal starter 12 closes its contacts, thus connecting up the control-current circuit of the auxiliary motor 15 to the current supply over the contact 64 of the reversing drum 14. The motor 15 then rotates the switch 14 into position II, whereupon the cams open the switches 52 and 53, thus disconnecting the starting resistances 21 from the phase changer which can now be connected up to the field windings 17 of the motors 7.

On moving the main controller from the zero position, the tapping switch is brought into the first position. The switch 27 then opens, is moved towards the right by its springs, and short-circuits the contacts 27b so that the auxiliary motor 15 receives current through the contact 65 of the change-over switch 14 and the contact 27b and moves the switch 14 into position III. In this position the switch 51 of the change-over switch 14 is closed by the cams and connects the field windings 17 of the driving motors 7 to the phase changer. The motors 7 are then excited and generate an electromotive force, the magnitude of which depends on the speed of the locomotive. When the transformer tapping switch is moved from the position I, the switch 9 moves simultaneously to the left and closes its contacts, thus
preparing the motor 18 for operation. The switch 9 is locked by the catch 19.

The tapping switch is now moved on from one position to the next until the transformer pressure is approximately equal to the terminal voltage of the driving motors. The paralleling relay 8, which operates according to the difference between these pressures, then trips and closes the control circuit for the motor 18. This motor closes the low-tension switch 6, which connects the driving motors 7 to the contact wire through the main transformer, and the regenerative braking begins.

The purpose of the contacts 71 to 74, which are short-circuited when the change-over switch is in the braking position, is as follows:— The contact 71 closes a circuit of the control motor for the tapping switch (the motor is not shown in the diagram), when the switch 14 for the phase changer is in position II or III over contact 61 of the switch 14. The motor control relays are denoted by 20 and 22. Contact 72 closes the circuit of the exciting winding of the paralleling relay 8. Contact 73 is for interlocking the circuit of the motor 18, which is closed by the paralleling relay 8, to prevent its being closed unless the change-over switch is in the braking position. The current for energizing the relays 29 and 39, which are connected in parallel, is led over the contact 74. Relay 39 releases the switch 6, which is operated by the auxiliary motor 18, while the change-over switch is being moved into the braking position; relay 29 releases the catch 19 and, therefore, the switch 9, when the braking position has been reached. Special contacts are provided in the usual manner for preventing the switch 9 from opening during the braking period.

To interrupt the regenerative braking, the switch 6 must be opened by a push button (not shown) or by remote control. This moves the tapping switch to the zero position. When this is reached, the change-over switch is moved to the position for running forwards or backwards. The current to the no-volt relay 13 is thus interrupted; the armature of the relay short-circuits the lower contacts and closes the circuit for causing the servo-motor 15 to run reversed over the contact 66 on the switch 14 and the exciting winding 15b. The motor 15 turns the switch 14 into its neutral position and brings the phase changer 11 to rest.

If the pressure falls in the contact wire, the main switch 3 opens and the no-volt relay 13 trips, whereupon the servo-motor 15 brings the switch 14 to the neutral position and the phase changer stops. The low-tension switch 6 can then be opened again by a push-button switch.

To enable the driver to start up the phase changer during the run so that it is already generating its full voltage and running at full speed if it should be necessary to resort suddenly to regenerative braking, a push-button 16 is provided. On depressing this push-button, the no-volt relay 13 is put under tension, closes its upper contact, and, as already described, operates the switch 14 by means of the servo-motor 15 and prepares the phase changer 11 for the regenerative braking. By allowing the phase changer to run, it is always ensured that it is cooled sufficiently. Regeneration is again introduced by moving the tapping switch 5 back to the zero position by means of the main controller, and by moving the change-over switch into the braking position. The switch 6 then opens and, as previously described, the phase changer is connected up to the field windings 17 of the driving motors 7 and these motors are connected to the contact wire.

An important order we received during the past year was one for 144 axle-bearing motors for the Rotterdam Tramways. The motors have an output of

Fig. 43. — Direct-current tramway motor with forced ventilation, 34.5 kW, 550 V, 830 r.p.m.
24.5 kW at the one-hour rating at 900 r.p.m. and are cooled on our forced ventilation system. They are intended for four-axle trams and will be connected together in pairs in permanent series at a contact-wire pressure of 550 V. An order for the Posen Tramways is being executed at the present time. This is for 90 forced-ventilated axle-bearing motors for 34.5 kW at the one-hour rating at 830 r.p.m. and 550-V terminal pressure; for 90 controllers of the design with individual blow-out; and for the corresponding starting resistances. The motors (Fig. 43) are of particular interest in that not only the motor armature bearings, but also the axle bearings are made as roller bearings.

The increasing use of high-tension direct-current up to 3000 V for narrow-gauge interurban railways on which, as a rule, motor coaches are employed exclusively or, at any rate, for all the passenger traffic, is very interesting. In connection with this development, which seems to indicate the probability of using direct-current contact-wire pressures of 5000 to 6000 V for main-line railways, the electrification of the Tramvie Vicenza-Recoaro-Chiampo and the Ferrovie delle Dolomiti (Calalzo-Cortina d'Ampezzo-Toblach) might be mentioned, in addition to that of the standard-gauge sections of the Ferrovia Nord Milano, described some time ago.

For the first-mentioned of these railways, the Tecnomasio Italiano Brown Boveri, Milan, supplied three B0—B0 goods locomotives and also the electrical equipment for seven four-axle motor coaches. The aggregate motor rating of the locomotives and motor coaches is 600 H.P. The electrical equipment for two B0—B0 goods locomotives with a combined rating of 520 H.P., and for six four-axle motor coaches with an aggregate rating of 300 H.P., is at present under construction for the second railway. On both these railways the contact-wire pressure is 3000 V.

In conclusion we give particulars of some Diesel-electric vehicles. We are at present building three Diesel-electric motor coaches in co-operation with Messrs. Fiat, Turin, who are supplying the Diesel engines. The engine in each coach is coupled to a Brown Boveri direct-current generator developing 85 kW at 400 V and driving two axle-motors having
motor mounted above the axles and driving through reduction gearing and coupling rods (Fig. 46). The equipment of both 1 D 1 locomotives is otherwise the same.

We are also building an experimental Diesel-electric motor coach in co-operation with Messrs. Linke Hofmann Busch Werke. This machine will be equipped with two motors supplied from a 95-kW, 450-V generator direct coupled to a high-speed Diesel engine.

In addition to the electric locomotives, already described, which we have supplied to the Swiss Federal Railways, the following have also been put into service during the past year: The four $B_o-B_o-B_o$ express locomotives (group E 625) for the Benevento-Foggia section of the Italian State Railways, operated on 3000-V direct current (Fig. 47), the 2 $C_0-C_0$ express locomotive No. 4002 $EC$ for the Great Indian Peninsula Railway (Fig. 48), and three of the second group of seven 1 $D_o$ locomotives (Series E 1601) for the German State Railway.

Finally, the so-called Nordkettenbahn near Innsbruck was put into service during the past year. This comprises two sections of aerial ropeway. One section, with an average gradient of 41%, connects the terminal station of the Hungerburg Railway with Seegrube Station which lies 1043 metres higher (1906 metres above sea-level); the second section extends to Hafelekar (2258 metres above sea-level) and has an average gradient of 56%. The winding engines for both sections are installed at Seegrube Station. They consist of two three-phase motors, one of 80 H.P. and the other of 83 H.P., which, together with all the control gear, were supplied by us. The cars have a carrying capacity of 23 passengers in addition to the driver and luggage. The mean speed on the lower section is 4 metres/sec and on the upper section 3.5 metres/sec. The illustration on the last page of this Review shows a view of Seegrube Station; at the top of the mountain the terminus of the ropeway at Hafelekar can be seen.
II. WORK OF THE TURBINE DEPARTMENT.

1. Steam turbines.

During the past year, Brown, Boveri & Co. have received orders for steam turbines of an aggregate rating of over one million kilowatts, 630,000 kW of which are accounted for by their latest multi-cylinder type. This brings the total output of all Brown Boveri turbines delivered or on order up to 11.7 million kilowatts, that of the multi-cylinder type being 2.2 million kilowatts (Fig. 50). Figures such as these have not been even approached by any other European firm. Two years ago, Brown, Boveri & Co. received an order for the largest steam turbine in the world — that for Hell Gate Power Station, New York. Now we have on order the largest turbo-set in Europe. This is an 85,000-kW three-cylinder turbine with generator for the Zschornewitz Power Station of the Berlin Electricity Supply. This sudden advance in steam-turbine construction is due, above all else, to the great success of our new multi-cylinder machines. The manufacture of this type of turbine has been such an outstanding feature of the past business year, and, it might be said, almost without parallel in the history of the steam turbine, that it will be interesting to indicate once more the reasons for its development.

The success of the Brown Boveri multi-cylinder steam turbine, from a technical point of view, can be traced first and foremost to the use of high-grade material. The higher manufacturing costs, and, consequently, somewhat increased price which this inevitably necessitates, do not, however, restrict sales in any way. The chief advantages of this type of turbine are as follows:

- High efficiency;
- Very high degree of reliability;
- Short time required for starting up;
- Insensitivity to sudden changes in load;
- Running qualities and efficiency remain unaltered throughout the life of the turbine.

The means taken to achieve these characteristics will now be briefly described, reference being made to Fig. 51 in which a section of the previously-mentioned 85,000-kW turbine for Zschornewitz Power Station is reproduced.
The fundamental principle of the design lies in the division of the turbine into separate parts according to the temperature. The high-pressure cylinder and shaft have only to withstand high temperatures and the low-pressure cylinder and shaft only low temperatures. Material suitable for the prevailing temperature can then be used in each part, which can be designed accordingly. The temperature differences in each cylinder are small, dangerous stresses and deformation due to the heat are avoided, and the correct blade clearance and play in the packing glands, which have such an important bearing on the efficiency of the machine, can be permanently maintained. The casings are short, and of small diameter; they are of simple design and are free to expand in all directions. Large masses of material on the casings and shafts have been avoided, thus enabling the temperature of the machine to change rapidly and uniformly when starting up or when the load varies. Such a turbine can be started up in a few minutes and is completely insensitive to sudden changes in load.

The blading comprises one or two impulse stages and 30 to 40 rows of reaction blades. This patent Brown Boveri reaction blading has been very highly developed during the last few years and now has an efficiency of 94 %, which is higher than that of any other steam-turbine blading. Leakage losses were reduced to a very great extent by mounting the blades in the different cylinders in such a way that the axial thrusts compensate each other, thus enabling balance pistons to be eliminated, and by
Fig. 52. — Increase in the average steam pressure and average steam temperature used in Brown Boveri turbines.

 adopting a new type of packing gland of smaller diameter. The losses at exit from the low-pressure cylinder were reduced to about a quarter of their previous value by working the last two rows of blading in parallel. In the low-pressure cylinder special channels are now provided for leading away the water which condenses as the steam expands, thus reducing the braking effect of the water and diminishing the extent to which the last rows of blading are eroded. All these measures result in the turbine having a coupling efficiency of 84 to 86%, a figure which cannot be attained with any other design of turbine. Thus the Brown Boveri multi-cylinder steam turbine also occupies a leading position as regards economy. Reliability, insensitivity to all conditions of loading, and high efficiency are factors of such great importance for the smooth and successful operation of a power station that the preference shown for this type of turbine and the numerous orders placed with Brown, Boveri & Co. are easily explained.

Another important characteristic in the design of the new Brown Boveri multi-cylinder turbine is that it takes into full account the modern tendency towards the use of higher pressures and temperatures (Fig. 52). It is quite safe to use steam at a much higher initial temperature. When using steam at higher pressures, the number of rows of blading must be correspondingly increased if the increased heat drop is to be utilized efficiently. It thus becomes all the more necessary to divide the steam turbine into several cylinders as the use of higher steam pressures and temperatures continues to grow. The single-cylinder turbine is, therefore, only really suitable where the efficiency is not of primary importance or where the space available is insufficient for the installation of a multi-cylinder machine.

Brown, Boveri & Co. have always held the view that peak loads in power stations can be produced much more economically by good machines capable of being heavily overloaded than by cheap machines of low efficiency. The Brown Boveri multi-cylinder turbine is particularly suitable to be used as a peak-load machine as it can readily be built for heavy overloads, it can be started up in a few minutes, and heavy and rapid load variations can be accommodated with ease.

With regard to high-pressure steam plants we have very gratifying success to report. The 4800 and 7000-kW steam turbines for the super power station at Mannheim are now in service and are giving complete satisfaction. These turbines, which were mentioned in last year’s report, are supplied with steam at a pressure of 100 kg/cm². (Fig. 53).

Since 1925, a Brown Boveri 1650-kW primary turbine, for steam at 55 kg/cm² and 450°C, has been in continuous service in the Langerbrugge Power Station of the company “Centrales Electriques des Flandres”. During the year under review, this same company ordered another turbine from us for the same steam conditions, but this time for an output of 7000 kW. By the installation of this primary turbine with its high-pressure boilers, the existing plant, which has been running since 1920 and comprises four Brown Boveri normal-pressure turbines each for an output of 6600 kW and for steam at 20 kg/cm², has been converted into a modern high-pressure power station operating on steam at an initial pressure of 55 kg/cm². Without increasing the coal consumption it has been possible to raise the output of the plant from 26,000 kW to 33,000 kW. The Centrales Electriques des Flandres also placed an order with us during 1928 for a 25,000-kW three-
cylinder turbo-alternator set. The steam expands in a single unit from a pressure and temperature of 55 kg/cm² and 450° C, respectively, to a 96% vacuum. This is the first straight-condensing turbine to be built for such a high pressure. Provision is made for feed-heating, but when the turbine is run without feed-heating, i.e., under the most unfavourable conditions, the steam consumption is 3.74 kg/kWh; with feed-heating the consumption of the whole plant is only 2520 kilogram-calories per kWh.

It is worthy of note that the standard Brown Boveri three-cylinder turbine, with blading suitably modified but with all other parts unaltered, can be used for this high pressure; this illustrates clearly that those who designed this type of turbine foresaw the development towards high temperatures and pressures. A section through this 25,000-kW high-pressure condensing turbine is reproduced in Fig. 54. The steam expands from 55 kg/cm² to 12 kg/cm² in the high-pressure cylinder. At the prevailing temperature of 450° C this high initial pressure puts particularly severe stresses on the materials used. Any danger which this might occasion has been obviated by making the casing of "dead-annealed" molybdenum steel.

It will be appropriate to point out here what very valuable service has been rendered in the development of the high-pressure steam turbine by such men as Herry and Marguerre. Merely for designers to realize the advantages of high pressures and temperatures and to prepare designs for machines capable of utilizing them was not sufficient. It was also necessary that works directors should appreciate these advantages, and, having faith in the designers and the courage of their own convictions, be prepared to carry through new schemes and to bear the technical responsibilities and financial risks.

During the past year, work on the 160,000-kW steam turbine for the Hell Gate Power Station of the United Electric Light & Power Co., New York, was completed. This machine was taken to Antwerp, for shipping to America, on 82 railway wagons of which 14 were special six to eight-axle wagons (see illustration on inside of cover). The turbine was erected by our workmen in the exceedingly short time of about 18 weeks and has been running

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Fig. 53. — High-pressure primary turbine for steam at 100 kg/cm² and 430° C installed in the super power station at Mannheim.
Fig. 54. — Langerbrugge Power Station of the company "Centrales Electriques des Flandres". Section of the turbine for 25,000 kW, 55 kg/cm², 450° C.

Fig. 55. — 160,000-kW turbine for Hell Gate Power Station, New York.
The high-pressure cylinder on the test bed.
since the end of the year. Views of various parts of the machine in the workshops, and of the turbine being erected on site, are reproduced in Figs. 55 to 62.

A very important improvement in steam turbine construction is the new steam turbine governing system which we have recently developed for large turbines. A diagram showing how this system operates is given in Fig. 63, and in Fig. 64 a section through the governor, oil-pump, and driving gear is reproduced. The principle is the same as that of the previous Brown Boveri governing which has proved so very satisfactory and has been adapted with such ease to all special cases. The main stop valve, however, is no longer opened by hand but by an oil-operated piston and is closed by a powerful spring when the oil pressure fails. It was necessary to adopt this expedient because it has been found practically impossible to operate by hand the large unbalanced stop valves now used for large modern turbines with high initial steam pressures, even though very big leverages were employed. Even an oil-operated valve of this type must be relieved by means of an auxiliary by-pass valve before it can be opened, and this again is only possible if the nozzle valves remain closed while the main stop valve is opened. The most simple way of ensuring that the various operations which have to be performed when starting a turbine are made in their correct sequence is to use a pilot controller. The handwheel of this controller is turned, where previously the handwheel of the stop valve was turned, with very little effort, and the following operations take place, in the order given: the nozzle valves a close, the auxiliary by-pass valve m opens and the main stop valve i and then the nozzle valves a open, the turbine then starting up. When full speed is attained the oil port h is uncovered and the governor
takes over the regulation of the oil pressure and the control of the machine. When shutting down the turbine the same operations take place but in the reverse order. The safety device has been very ingeniously combined with this starting controller. The emergency governor o is mounted directly on the turbine shaft p instead of on the governor shaft as previously, so that even in the unlikely event of a breakdown in the mechanism driving the governor shaft the turbine will not be in danger of running away. The safety trip no longer has to release a relatively heavy mechanism; it merely starts the return movement of the control piston q of the pilot controller n. The latter is then brought to the shutting-down position, its oil-release valves open, and the main stop valve and nozzle valves are closed by their springs. With this new Brown Boveri governing, double safety is obtained if the governor should fail, because the steam supply to the turbine is cut off by two valve systems which operate one after the other.

The worm drive for the governor and the oil pump has been replaced by an ordinary reduction gear r which, as is well known, can be made with greater accuracy than worm gearing. Another noteworthy improvement in the governing

Fig. 57. — 160,000-kW turbine for Hell Gate Power Station, New York.
Last wheel of the low-pressure turbine.

Fig. 58. — 160,000-kW turboalternator set for Hell Gate Power Station, New York.
Rotor of the alternator driven by the low-pressure turbine; 85,000 kW, 1,200 r. p. m.
Fig. 59. — 160,000-kW turbine for Hell Gate Power Station, New York.
Part of the low-pressure cylinder with blading.

Fig. 60. — Erecting the high-pressure cylinder of the 160,000-kW turbine in Hell Gate Power Station, New York.
system is the device for testing the emergency governor. With the previous governing system it had to be tested by running the turbine above normal speed, i.e., with generator disconnected. The emergency governor used with the new governing can be tested at normal speed by introducing oil under pressure through the valve into the centre of the shaft, thus causing the weight, which is built as a differential piston, to operate and release the valve of the controller and shut down the turbine. The oil pressure, which is read off on a manometer, provides a measure of the speed at which the safety governor trips. The method previously used of operating the nozzle valves directly by means of the oil controlled by the governor is no longer used for very big turbines. In these, the power available for operating the valves has been considerably increased by first using the pressure-oil in a preliminary regulator which controls the
pressure-oil for moving the pistons of the nozzle valves.

2. Condensers.

Brown Boveri condensers are still made in the patent OV form, with wide steam inlet to the tubes and with the water chambers built up in halves on the well-known Brown Boveri continuous-service principle. In modern steam power stations the feed-heating and evaporating system is combined with the condenser plant and pumps. Feed heaters are simply apparatus for transferring heat, but there are quite a number of important points connected

Fig. 63. — Diagrammatic arrangement of the new Brown Boveri steam-turbine governing system with oil-operated main stop valves and emergency governor.

a. Nozzle valves.
b. Springs of nozzle valves.
c. Operating pistons of the nozzle valves.
d. Pressure-oil system.
e. Gear oil pump.
f. Oil-regulating valves.
g. Governor.
h. Oil-regulating port.
i. Emergency valve. Main stop valve.
k. Operating piston of main stop valve.
m. By-pass valve.
n. Pilot controller.
o. Emergency governor.
p. Turbine shaft.
q. Tripping mechanism for main stop valve.
r. Reduction gear.
s. Testing gear for emergency governor.
t. Turbine-driven oil pump.
u. Automatic starting gear for oil pump t.

Fig. 64. — Sectional drawing of the new Brown Boveri steam-turbine governing system with oil-operated main stop valve and safety mechanism.
with them which it is often by no means easy to solve if all conditions likely to arise during service are to be fulfilled. The water-carrying parts of the feed heater have to withstand the full pressure of the feed water, i.e., a pressure greater than the boiler pressure, so that the tube nests and water chambers have to be made particularly strong. To prevent any risk of feed water flowing into the turbine should the water tubes leak, non-return valves are provided in the steam extraction mains. These valves (Fig. 65) close due to their own weight if the flow of steam ceases or reverses. Since they are so light, however, they offer only slight resistance to the flow of the steam. The steam side of the feed heater is only subjected to the relatively low pressure of the extraction steam, but must be protected by safety valves against excess pressures which might arise if the tubes began to leak. The tube nests are built up of bent tubes which can expand individually under changes in temperature.

To obtain an efficient interchange of heat in the feed heater, the water must flow through the tubes with sufficient speed. This introduces a certain loss in pressure which is overcome by the feed pump. In most regulations for boilers it is stipulated that it should be possible to supply double the quantity of feed water for short periods, in which case the loss of pressure in the feed heaters would increase fourfold. In order to avoid the necessity for making the boiler feed pumps large enough to meet these pressure losses, which occur only exceptionally, Brown, Boveri & Co. have developed an arrangement (patent applied for) in which the water-carrying parts of the feed heater are by-passed, though during normal service the by-pass lines are closed by spring-loaded valves. Referring to Fig. 66, a is the condenser and b the condensate pump. The boiler feed pump c forces the condensate through the feed heaters d and pipe e to the boiler. The by-pass lines f on the feed heaters are closed by the spring-loaded, or weighted valves g. When, in exceptional cases, the feed pump c has to deliver more water than normally, the valves g open and allow the extra quantity of water to be passed directly to the boiler. These valves also make it easier to cut a feed heater out of the feed-heating circuit, as the by-pass lines are opened automatically when the valves h and i open.

It can also happen with feed-heating plants that a boiler feed pump has to pump hot water at a pressure lower than that corresponding to the saturation temperature. This problem can be solved by the patent Brown Boveri method indicated in Fig. 67. The boiler feed pump a is required to pump hot water from the low-lying tank b in which the prevailing pressure corresponds to the saturation temperature. A tank c is therefore mounted several metres above the pump. This tank is fitted with a float valve e.
which enables steam to escape to the atmosphere or, for example, to be supplied to the tank f for heating the feed water. The water is therefore drawn up from the tank b through the pipe d to the tank c where the pressure is less by the height $H$ than that in the tank b. Part of this water evaporates, whereupon the temperature sinks to the saturation temperature, corresponding to the lower pressure. The water now flows to the pump at a pressure greater than the saturation pressure of the water by the height $S$, thus enabling the pump to work without difficulty.

### 3. Turbo-compressors.

During the past year our compressor department completed the largest turbo-compressor which has yet been built. It has a delivery volume of 2200 cubic metres of air per minute, with a compression ratio of 11.3:1, and requires a driving power of 10,000 kW. Figs. 68 to 70 show parts of this large machine in the workshops. The tremendous size of the cooler will be noticed. This has a total cooling surface of 1800 m$^2$ and weighs 47 tons, and marks a very noteworthy achievement for our cooler department. The photograph showing the compressor on the test bed, where it was driven by its own steam turbine, is very interesting (Fig. 68).

Last year it was mentioned that Brown, Boveri & Co. had supplied the largest blast furnace turbo-blower in the world (delivery volume 2200 m$^3$ of air per minute) for an American blast-furnace plant. In 1928 our compressor department began work on a still larger blower, for 2600 m$^3$/min.
and 8400 kW. The blower for the American plant draws in air from one side only (single-ended blower), whereas the newer and larger blower compresses the air in two parts connected in parallel (double-ended blower). Fig. 71 shows a section through this blast-furnace blower from which will be seen the two suction mains, the common delivery main and the shaft with its $2 \times 5$ impellers. The impeller discs are made of best nickel-chrome steel to withstand the big centrifugal forces, and, to reduce their weight, the blades are bored on the patent Brown Boveri method (Fig. 70). The blower is driven by a two-cylinder steam turbine for 34 kg/cm², 400°C and 3300 r. p. m., of the same design as those used for driving generators up to 10,000 kW.

This blower plant is particularly noteworthy because here a turbo-blower, driven by a modern high-pressure steam turbine working on an improved cycle obtained by heating the boiler feed, was preferred to a gas-engine driven reciprocating blower. The high-pressure steam plant with turbo-blower now has an efficiency practically equal to that of the gas-engine driven reciprocating blower and, in addition, is more reliable and has lower initial and maintenance costs.

Closed-circuit cooling is now very extensively used for large generators and it may safely be said that in future it will be provided on all such machines. With this system the temperature of the cooling air remains lower during the hot summer months than when fresh-air cooling is used because the cooling water remains at a temperature appreciably lower than that of the atmosphere. The air is free from dust, the risk of fire appreciably diminished, and the noise of the blower very greatly reduced. Fig. 72 shows a cooler element with frame as delivered ready for erection. From Fig. 73 it will be seen that the tube nests can be cleaned after simply removing a cover and without dismantling any pipes. The water pipes are so arranged that part of the cooler can be shut down for cleaning purposes during service.

The problem of cooling high-speed turbo-alternators of large output is by no means simple, because
the volumes of air and therefore the fans are exceptionally large. It is no longer the practice to build the fans integral with the generators, as in small units. Instead, they are mounted in special casings and driven either direct from the generator shaft or by means of a special slow-running motor. When the fans are direct driven, high peripheral speeds are attained which make it necessary to adopt special measures in order that the difficult aero-dynamic conditions can be fulfilled and the big centrifugal forces resisted. When the fan set is driven by a separate motor, the generator exciter is very often direct coupled to it in order to reduce the overall length of the main set. This expedient also enables the blower to be driven at a lower and more suitable speed. Although the danger that this auxiliary motor may break down is very small, a special auxiliary steam turbine is sometimes provided in addition to the motor, as with the auxiliary machines for the condenser plant. Should the motor break down, this turbine automatically starts up and drives the auxiliary set. During normal service the auxiliary turbine is coupled up to the condenser, the power which it consumes then being negligible.

The air circuit from the fan through the cooler and generator must be as simple as possible to avoid losses in pressure and the need for complicated conduits.

Fig. 69. — Air coolers for a high-pressure turbo-compressor for 132,000 m³/h and compression ratio of 11:3.

Fig. 70. — Large impeller for a turbo-compressor. The blades are bored according to a Brown Boveri patent to reduce the centrifugal forces.
The arrangement adopted by Brown, Boveri & Co. when the fan is direct driven is shown in Fig. 74. The air passes out at the top to the generator, returns to the fan and is forced downwards through the cooler and again to the generator. The separately-driven fan is mounted, together with its motor, underneath the generator, and the fan so built in between the foundations that the cooler is completely enclosed; a special fan casing is then unnecessary. A generator cooling plant with separately-driven fan is illustrated in Fig. 75.

Fig. 76 shows a scavenging turbo-blower with double drive comprising two direct-current turbo-motors, both of which can be uncoupled. Only one motor is run at a time, the other serving as standby. Four blowers of this type have been supplied for the cargo vessels “Poelau Bras”, “Poelau Roebia”, “Poelau Laut” and “Poelau Tello” of the Stoomwart My. Nederland, Amsterdam. These will be the fastest cargo vessels trading between Holland and the Dutch East Indies. Each is engined with a Sulzer eight-cylinder two-stroke Diesel engine developing 7040 S.H.P. at 100 r.p.m., the most powerful single-acting two-stroke Diesel engines in the world. A new arrangement has been adopted in these ships, the blowers being mounted with their shafts at right angles to the Diesel engines, thus simplifying the layout of the pipes very appreciably. During the past year work was commenced on two scavenging turbo-blowers — the largest that have yet been built — for a driving power of 1500 H.P. each. They are to be used for scavenging two M.A.N. double-acting two-stroke Diesel engines, and will be driven by auxiliary Diesel engines through gearing for increasing the speed, this gearing also being supplied by Brown, Boveri & Co. The design of the coupling is particularly difficult in this type of drive as it has to suit the peculiarities of the driving and driven machines. For the two blowers just mentioned, we have developed a special coupling based on the experience we have had with similar couplings on electric locomotives. Up to the end of November, 1928, we have supplied no less than 212 scavenging blowers for two-stroke Diesel engines.
Further developments were made during the past year in the supercharging of four-stroke Diesel engines. In addition to certain supercharging blowers with electric drive, we have built a large number driven by exhaust-gas turbines on the Büchi principle. The number of supercharging blowers driven by exhaust-gas turbines already built or on order is 50, out of a total of about 80 supercharging blowers. The alterations made to the motor ship "Raby Castle" (Fig. 77), owned by Messrs. James Chambers & Co., Liverpool, are very interesting. The vessel is equipped with a Werkspoor eight-cylinder four-stroke Diesel engine built by the North Eastern Marine Engineering Company, and has been in continual service since 1925. By providing the engine with a supercharging blower driven by an exhaust-gas turbine the output could be raised from about 2100 S.H.P. to 3000 S.H.P. and the speed of the vessel thus increased from approximately 11.9 to 13.3 knots. Fig. 79 shows the arrangement of the Diesel engine and the supercharging blower and their relative sizes. As will be realized from this example, supercharging is a simple and comparatively inexpensive method of increasing the output of existing Diesel engines and thus putting old vessels on a competitive footing with new ones.
the exhaust steam of the engine, the power of the turbine being transmitted to the propeller shaft through reduction gearing. This system embodies an old idea of Parsons proposed in 1894, but since then almost forgotten. Turbines can be constructed to work with vacuums down to 96%, whereas the limit with a reciprocating engine is about 85%. The use of an exhaust-steam turbine in combination with a reciprocating steam engine not only enables a larger heat drop to be utilized, but also considerably increases the efficiency of the L. P. cylinder of the engine. An increased total S. H. P. of some 20 to 35% is thus obtained; or the fuel consumption can be reduced, the total power being kept the same. It is therefore
possible to write off the cost of the turbine within a few years. In these plants with reciprocating engines and exhaust-steam turbines, the problem arises of changing the direction of the vessel from forwards to astern, or vice versa, as rapidly as possible when manoeuvring in spite of the large kinetic energy of the fast-running turbine rotor. Other firms attempt to achieve this result by disconnecting the turbine from the propeller shaft when manoeuvring, so that only the reciprocating engine has to be reversed. A fluid coupling, which is disengaged by draining off the fluid, is employed.

Brown, Boveri & Co., however, consider it dangerous to uncouple the turbine. It will be seen on consideration, and, indeed, it has been found by experience, that should any part of the control mechanism break, the coupling fail to fill up, or if
The change-over valve between the engine or turbine is not steam-tight, the uncoupled turbine can run away. In the Brown Boveri system the turbine is not uncoupled, and to enable it to be reversed in spite of its high kinetic energy, one or two rows of astern blading are provided to which live steam is admitted simultaneously with the throwing over of the control lever to "astern". When changing over again to "ahead", live steam is likewise admitted to the ahead turbine. The valves for supplying live steam to the turbine when manoeuvring, and those for admitting the exhaust steam of the reciprocating engine to the turbine or for by-passing it direct to the condenser, are positively operated by a pressure-oil system.

Fig. 80 shows the plan and elevation of a reciprocating engine with exhaust-steam turbine, and in Fig. 81 a section of the turbine and reduction gear is reproduced. The various parts are explained in the text below the figure. The turbine b (Fig. 81) runs at about 3400 r. p. m. and drives the large gear wheel e through double-reduction gearing. The wheel e is mounted
Fig. 80. — Propelling machinery for a cargo vessel, comprising reciprocating engine and exhaust-steam turbine. Total output 4250 I. H.P. at 76 propeller revolutions per minute.

- a. Reciprocating engine.
- b. Exhaust-steam turbine.
- d. Flexible coupling.
- e. Propeller thrust bearing.
- f. Change-over valve.
- g. Condenser.

Fig. 81. Brown Boveri exhaust-steam turbine plant.

- b. Exhaust-steam turbine.
- c. First reduction gear.
- d. Torsion shaft.
- e. Second reduction gear.
- f. Hollow shaft.
- g. Flexible coupling.
- h. Propeller shaft.
- i. Propeller thrust bearing.
due to its flexibility permits slight misalignment of the shafts it connects, such as might occur due to wear in the crankshaft bearings.

We are firmly convinced that the use of the exhaust-steam turbine in combination with the reciprocating engine in marine plants will be widely adopted in the future, and that the reliable and efficient Brown Boveri system will play a leading part.

5. Toothed gearing.

It is being continually proved that toothed gearing is a very convenient and efficient method of transmitting power between two machines running at different speeds. Each machine can run at its natural and most efficient speed, enabling its price to be kept as low as possible. With the introduction of the modern high-efficiency reduction gear, direct-coupled steam turbines running at an unnaturally slow speed, and high-speed direct-current
generators with their unsatisfactory commutation, have disappeared. A reduction gear for transmitting 150 kW, with a ratio of 1170 to 65 r. p. m., is illustrated in Fig. 82. The gears have single-helical teeth, the axial thrusts being taken up by special thrust rings at the wheel circumferences. These single-helical gears have the advantage over double-helical gears that by correctly adjusting the shaft bearings accurate contact over the full tooth width can be obtained.

6. Workshops.

Last year we described the construction of a large new erecting shop for enabling the largest steam turbines and generators to be built. Briefly, this shop is 27 m wide, 28 m high and has two 75-ton overhead travelling cranes and five 8-ton bracket cranes. During the past year some large and expensive machine tools were installed in this shop and put into operation. Fig. 84 shows the horizontal milling and boring machine while machining the low-pressure cylinder casing of the 160,000-kW turbine for Hell Gate Power Station, New York. The machine can bore up to 5.5 metres diameter and a length of 12 metres. The boring arms are provided with boring heads by means of which the tools can be moved in both axial and radial directions simultaneously, thus enabling the conical turbine cylinders to be bored out with ease. A new lathe for taking work three metres in diameter and ten metres long is shown in Fig. 85. In Fig. 86 a photograph is reproduced of a large radial drilling machine for drilling holes up to 80 mm diameter. The maximum spindle radius is 3.5 m and the maximum height below the spindle 3.3 m. A noteworthy feature of this machine is that the various movements
are all made by means of electric power and that direct electric drive for the drilling spindle is employed (Fig. 87). The column can be moved two metres along the bed, giving the machine a big range without shifting the work. The milling and boring machines, one of which is illustrated in Fig. 88, can be moved about on a large bed, so that the position of the work has to be changed as little as possible. The spindle diameter of the largest of these machines is 175 mm. The maximum height of the boring bar above the bed is four metres, and the machine can bore to a depth of 1600 mm at one setting. The column of this milling machine can be traversed sideways a distance of four metres on its own bed, that is, without dismantling any part of it. A very accurate marking-off bed with an area of 37-5 m² on which the large castings to be machined are marked off has also been installed in the new erecting shop. Finally, Fig. 89 shows our large double-column planing and milling machine. This has three planing tool boxes and two milling heads, and work up to three and a half metres high, four metres wide, eight metres long and of a weight up to 100 tons can be machined on it. The two milling spindles, which are mounted on the cross-slide, are driven by separate variable-speed motors and can take milling heads up to 600 mm in diameter. Very broad tools can be used for rough planing and a feed up to 100 mm per cutting stroke can be obtained. The feed is motor driven. This planer is driven by a Ward Leonard set which enables the speed of the motor driving the bed to be varied between 350 and 900 r. p. m. on the cutting stroke and between 900 and 1400 r. p. m. on the return stroke, giving a bed speed of 7 to 28 m/min. The other machines are also operated on direct current, which is supplied to each

Fig. 85. — Large slide lathe for turning work up to three metres diameter and ten metres long.
Fig. 86. — Heavy-duty radial drilling machine for drilling up to 80 mm diameter.
Maximum height below spindle 3.3 metres.

Fig. 87. — Saddle of the heavy-duty radial drilling machine.
Spindle driven by separate electric motor.

machine by a separate motor generator set. By means of shunt resistances the speed of the motors can be reduced to one third the full speed, thus simplifying the drives of the machines to a very considerable extent. (See pages 11 to 14.)

In addition to these machine tools, as already mentioned last year correspondingly large test beds have been built on which the largest steam turbines can be erected and tested. The boiler plant is capable of supplying 60,000 kg of steam per hour, all of which can be condensed in a suitable condenser plant after passing through the turbines.

Fig. 88. — Milling and boring machine with 175-mm diameter spindle for machining work up to 4000 mm high and 1600 mm long.
The column has a sideways movement of 4 metres on its own bed.
It reflects great credit on the organization that, in spite of all the moving about necessary in connection with the building of the new shop and the installation of the new machines, the extent to which normal work was interfered with was negligible. This achievement was rendered all the more difficult because the place where the new erecting shop was to stand was occupied by various departments which had to be transferred to other shops before building operations could commence.

By building the new erecting shop with its powerful cranes, and by installing the new machine tools and test plant already described, the Baden Works of Brown, Boveri & Co. have, at no small cost, been brought absolutely up to date and made large enough to meet a big future development. The head works of the Brown Boveri concern are now in a position to build the largest machines which are likely to be required for many years to come; to investigate, by means of their own test plant, results obtained in the design and research departments, and to gain practical experience regarding their own manufactures. Considering again the turbines for nearly 12 million kilowatts which Brown, Boveri & Co. have built, and the experience of the firm itself and all the affiliated companies, the confidence placed in Brown Boveri products the whole world over will be readily understood.
Fig. 90. — 160,000-kW turbo-alternator set in Hell Gate Power Station of the United Electric Light and Power Co., New York.
III. WORK AND EQUIPMENT OF THE MATERIALS-TESTING DEPARTMENTS.

The greatest activity within the field of physical research is still to be found in investigations regarding the process taking place in mercury-arc rectifiers.

By means of the Holborn and Kurlbaum optical pyrometer we have definitely established the fact that the temperature of the cathode spot, about which many conflicting opinions are to be found in technical literature, is $2087^\circ C \pm 25^\circ C$. A special rectifier in which the cathode could be observed through a glass plate was used for the determination of this temperature. To prevent mercury vapour condensing on the glass, the latter was maintained at $50^\circ C$ by means of an electric heater, while the anodes and the cathode were kept at a temperature of $15^\circ C$ by oil and water cooling. Fig. 91 shows the apparatus used. The cathode spot is observed through the optical pyrometer, the spot being maintained in a fixed position by means of a rod of tungsten which projects through the surface of the mercury. A smoked glass is placed before the objective, and a green filter in front of the eye-piece.

The apparatus shown in Fig. 92 was used for determining the voltage drop in the mercury arc. The arc burns between the fixed steel anode and the movable mercury cathode K in a vertical barometer tube with an internal diameter of 2·5 cm and a length of approximately 80 cm. Any length of arc can be obtained by altering the position of the mercury cathode by means of compressed air. The arc is struck underneath by means of the mercury ignition anode and the mercury cathode. The steel anode is screwed on to a copper rod 1 cm diameter and 14 cm long.

At the top of this rod is a thin-walled cooling vessel of copper with inlet and outlet pipes for water. The energy conducted away by the anode, the voltage drop across the arc, and the temperature of the arc can be determined by accurately measuring the inlet and outlet temperatures of the cooling water. The temperature at the outside of the glass barometer tube was obtained by measuring the resistance of a platinum wire 0·1 mm diameter and 220 mm long wound round the tube in two and a half coils. The current flowing through the arc and the arc voltage were measured with accurate moving-coil milli-voltmeters and milli-ammeters as shown in Fig. 92. The tube itself was mounted in a vertical wooden box which could be filled with oil for the purpose of cooling the tube.

With a constant current across the arc of 4·46 A, a constant arc length of 71 cm, and with only an air-cooled tube, the total voltage drop in the arc immediately after ignition was about 40 to 42 V, and, after about 30 seconds, 50 to 53 V. Short and rapid variations in the arc voltage then occurred, and, after 60 seconds, decreased along a fairly rapidly
falling curve to a final constant value of about 40 to 41 V.

If the lower part of the tube is cooled externally with transformer oil at about 20°C, the arc voltage and the voltage drop in the arc, as well as the temperature of the tube, are all altered very appreciably. Here again the voltage drop in the arc was small (about 44 V) at the commencement, but increased rapidly to approximately 54 V within the first 15 seconds. It then decreased again to about 48 V, to increase slowly to a constant value of 50 V, which is 10 V higher than without cooling.

Superimposed on those variations which can be read on ordinary measuring instruments are other very high frequency variations of 70 to 80 % their amplitude which can only be measured or recorded by means of oscillographs.

The total arc voltage and the voltage drop plotted against length of arc give practically straight curves.

When the length of arc was kept constant, there was no appreciable variation in the voltage drop across the arc with alteration in the current, though it was dependent to a very great extent on the pressure in the tube. For example, with a constant current through the arc of 4.46 A, the voltage drop was 59 V and 48 V according as to whether the vacuum was 0.0025 or 0.001 mm of mercury.

The figures on plate I are micrographs taken in the materials testing department. From such photographs the structure of the materials can be judged, and, therefore, their quality and the uses for which they are suitable.

Fig. a is a section, magnified 150 times, through ordinary cast iron with a tensile strength of about 8 kg/mm². Note the characteristic coarse graphite flakes surrounded by ferrite.

Figs. b and c (magnification × 1000) show the alteration in the structure of cast iron that has "grown". From Fig. c will be seen the decomposition of the iron carbide in iron and carbon after being heated for 1000 hours at 600°C. Fig. b is a section taken from near the edge of the same specimen. The graphite flakes are burnt by the oxygen which has penetrated, and the adjacent iron has become oxidized.

Fig. d (magnification × 1500) shows the homogeneous structure of cylinder cast iron, with a strength of 30 kg/mm² as produced in our electrode furnaces (see Fig. 36).

Figs. e (unetched) and f (etched) are sections, magnified 500 times, of eutectic pearlitic cast iron with a strength of 40 kg/mm² as produced in our electrode furnaces of our manufacture. The graphite is distributed in very fine veins, and the remainder is pure pearlite.

Figs. g to l are longitudinal and cross-sections, magnified 2.7 to 14 times, of an ignition rod from a mercury-arc rectifier. Due to deformation and shrinkage during use it recrystallized. The size of the crystals increases as the temperature rises (approx. 600—900°C).

Fig. m is a section, magnified 150 times, taken from an anode of a mercury-arc rectifier; the straight slip lines in the pure ferrite indicate that a slight deformation has taken place.

The section shown magnified 100 times in Fig. n is taken from nickel steel with an ultimate tensile strength of approx. 80 kg/mm² and a strength according to the notch test of 30 kg/cm² (from the end plate of a turbine rotor).
a. Ordinary cast iron. \( x \times 150 \)
b. Oxidation of cast iron. \( x \times 1000 \)
c. Decomposition of carbide. \( x \times 1000 \)
d. Pearlite cast iron. \( x \times 1500 \)
e. Eutectic pearlitic cast iron, unetched. \( x \times 500 \)
f. Eutectic pearlitic cast iron, etched. \( x \times 500 \)
g. Longitudinal section of a recrystallized ignition rod. \( x \times 8 \)
h. The deformed rod. \( x \times 5-7 \)
i. Cross-section at A–A. \( x \times 14-5 \)
j. Cross-section at B–B. \( x \times 14-5 \)
k. Cross-section at C–C. \( x \times 14-5 \)

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m. Ferrite with slip lines.  × 150

n. Austenite of a 25% nickel steel.  × 100

t. Brass.  × 150

o. Stainless chromium steel.  × 1500

p. Section of punched sheet steel, untreated.  × 150

q. Section of punched sheet steel, annealed.  × 150

r. Strongly etched copper.  × 1500

s. Section through brass tube.  × 33

u. Recrystallized brass.  × 4

v. Copper die-casting (Dendrites).  × 15

w. Sections of porcelain.  × 9

x. Bituba insulation.  × 50
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 with a temperature of 480°C in the superheaters can be produced in 10 stages, while steam at 130 kg/cm² 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
Fig. o (magnification $\times 1500$) shows the structure of stainless steel hardened in air, as used for turbine blades.

Figs. p and q (magnification $\times 150$) show sections of punched dynamo sheet steel. From Fig. p it can clearly be seen that the metal has been "drawn" in the direction of punching. Fig. q shows how the crystals, damaged by the punching, have been re-crystallized by annealing the sheet, thus reducing the iron losses.

Fig. r is an etched section of a copper crystal; Fig. s (magnification $\times 33$) a cross-section through a brass tube as used in condensers or oil-coolers for transformers; and Fig. t (magnification $\times 150$) shows the structure of the brass.

Fig. u gives a section, magnified four times, through a pressed-brass body in which, due to poor heat treatment and the use of an unsuitable alloy, the crystals are very coarse and brittle.

A section from a copper die-casting, as used for contact fingers, is shown magnified 15 times in Fig. v.

Sections from two 150-kV porcelain insulators are reproduced in Fig. w (magnification $\times 9$). One insulator is so porous as to be unusable.

From the section of Bituba, magnified 50 times, given in Fig. x the layers of paper and artificial resin can be clearly seen.

Fig. 93 (magnification $\times 150$) shows a section of a carbon packing ring which has too many hard spots.

Finally, in Figs. 94 and 95, respectively, sections (magnification $\times 150$) are reproduced of a graphite carbon with homogeneous graphite structure for brushes for direct-current commutators, and of a bronze carbon with more flakey structure for brushes for slip rings.

Some interesting apparatus and testing machines were also installed in the materials-testing department during the past year.

A quartz lamp for examining materials in ultraviolet light (ultimate strength tests and ageing processes) is illustrated in Fig. 97.
Fig. 96 shows a Vogel-Ossag viscometer for determining absolute kinematic viscosities.

Fig. 99 gives a view in the newly equipped laboratory for determining the calorific values of solid, liquid and gaseous fuels.

The machine illustrated in Fig. 98 is for measuring the bending strength of materials such as presspan, cardboard, etc. In Fig. 102 a mirror extensometer is shown, and in Fig. 100 an expansion meter for determining the critical points in steel, etc., at various temperatures. A temperature-expansion curve for 5‰ nickel steel taken with this apparatus is reproduced in Fig. 107.

In connection with the extension and rebuilding of the workshops, which were brought to a conclusion during the past year, the testing department for electrical machinery (Fig. 103) was completely reorganized. It is now situated at the south end of the large erecting shop\(^1\). The whole of the floor area can be utilized

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\(^1\) The Brown Boveri Review 1928, No. 10, p. 298.
vertical-shaft machines can be erected and tested.

The rectifier testing department adjoins the separate machine room so that the same auxiliary testing equipment can be used for both test beds.

To enable the properties of insulating materials to be tested when subjected to high-frequency oscillations and voltage surges such as are produced in practice by intermittent shorts to earth or between phases, or by steep-crested transient waves caused by lightning or switching operations, etc., we have installed a test plant for making surge tests (Fig. 105). By means of a Tesla transformer and bank of condensers, frequencies of 30,000 to 40,000 cycles at 550 kV, and 25,000 to 35,000 cycles at 1000 kV can be produced between any pole and earth. Between the poles, a. c. pressures of 1000 kV at 30,000 for erecting the machines to be tested. All the permanent test plant, such as transformers, generators, etc., and other auxiliary equipment, are arranged in a separate machine room, and all the distribution gear in an underground tunnel. There are also test beds on which the largest horizontal or

Fig. 99. — Heat laboratory.

Fig. 100. — Expansion meter.

Fig. 101. — Oscillogram (frequency 40,000 cycles) taken on the cathode oscillograph shown in Fig. 103.

Fig. 102. — Mirror extensometer for taking accurate measurements.
to 60,000 cycles can be produced. It is possible to obtain surge voltages up to 200 kV with a single-pole earth and up to 500 kV or, using special connections, 1000 kV, between the poles.

Phenomena taking place at such high frequencies are best observed by means of a Dufour cathode oscillograph (Fig. 104) which can record oscillations up to $10^9$ cycles (Fig. 101).

As transmission systems are being continually increased in size and more closely interconnected, all the machines, transformers and apparatus must be made suitable for the correspondingly increased stresses produced when short circuits occur. We have therefore decided to build a test plant in which heavy short circuits can be produced; this is now under construction. Besides enabling the rupturing capacities of oil circuit breakers to be determined, the apparatus will also be used for testing the resistance to short circuit stresses of windings, choke coils, etc., which have such high impedances that they can only be tested by employing very high capacities.

When completed, our test plant, shown in Fig. 105, will contain two alternators each weighing about 300 tons, and, reckoned on their dimensions, having a rating of approx. 70,000-kVA each. As far as we know, these are the largest generators of this type ever built. We will then be able to produce the following short-circuit capacities:
Maximum three-phase closing capacity (calculated on the effective value of the first half wave) approx. 1,600,000 kVA. Three-phase rupturing capacity approx. 1,000,000 kVA. Maximum short-circuit current peak of the plant 300,000 A.

(KS 530) K. Sachs (Parts I and III);
P. Faber (Part II). (E. J. B.)

Fig. 106. — The new plant for carrying out short-circuit tests.

Fig. 107. — Temperature-expansion curve of a five-percent nickel steel taken with the expansion meter shown in Fig. 106.

Di = expansion. T = temperature.
BROWN, BOVERI & COMPANY LIMITED

BADEN (SWITZERLAND)

WORKS: BADEN AND MUNCHENSTEIN (SWITZERLAND)

ELECTRICAL EQUIPMENT OF FUNICULAR RAILWAYS FOR ALL KINDS OF CURRENT AND OF ALL TYPES FOR PASSENGER AND GOODS TRAFFIC