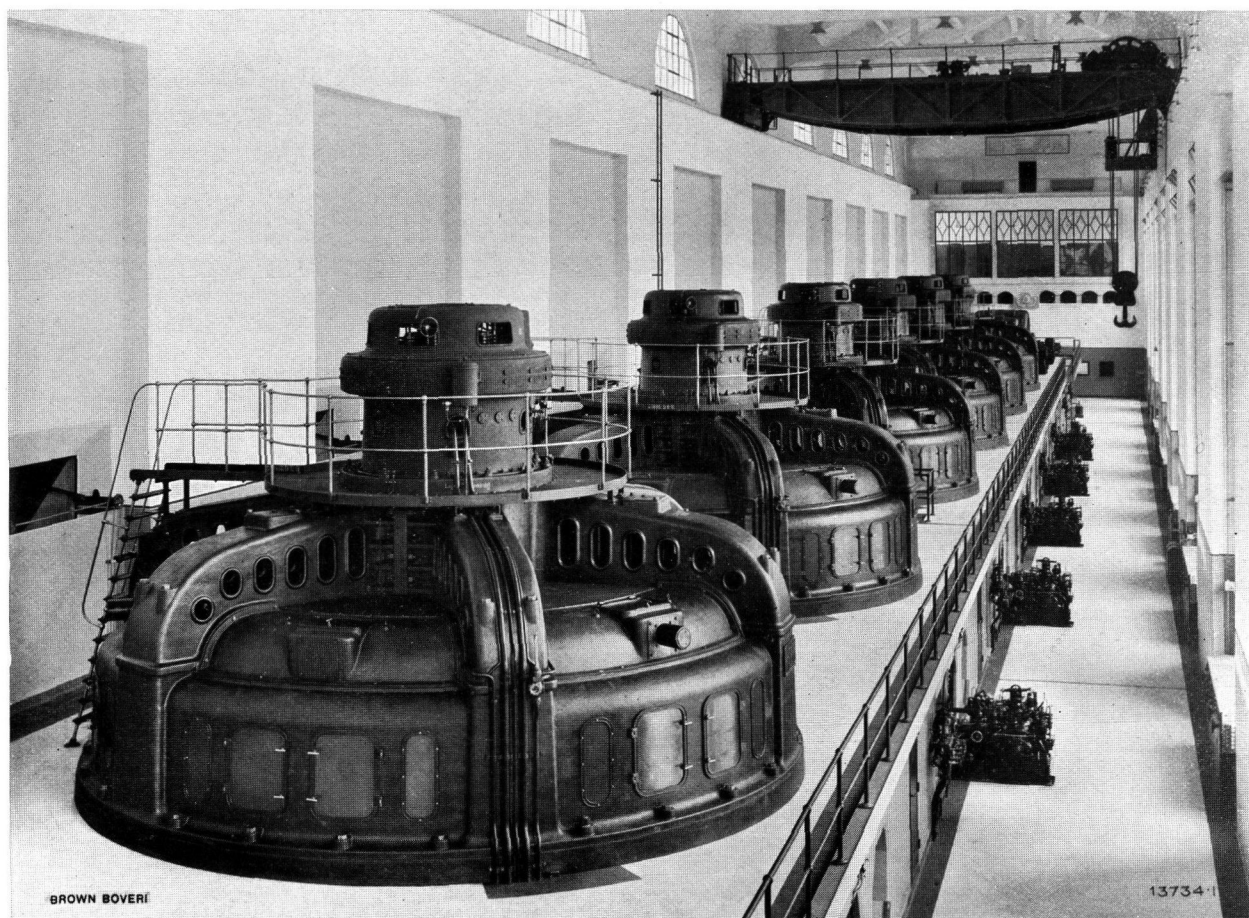


THE BROWN BOVERI REVIEW

EDITED BY BROWN, BOVERI & CO., BADEN (SWITZERLAND)

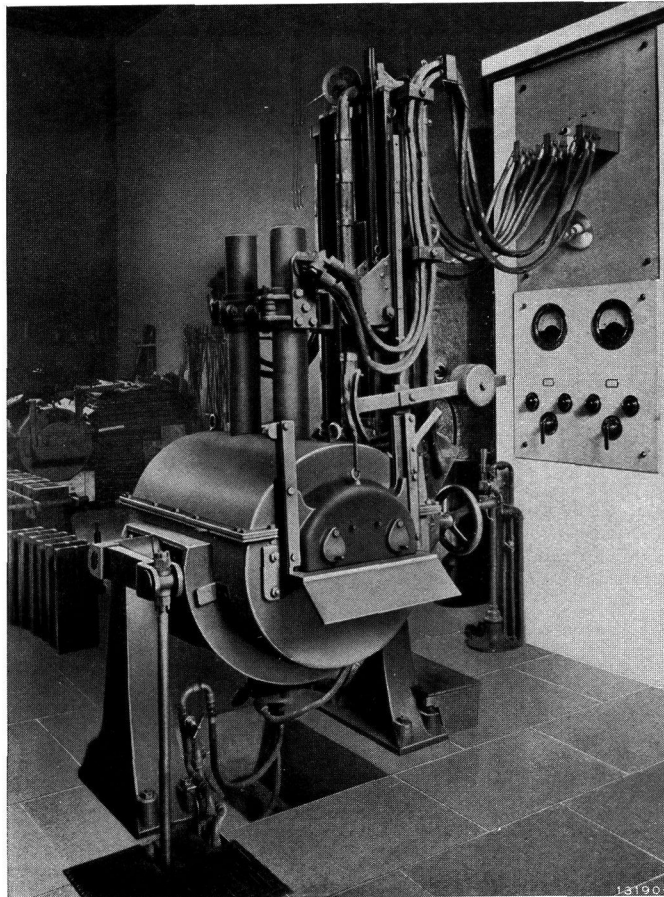


MUHLEBERG-ON-THE-AARE POWER STATION, BERNESE POWER WORKS, BERNE.
Six units, each for 8000 kVA, 16000/17600 V, 50/40 cycles, 167/133 r.p.m.

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ELECTRIC FURNACES OF OUR OWN DESIGN
FOR MELTING
METALS AND ALLOYS



BROWN BOVERI ELECTRIC MELTING FURNACE IN THE FOUNDRY OF
THE SWISS MINT, BERNE.

NO CONTAMINATION AND NO CHEMICAL REACTIONS
IN THE BATH
SIMPLE REGULATION - EASY ATTENDANCE
HIGHEST EFFICIENCY

THE BROWN BOVERI REVIEW

THE HOUSE JOURNAL OF BROWN, BOVERI & CO., BADEN (SWITZERLAND)

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BROWN BOVERI ELECTRIC MELTING FURNACES FOR METALS AND ALLOYS.

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Summary.

THE scarcity of fuel and labour during the war gave considerable impetus to the use of electricity as a heat agent. On this account, the development of electric furnaces and their accessory apparatus was actively pursued, so that at the present time electric melting furnaces are more than able to hold their own against the older types of furnaces, which they are gradually displacing. The construction and advantages of Brown Boveri melting furnaces are set forth in the following article.

GENERAL.

THE last ten years have witnessed a rapid extension in the use of electricity for producing heat in metallurgical processes, and the way the electric melting furnace has come to the fore during this period testifies to this fact. The elimination of all source of contamination of the molten bath by fuels and gases, as well as the absence of chemical reactions, has greatly contributed towards this development, since the purity of the products obtained is superior to that when utilising any other source of heat, such as coke, tar oil, gas, etc.

Brown, Boveri & Co. went thoroughly into the problem of melting metals by electricity, and the outcome of their investigations, which lasted many years, was an electric furnace of a patented design built by the firm for their Baden workshops. The operation of this plant was so satisfactory that it was decided to take up the manufacture of such furnaces, and place them on the market. In the meanwhile, the development of electric melting furnaces progressed to such an extent that the firm put a new electric foundry for non-ferrous metals into commission in 1919 at Baden, which comprised three melting furnaces capable of meeting all the requirements of the works. Amongst the Brown Boveri electric furnaces already completed for outside firms may be mentioned:

Three complete furnaces for the Schweizerische Metallwerke Selve & Co., Thun. Two furnaces for the Clus ironworks of the Société des Usines L. de

Roll. One furnace for the Swiss Locomotive and Machine Works, Winterthur. One furnace for the Swiss Mint, Berne.

DESCRIPTION OF THE FURNACE.

The furnace is designed for a normal capacity of 200—300 kg, and is intended for melting metals and alloys. It is equally suitable for non-ferrous metals — such as copper, nickel, tin, lead, silver, bronze, brass, cupro-nickel, anti-friction alloys, etc. — as for melting grey cast iron, ferro-manganese and special alloy steels. Furthermore, it can be used for the reduction of metallic oxides like oxide of tin, for instance, which is obtained as a by-product in dye works.

Operating principles.

Use is made of a combination of different properties of the arc and resistance types of furnace whenever three-phase current is available — which is usually the case, on account of the many economic advantages of distributing this form of energy. Two vertical and adjustable electrodes are located in the upper part of the furnace, and the third is embedded in the lining of the hearth at the bottom of the crucible. Each electrode is connected to one of the three phases, and it follows that since the hearth electrode is directly connected to the bath, the latter forms a pole of the electric system. The electric current must therefore go through the entire depth of the bath contained in the crucible, where the ohmic resistance causes it to be fully utilised. By placing the electrodes vertically, a strong electromagnetic effect is created, which sets up a continual circulation of molten metal in the crucible, thus ensuring uniform final products.

Constructional features.

As can be seen in Figs. 1 and 2, the furnace consists essentially of:

1. A tank with a refractory lining.
2. A carrying ring with two trunnions.

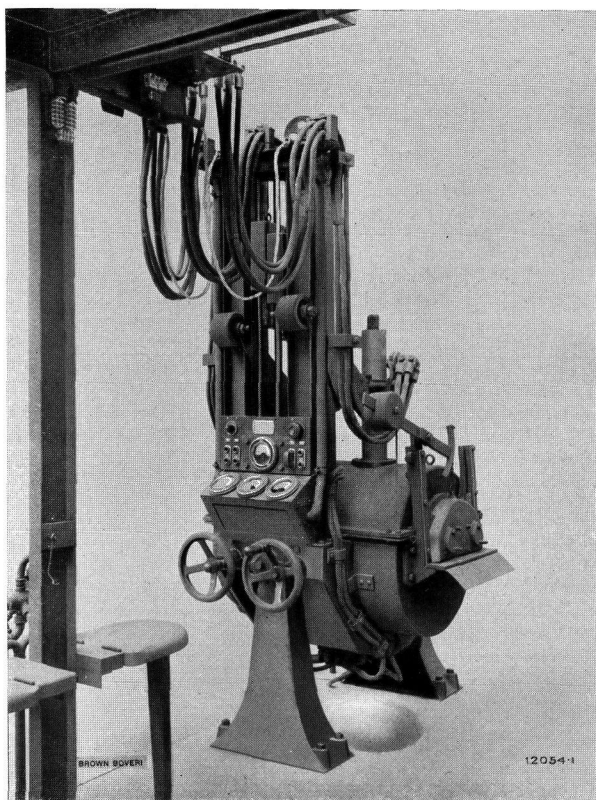


Fig. 1. — Brown Boveri three-phase electric melting furnace having a capacity of 300 kg.

The two upper electrodes are regulated by hand.
The tilting device is operated hydraulically.

3. Two masts for guiding the gallows-arms, which can be moved up or down, and which carry the electrodes.
4. The electrical measuring instruments.
5. The appliances for tilting the furnace, which can be operated either manually or hydraulically.

1. *The tank* is formed by a horizontal steel cylinder, the lower part of which forms the hearth and the upper part the roof, which has two openings. The latter are lined with firebrick in such a way that the two upper electrodes fit exactly into them.

A charging door, which is lined with refractory material, is fitted at one extremity of the cylindrical hearth. By giving a slight inclination to this door it always remains closed, so that all access of air to the furnace is prevented. The lever for opening the door is supplied with a counterweight in order to facilitate its opening and closing. Two small sight holes, which are normally closed by flaps, are provided in the door, so that the state of the molten bath can be examined by the furnaceman whenever

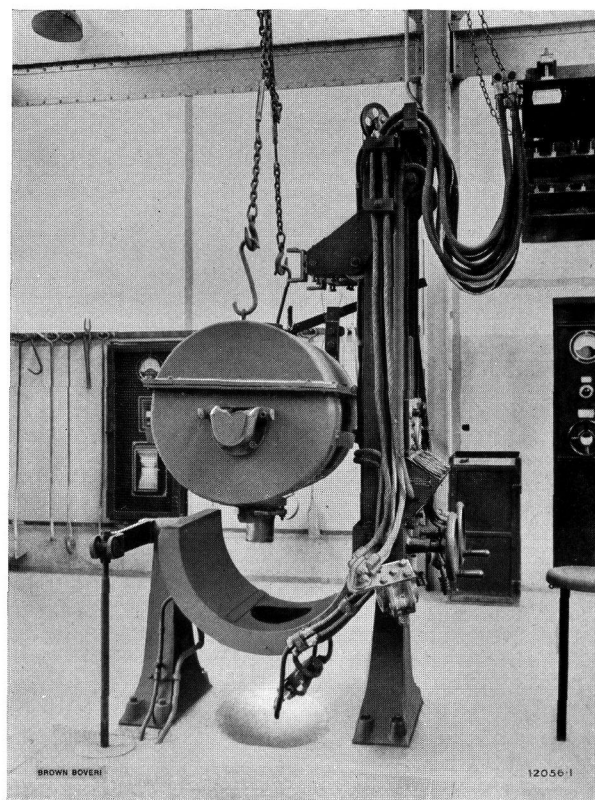


Fig. 2. — Brown Boveri three-phase electric melting furnace with tank lifted for removal.

necessary, without admitting a considerable quantity of cold air into the furnace.

An opening with a spout — which is also lined with refractory material — at the other extremity of the tank serves for pouring off the molten metal. A cast iron stopper with a handle enables this opening to be rendered airtight when the furnace is in operation.

The lower part of the crucible has an opening for the hearth electrode which penetrates into the lining, and which is embedded in the same. This design of the hearth enables this electrode to be easily changed whenever it requires renewing. The hearth electrode can be either a carbon electrode with a cast-on metal holding ring, or a water-cooled electrode, according to the temperature in the furnace, which depends on the metal to be treated.

By loosening a screw in the contact ring leading the current from the carrying ring to the hearth electrode, the entire tank can be readily lifted by shackles screwed into the roof (Fig. 2) and replaced by another if desired. The ease and rapidity with which this operation can be carried out enables several tanks to be used with the same framework.

A separate tank can therefore be employed for each different metal or alloy dealt with, and all undesirable mixing of metals is thereby avoided, so that the utmost purity of the product is ensured.

2. *The carrying ring* supports the tank, and is provided with two trunnions for tilting the furnace. It is carried by two cast iron pedestals fixed to the floor by foundation bolts.

3. *The two masts* for supporting the electrodes are built up of rolled steel sections, and are rigidly connected to the carrying ring. Their upper extremities are united by a cast iron saddle which carries the pulleys of the wire ropes for the counterweights and the cleats for fastening the copper cables leading the current to the electrodes. The masts serve to guide the gallows-arms which can be displaced up or down independently of one another, in order to allow the position of the electrodes — and consequently the current consumption — of being adjusted exactly, by means of separate handwheels which operate through bevel gear and a spindle. The electrode holders, which are carefully insulated from the framework, are situated at the outer extremity of the gallows-arms. Rollers at the other end of the latter facilitate movements up and down the guide rails of the masts. Sufficient space is left between these for allowing the free displacement of the two counterweights which balance the weight of the gallows-arms together with the electrodes and their accessories. Hence, only a small effort is required to turn the handwheel for controlling the position of the electrodes.

The electric cables leading the current to the electrodes are subdivided so as to be sufficiently flexible to follow easily the vertical movements of the electrodes as well as the tilting of the furnace (Fig. 3).

4. *The electrical measuring instruments*, which are carefully insulated, are located in a small desk-type panel immediately above the handwheels for controlling the electrodes (Fig. 1). They comprise a voltmeter with change-over plugs, which allow the pressure of the three phases in the furnace to be measured, and three ammeters, which, by showing the value of the current, permit the two upper electrodes to be suitably adjusted. All these instruments are of special dustproof design. An indicating lamp fitted at one side of the panel lights as soon as the furnace is energised. On the other side, a circuit breaker is provided, which enables the current to be immediately cut off from the furnace whenever necessary.

5. *The tilting gear* permits the entire furnace, i. e., the tank and carrying ring together with the masts and gear belonging thereto, to be rotated about the trunnions, which have already been mentioned, without it being necessary to withdraw the upper electrodes from the roof. According to local conditions, the tilting gear can be worked either by hydraulic power (Fig. 3) or manually. In the latter case, a handwheel and gear mechanism have to be provided for operating the tilting gear. When the control is carried out hydraulically, a two-way cock for admitting water under pressure to either side of the piston of a servo-motor placed under the floor is required. The furnace can be tilted in either direction, according to whether it is desired to pour the metal or draw off slag. The operating cock is placed close to the furnace, and arranged in such a way that the direction in which its handle is turned corresponds to that in which the furnace has to be tilted, thus rendering the possibility of wrong movements very remote.

Lining and electrodes.

The tank has a refractory lining whose chemical composition and fire-resisting properties are chosen to suit the metal to be melted. The majority of Brown Boveri melting furnaces are lined with plastic material, as many years' practice has shown that this class of lining gives the best results for this kind of work. The lining is rammed either pneumatically or by hand; wooden or iron shapes — which can be supplied by the firm if desired — are required when the lining is being pressed into the crucible, but are not necessary for the roof.

Only best-quality graphite electrodes are employed, which are jointed by means of screwed nipples so that they can be fully utilised. Their cross section depends on the nature of the material to be melted, and varies from 78 sq. cm (diameter 10 cm) to 133 sq. cm (diameter 13 cm) — the accessories for the electrodes and the holes in the roof being dimensioned accordingly.

Instructions for renewing the lining and for handling the electrodes are supplied with all furnaces built by the firm.

ELECTRICAL EQUIPMENT.

A diagram of the electric connections is given in Fig. 4. Almost without exception, the tension of the supply systems is too high for allowing a direct connection to the electric furnace to be made. Hence, a special furnace transformer has usually to be placed

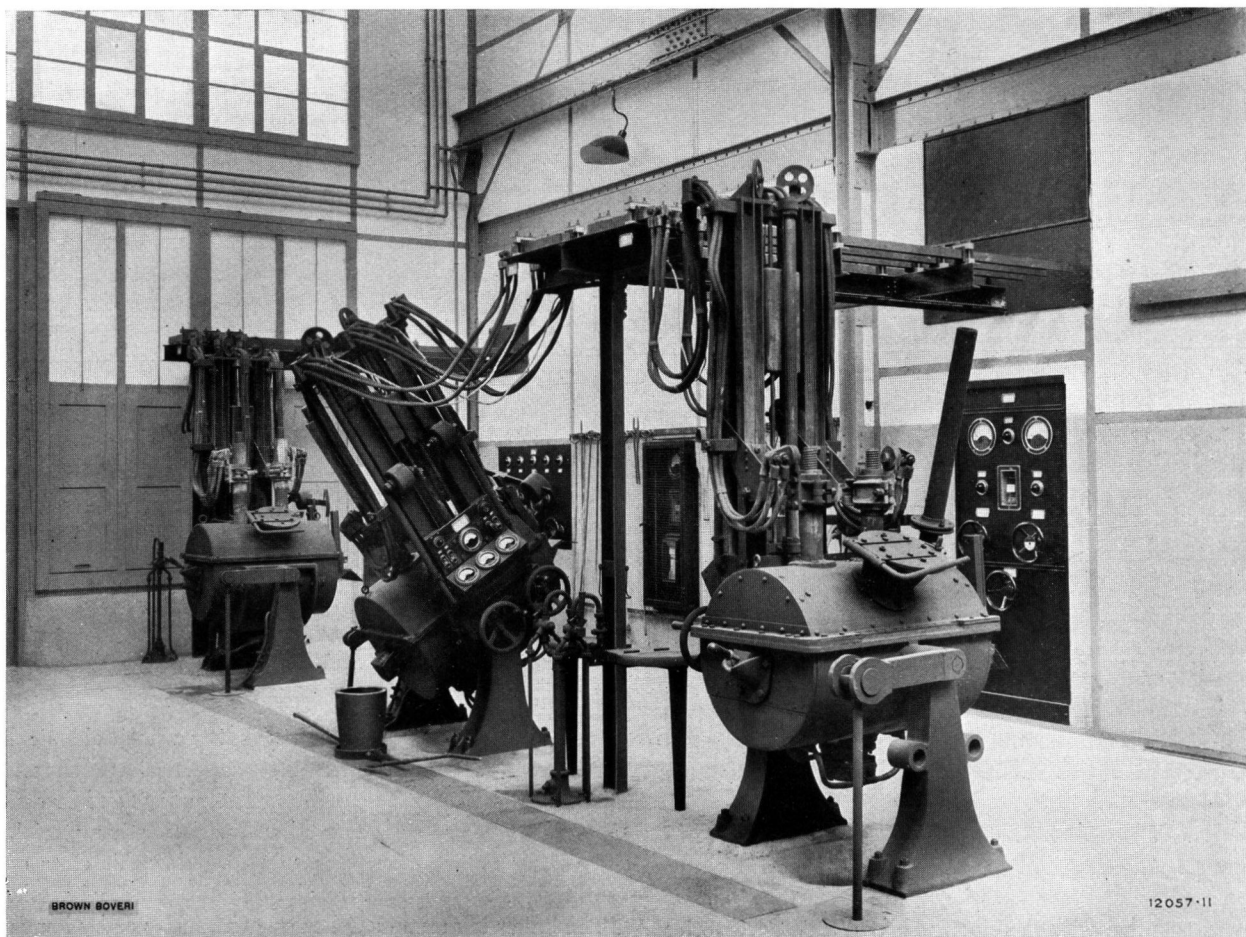


Fig. 3. — Electric melting furnaces in the foundry of Brown, Boveri & Co., Baden.

The installation comprises three Brown Boveri electric melting furnaces having a capacity of 300 kg each. The switchboards and high-tension measuring instruments can be seen in the background.

between the furnace and the high-tension A. C. lines, which lowers the pressure to a suitable value.

The continuous rating of the transformer for a furnace having a capacity of 200—300 kg varies from 80 to 140 kVA according to the properties of the material to be melted. The transformer is generally oil immersed, with natural cooling, of a robust design specially suitable for furnace work and with short-circuit proof supports for the windings (Brown Boveri patent).

In order to keep the reactance of the secondary circuit of the transformer as low as possible, the low-tension windings are interleaved, as are also the copper bars between the transformer terminals and the flexible cables of the furnace.

Two pressures are ordinarily sufficient to satisfy the requirements of the furnace in practice. The necessary adjustment is usually obtained by tappings on the primary side of the transformer — the output

being assumed the same in both cases. The pressure is altered in a very simple manner by a three-pole two-way switch, which is interlocked with the main oil-switch so that it can only be operated when the circuit is open. This arrangement safeguards against all false manipulations of these two switches.

The current from the mains goes first of all through a three-pole isolating switch, which enables all the switchgear to be disconnected from the system.

The oil-switch is placed immediately after the isolating switch, and is provided with a no-volt coil for automatic release. Protection against overloads is ensured either by a two-pole relay which is built on to the main oil-switch, or by an overload time-limit relay, generally mounted on the switchboard as shown in Fig. 4. In both cases, it is possible to set the time lag and releasing current, which can be adjusted from 1 to 12 seconds and from 1.4 to 2 times the normal current respectively, according to

whether the plant has to be more or less carefully protected.

A three-phase choke coil is usually fitted in the high-tension circuit in order to damp heavy current surges such as are liable to occur when starting

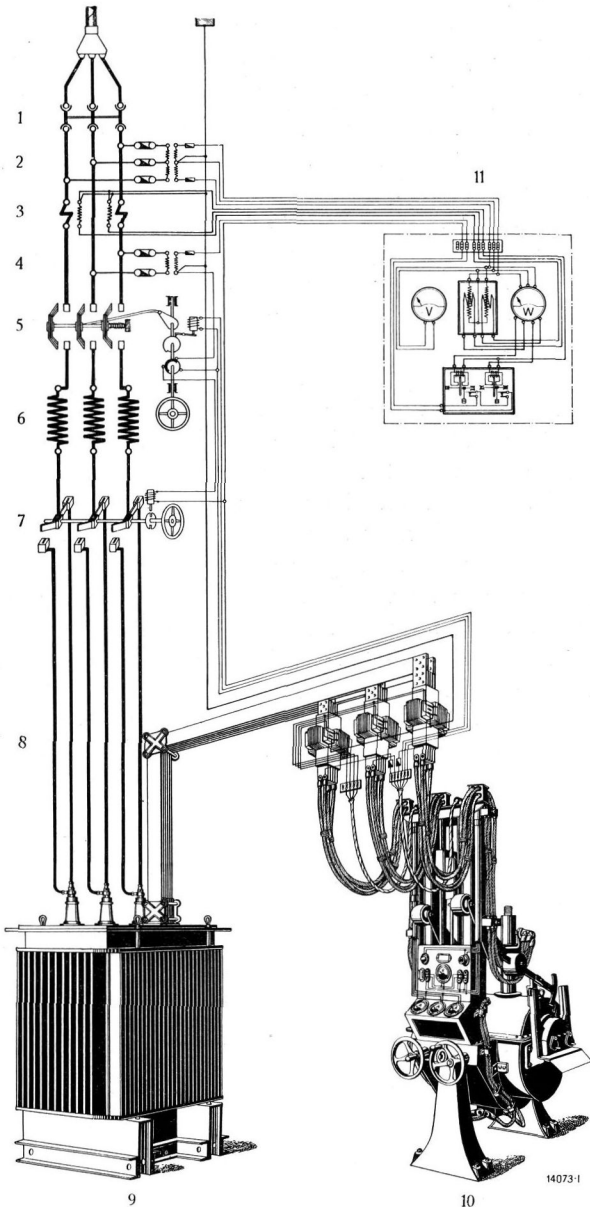


Fig. 4. — Diagram of a Brown Boveri electric furnace plant.

1. Three-pole isolating switch.
2. Potential transformer.
3. Current transformer.
4. Potential transformer for auxiliary circuit.
5. Three-pole main oil-switch with hand control and no-volt release.
6. Three-phase stabilising choke coil.
7. Hand-operated three-pole two-way switch with interlocking device.
8. Current transformers for furnace measuring instruments.
9. Oil-immersed furnace transformer with primary windings.
10. Brown Boveri electric melting furnace with instruments and accessories.
11. High-tension switchboard.

to melt down a cold charge. If desired, a three-pole switch can be supplied which enables the choke coil to be bridged over at will (this arrangement is not indicated in Fig. 4). The magnitude of these surges is determined principally by the nature and composition of the bath; other factors which are also of importance in this respect are: the nature of the charge, — the material fed into the furnace may be in large blocks or in pieces which are more finely divided, — the state of the furnace (hot or cold) and the dexterity of the furnaceman.

The power factor of electric melting furnaces depends on whether the choke coil is in circuit or bridged over, and varies within the following limits:—

- 0.97 — 0.93 with the choke coil bridged over.
- 0.92 — 0.88 with the choke coil connected.

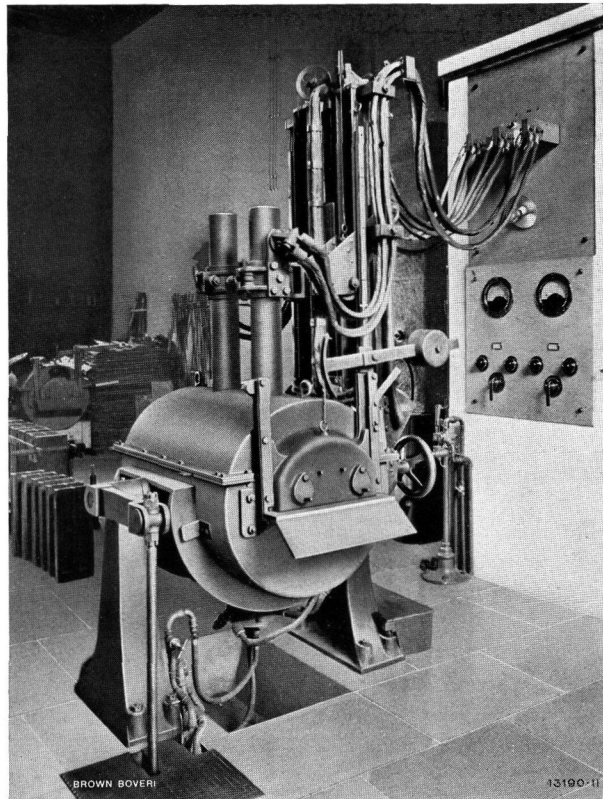


Fig. 5. — Brown Boveri three-phase electric melting furnace having a capacity of 300 kg in the foundry of the Swiss Mint, Berne.

The tilting device is operated hydraulically, and the switchgear has remote control.

The switches for operating the furnace (main oil-switch, switch for connecting up the transformer windings and, in certain cases, the switch for bridging over the choke coil) are generally controlled by handwheel and wire rope drive. The handwheels

are placed as close as possible to the furnace in order to expedite the manipulations.

Should insufficient space be available for locating the switchgear and transformer close to the furnace, motor-driven remote control is provided (Fig. 5) instead of manually-operated drives.

Finally, mention must be made of the measuring instruments for the primary circuit, which are mounted on a switch panel in the furnace room. A voltmeter, a watthourmeter and a wattmeter for indicating unequally-loaded phases are sufficient in the majority of cases. The current and pressure transformers are placed immediately after the isolating switch. The watthourmeter consequently records the energy consumed by the furnace, inclusive of the losses in the switchgear, choke coil and main transformer.

METALLURGIC CONSIDERATIONS.

Electric furnaces have been employed since about 1900, and considerable numbers of them are now in use. The introduction of the electric process for melting metals dates only from the war period. The principal reasons which prevented the development of electric melting furnaces at an earlier date were the prejudiced and erroneous opinions formerly prevalent as to the enormously high temperatures which were supposed to exist in the neighbourhood of the electrodes, and which would, so it was assumed, certainly cause the metal to be overheated so that it would be burnt and volatilised. Experiments undertaken with Brown Boveri furnaces have shown such suppositions to be quite unfounded.

Operation.

The attendance required for these furnaces is extremely simple so that they can be looked after by an unskilled workman after a very short period of instruction.

The furnace does not need to be warmed up in advance, but can be started cold when once charged. The two upper electrodes are raised whilst charging is being carried out in order to prevent their being injured and to leave the interior of the furnace free. According to the nature of the material to be melted, the furnace is only partly filled or loaded right up to the roof.

A two-way switch enables the transformer tapping which gives the required pressure to be connected, and, by closing the main oil-switch, the entire plant is put in circuit. The two upper electrodes can then be lowered until two arcs between the electrodes and the charge are struck. The heat of the arcs rapidly

causes funnels to be melted out of the metal, and the current soon ceases to fluctuate as the arc plays on the molten bath which forms in the hearth. The electrodes now require very little attention until the end of the heat, and the electrical load is easily kept constant.

The electrodes must be withdrawn, and the furnace disconnected either by opening the main oil-switch by its handwheel, or by tripping the circuit breaker (p. 201 under heading 4), should a supplementary charge have to be loaded, metals for alloying added, or slag drawn off.

Once the metal is ready for pouring, the main oil-switch is opened and the furnace tilted by the hydraulic gear provided for this purpose. As soon as the furnace is emptied, it is ready for taking a fresh charge.

Output of the furnace.

The rate at which the metal can be melted depends to a great extent on the energy consumed by the furnace, on the temperature at which the metal is poured and on its specific heat. The skill of the operator when charging and regulating the electrodes also exerts a considerable influence on the production of the furnace. The output of the transformer varies according to the melting point of the various metals treated (see p. 202). For instance, a furnace which has chiefly to melt soft metals (such as tin, lead or their alloys) requires a smaller transformer than a furnace of the same capacity which has to deal with steel, nickel, etc.

The daily output of one of these furnaces when melting different metals and when working 8 and 24 hours continuously is given in Table I, columns 6 and 7. These results are obtainable in a well-organised foundry; account has been taken in both cases of the time required for charging the furnace and for pouring the molten metal. For instance, with silver the output of 1600 kg per 8-hour day can be melted down in five hours, the rest of the time being taken up by charging the furnace and pouring the metal into small chills.

The possibility of keeping an electric furnace in continuous operation enables the greatest amount of work possible to be got through in a given time by having day and night shifts. Such an increase of the working hours can be undertaken with Brown Boveri melting furnaces without any fear of damage to the plant, since the furnace as well as the electrical equipment is designed to withstand continuous operation. The sum to be put aside for the

TABLE I.
Characteristics of Brown Boveri electric melting furnaces.

Material	Energy consumption kWh per 100 kg of metal charged		Electrode consumption kg per 100 kg charged	Metal loss Per cent.	Daily output in kg		Life of lining kg of metal melted per lining	Remarks
	8 hours continuous working	24 hours continuous working			8 h continuous working	24 h continuous working		
1)	2)	3)	4)	5)	6)	7)	8)	9)
Copper, pure	42	39		0.4	1 350	4 300	130 000	The data in column 8 are only valid for continuous operation.
Brass, 72/28 (a) from alloy of pure metals .	40	37		1.0	1 500	4 600	130 000	
(b) from scrap and heavy turnings	43	40		2.0	1 450	4 700	130 000	
(c) from light turnings	55	52	0.08—0.2	10.0	900	2 800	130 000	Turnings with about 3% of oil.
Bronze, 85/15 (a) from alloy of pure metals .	39	36		0.5	1 500	4 400	130 000	
(b) from scrap	40	37		1—1.5	1 400	4 200	130 000	The electrode consumption (graphite electrodes) varies within comparatively wide lim- its (column 4) according to the quality.
Nickel, pure	160	140	0.15—0.4	negligible	400	1 450	20 000	
Cupro-nickel (a) 60% Cu, 40% Ni	80	65		negligible	700	2 500	80 000	
(b) 75% Cu, 25% Ni	71.3	60		negligible	800	2 800	80 000	
Coin silver	21.3	19	0.08—0.2	0.12	1 600	5 500	200 000	
Anti-friction alloy (a) 78% tin (remainder Cu & Sb)	8—10	7—9		0.8	3 600	11 000	400 000	
(b) 86% lead (remainder Sn & Sb)	6—8	5—7	0.06—0.1	0.8	4 500	14 500	400 000	
Grey cast iron from scrap with certain additions	85	78	0.25—0.6	2.0	720	2 400	80 000	Specially suitable for intricate castings.

depreciation per 100 kg produced is therefore very low, thanks to the efficient utilisation of the plant. Furnaces for melting ingots for rolling mills usually are worked continuously. As an electric melting-furnace installation requires only about one-third of the space taken up by coke or oil-fired furnaces for the same 24-hour output, the considerable saving in the outlay, due to the smaller buildings required for electric furnaces when constructing new plants or enlarging existing installations, is sufficient to pay off the capital costs of an electric furnace plant in the first year of service.

Energy consumption.

The energy consumption for melting different metals with an 8 and 24-hour working day are shown in the first two columns of Table I. These figures are the average of results obtained in practice, and include all losses in the transformer and cables. Attention may be called to the fact that figures are often published which are barely equal to the theoretical minimum power consumption. Such worthless data are misleading, and their groundlessness is immediately borne out by the fact that the figures guaranteed by the builders are always substantially greater.

Electrode consumption.

Amorphous carbon electrodes do not give satisfactory results with small electric furnaces; on this

account Brown Boveri furnaces are adapted for using graphite electrodes. The wear of the electrodes depends almost exclusively on their quality; with electrodes of the same quality, however, it varies within narrow limits according to the metallurgical treatment for which they are used. For instance, electrodes burn away slower when melting silver, copper, bronze, etc., than with processes where refining and reduction takes place as well as melting.

Metal losses.

Oxidation losses can be practically prevented by choosing suitable secondary pressures and electrodes having a corresponding section, and by covering the bath with a layer of suitable protecting matter. As 2–5% of metal is unavoidably lost through oxidation with all existing types of oil or coke-fired melting furnaces, the introduction of the Brown Boveri melting furnaces also represents in this respect a noteworthy advance in the art of melting metals.

The values given in Table I, column 5, are the small losses, which cannot be prevented, due to the

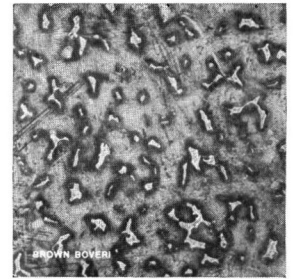


Fig. 6. — Microstructure of bronze (88% Cu, 12% Sn) treated in a Brown Boveri melting furnace.

The sample is polished, slightly etched, and magnified 136 diameters.

TABLE II.
Properties of metals treated in Brown Boveri electric melting furnaces.

Material	Smallest dimensions of the test piece				Strength		Elongation * per cent.	Reduction of area per cent.	Remarks
	Before testing		After testing		Yield point kg/sq.mm	Maximum load kg/sq. mm			
	Section sq. mm	Distance between notches mm	Section sq. mm	Distance between notches mm					
1)	2)	3)	4)	5)	6)	7)	8)	9)	10)
Coin bronze from the Swiss Mint . . . }	250	180	168	230	9.6	28.1	28	33	Chilled casting, unrolled
New silver	78.5	100	52	148	12.7	28.8	48	34	Chilled casting, unrolled
Cannon bronze . . .	172	150	141	185	12.8	29.2	23.4	19	Sand casting
Cannon bronze . . .	8.5	100	6.9	129	17.9	40.3	29	19	Chilled casting
Bronze, 88 Cu, 12 Sn	174	150	134	174	14.0	27.0	16.0	22	Sand casting
Bronze, 88 Cu, 12 Sn	200	160	165	177	14.1	28.9	10	10	Chilled casting
Bronze turnings . .	173	150	147	170	13.0	25.4	13.3	15	Sand casting
Brass, 72/28	50	80	42.5	104	13.2	30.0	25	15	Chilled casting
Brass, 72/28	78	100	57	124	26.5	43.7	24	27	Rolled and drawn
Electrolytic copper .	84	100	32.4	147	5.36	21.5	47	62	Rolled and drawn soft
Electrolytic copper .	96	110	39.1	114	22.4	27.6	3.6	59	Rolled and drawn hard
Silicious bronze . .	192	160	151	193	11.4	33.3	20.5	21	Sand casting
Silicious bronze . .	50.3	80	31	98	28.4	44.5	22	38	Sand casting, forged

* Distance between points for measuring elongation = 10 × diameter of test piece.

* Distance between points for measuring elongation = $10 \times$ diameter of test piece.

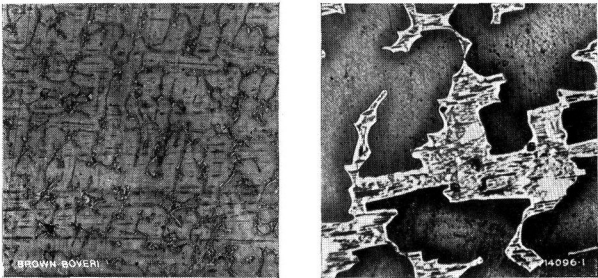


Fig. 7.
Magnified 136 diameters. Magnified 530 diameters.
Microstructure of bronze (84% Cu, 16% Sn) treated in a Brown Boveri melting furnace.
The sample is polished and etched.

spluttering of the metal and its absorption by the lining of the furnace and ladles. The low losses obtained when melting silver show that they depend a great deal on the care with which the pouring is carried out.

Quality of metals melted in electric furnaces.

So many perfections have been made in melting processes these last two decades since the introduction of electric furnaces for industrial purposes, that

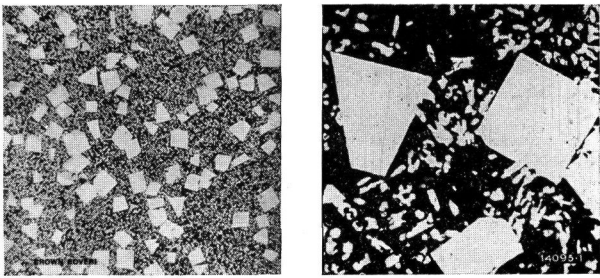


Fig. 8.
Magnified 18 diameters. Magnified 136 diameters.
Microstructure of an anti-friction alloy (78% Sn, 13% Sb, 6% Cu, 3% Pb) treated in a Brown Boveri melting furnace.
The light cubic grains are hard antimonious crystals, and the dark mass is an alloy mainly composed of tin.

electric steels are now practically synonymous with high-quality steels. Brown Boveri furnaces have proved suitable for melting special high-speed tool steels and acid cast steel, the quality of which compares favourably with that of steels obtained by any other process.

Electricity has been used only these last few years for melting metals and alloys on a large scale. Notwithstanding this fact, Brown, Boveri & Co. have

TABLE III.
Comparative costs for melting 100 kg of bronze in a Brown Boveri electric melting furnace and in a Lunkenheim oil-fired furnace.

Brown Boveri electric melting furnace	Lunkenheim oil-fired furnace
<i>Energy consumption</i> (incl. warming up and losses in transformer and switchgear). 39 kWh per 100 kg of bronze, at 0.04 Fr. per kWh Fr. 1.56	<i>Oil consumption.</i> 11 kg per 100 kg of bronze, at 0.15 Fr. per kg Fr. 1.65
<i>Electrode consumption.</i> 0.13 of American graphite per 100 kg of bronze, at 2.80 Fr. per kg. Fr. 0.37	
<i>Lining.</i> 300 heats of 300 kg per lining costing 300 Fr. Cost per 100 kg $\frac{300 \times 100}{300 \times 300} =$ Fr. 0.33	<i>Lining.</i> 100 heats of 300 kg per lining costing 200 Fr. Cost per 100 kg Fr. 0.66
<i>Metal losses.</i> 0.5 % at 2 Fr. per kg Fr. 1.—	<i>Metal losses.</i> 4 % at 2 Fr. per kg Fr. 8.—
<i>Wages</i> (for melting only, without casting). 12 Fr. per 1200 kg (per day). Per 100 kg Fr. 1.—	<i>Wages</i> (for melting only, without casting). 12 Fr. per 1200 kg (per day). Per 100 kg Fr. 1.—
<i>Depreciation and interest.</i> 15 % of the cost of the plant (30 000 Fr.), annual production 240 tons. Per 100 kg . Fr. 1.87	<i>Depreciation and interest.</i> 15 % of the cost of the plant (5000 Fr.), annual production 240 tons. Per 100 kg . Fr. 0.30
<i>Motor-driven blower.</i> Per 100 kg Fr. 0.05	<i>Motor-driven blower.</i> Per 100 kg Fr. 0.05
Total cost for melting 100 kg Fr. 6.13	Total cost for melting 100 kg Fr. 11.66

evolved melting processes suitable for the most common metals and alloys, which give results that are satisfactory from all points of view. Comprehensive and carefully carried-out tests have dispelled all fears formerly entertained as to the harmful effects of high temperatures around the electrodes. On the contrary, this high temperature enables slags having any desired composition and fluidity to be produced on the surface of the bath, so that non-ferrous metals can be refined

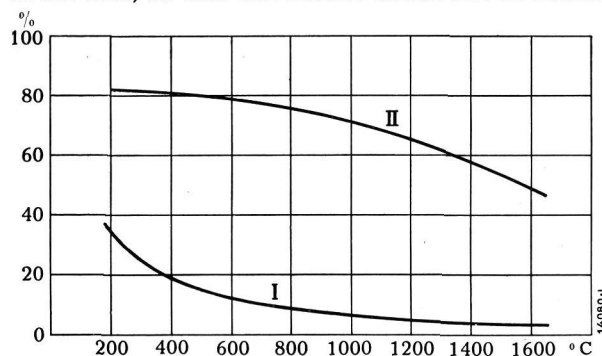


Fig. 9. — Utilisation of the heat produced as a function of the pouring temperature in degrees C.

Curve I: For a coke-fired furnace.

Curve II: For a Brown Boveri electric melting furnace.

similarly to steel. Particulars of tests of metals melted in Brown Boveri furnaces have been collected in Table II. The products obtained by melting and refining bronze turnings are specially remarkable, as all known processes existing hereto only gave inferior-quality products in such cases. Brown Boveri electric furnaces are therefore a valuable asset to works having to melt down their own scrap and turnings. The other figures tabulated indicate that the most favourable results possible are obtained without exception by Brown Boveri electric furnaces. The microphotographs, Figs. 6—8, show the remarkable purity and regularity of the structure of the materials thus refined, besides confirming and explaining the satisfactory results given in Table II.

Cost of operation.

In common with other apparatus where electrical energy is converted into heat, the price per heat unit is not the only factor which decides the comparative merits of electric furnaces and those making use of fuels. Practice has shown that other factors are also decisive in this respect, amongst which may be mentioned: the utilisation of the heat, consump-

TABLE IV

Comparative costs for melting 100 kg of coin silver in a Brown Boveri electric melting furnace and in a coke-fired furnace. *)

Brown Boveri electric melting furnace	Coke-fired crucible furnace
<i>Energy consumption</i> (incl. warming up and losses in transformer and switchgear). 23 kWh per 100 kg of silver, at 0.04 Fr. per kWh Fr. 0.92 <i>Electrode consumption.</i> 0.13 kg of American graphite per 100 kg of silver, at 2.80 Fr. per kg Fr. 0.37 <i>Lining.</i> 500 heats of 250 kg per lining costing 300 Fr. Cost per 100 kg $\frac{300 \times 100}{250 \times 500} =$ Fr. 0.25 <i>Metal losses.</i> 0.123 %. <i>Wages.</i> Wages bill per 8-hour shift 70 Fr., production 1600 kg. Per 100 kg $\frac{70}{16} =$ Fr. 4.37 Total Fr. 5.91 Balance in favour of the electric furnace . . Fr. 8.31	<i>Coke consumption.</i> 25 kg per 100 kg of silver, at 8 Fr. per 100 kg Fr. 2. — <i>Crucible consumption.</i> 30 heats of 125 kg per crucible costing 50 Fr. Cost per 100 kg $\frac{50 \times 100}{30 \times 125} =$ Fr. 1.33 <i>Lining.</i> Cost of renewals per 100 kg of silver . . Fr. 0.20 Wages for repairs: 2 hours at 1.40 Fr. per hour per 1200 kg (per day) of silver. Per 100 kg $\frac{2 \times 1.40 \times 100}{1200} =$ Fr. 0.25 <i>Metal losses.</i> 0.167 %. Balance against coke-fired furnace 0.044 %, at 105 Fr. per kg Fr. 4.60 <i>Wages.</i> Wages bill per 8-hour shift 70 Fr., production 1200 kg. Per 100 kg $\frac{70}{12} =$ Fr. 5.80 <i>Motor-driven blower.</i> 1.5 kW per furnace per crucible containing 150 kg of metal, at 0.04 per kWh. Per 100 kg $\frac{1.5 \times 0.04 \times 100}{150} =$ Fr. 0.04 Total Fr. 14.22

*) Some of the figures tabulated were recorded during the acceptance tests of the electric furnace supplied to the Swiss Mint, Berne.

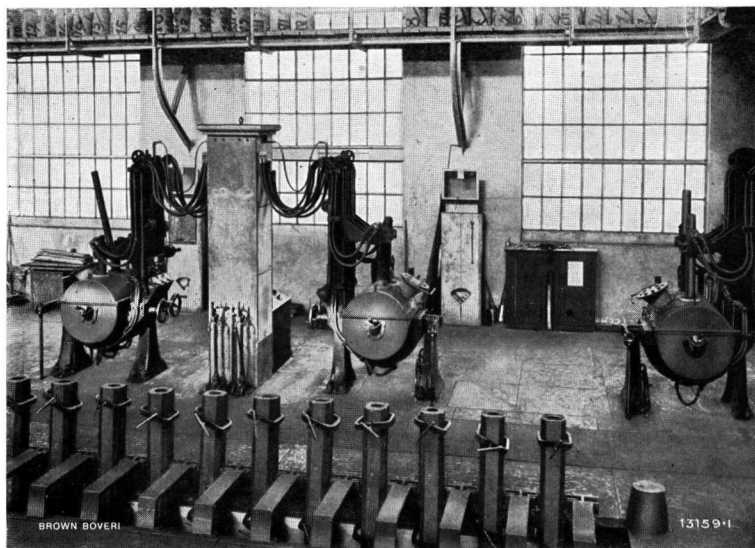


Fig. 10. — Three Brown Boveri three-phase electric furnaces in the foundry of the Schweizerische Metallwerke Selve & Co., Thun (Switzerland), having a capacity of 300 kg each.

tion and renewals of secondary materials (fluxes and lining), wages and metal losses. This explains the popularity enjoyed by electric furnaces even after the war, which have not only held their own, but have, in many cases, supplanted oil and coke-fired furnaces. The curves, Fig. 9, indicate the percentage of heat generated which is utilised in a Brown Boveri electric furnace and in a coke-fired furnace. The superior economy of the electric furnace over oil and coke-fired furnaces whenever metals melting at high temperatures, like steel, nickel, nickel alloys, etc., have to be dealt with, is clearly shown by these curves.

The costs of operating a Lunkenshimer oil-fired furnace and a Baumann coke-fired furnace are compared with those of a Brown Boveri electric melting furnace in Tables III and IV. The figures given are an average of values taken from report sheets in May, 1922 and are expressed in Swiss currency.

ADVANTAGES OF BROWN BOVERI ELECTRIC MELTING FURNACES OVER OTHER MELTING PROCESSES.

Attention has already been drawn in the preceding paragraph to the superiority of Brown Boveri electric melting furnaces over all other process using solid, liquid or gaseous fuels. The most valu-

able features of electric melting furnaces will now be briefly summarised:

1. Independence of the quality of the fuel, which enables a pure and good quality product to be always obtained.
2. Any desired pouring temperature can be maintained continuously as long as required.
3. The charge can be melted in an atmosphere which is perfectly neutral and free from all contaminating gases.
4. Possibility of carrying out any required treatment of the charge by altering the composition of the slag, thus allowing superior quality products to be refined from cheap raw materials.
5. All causes of annoyance to the workers through heat and fumes are removed, so that the furnaceman can give his undivided attention to the melting process.

The principal advantages of Brown Boveri electric furnaces over all other electric furnaces are:

6. The arrangement of the electrodes causes the passage of the electric current to set up a vigorous eddying movement in the bath, so that a continuous circulation of the molten metal is ensured, which becomes thoroughly mixed and evenly heated.
7. The arcs from the two upper electrodes form an extremely liquid slag on the surface of the bath,

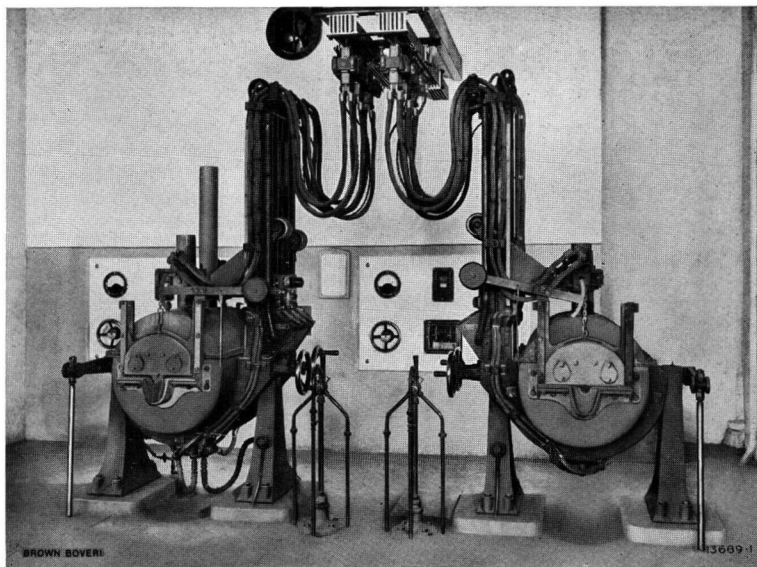


Fig. 11. — Brown Boveri three-phase melting-furnace plant.

The furnace on the left is for melting special steels and has a water-cooled hearth electrode, whereas that on the right, which is for melting copper and its alloys, has a self-cooled hearth electrode.

which is chemically very active. Consequently, the reactions in the bath not only take place in a very short time, but a final product of superior quality is obtained.

8. The furnace can be loaded either with a solid or liquid charge, and is always ready for service.
9. Brown Boveri furnace plants are designed from the mechanical as well as from the electrical point of view to withstand continuous service, so that they can be worked, if necessary, equally well on a 24-hour day as on an 8-hour day.
10. The interchangeability of the tank permits small plants having only one furnace installation to

deal with widely-differing metals, and of avoiding all danger of contamination by utilising a separate tank for each different metal or alloy.

11. Brown Boveri melting furnaces take up a very small space and do not require any special foundations.
12. The furnace is equally suitable for being connected to single, two or three-phase systems having any periodicity.
13. The high power factor is a valuable feature for the energy consumers, as it enables them, in majority of cases, to enjoy preferential tariffs.

J. Ritz & G. Keller. (D. M.)

CURRENT-CARRYING CAPACITY OF CABLES WHEN INTERMITTENTLY LOADED.

Decimal index 621.319.34.

In this article the following symbols are used:—

- a = load period.
 D = outside diameter of cable.
 E = terminal pressure.
 Δe = pressure drop.
 ϵ = 2.718, basis of natural logarithms.
 ϑ = temperature rise.
 ϑ_a = " " during load period.
 ϑ_p = " " " duty cycle.
 ϑ_t = " " " time t .
 ϑ_s = " " of the cable surface.
 I = current.
 I_{eff} = effective (root-mean-square) current.
 I_a = effective current during load period.
 I_p = " " " duty cycle.
 I_1 = current during time t_1 .
 I_2 = " " " t_2 .
 I_v = full-load current of motor.
 L = distance between motor and mains.
 P = duty cycle = load period + rest period.
 p = overload factor of the cable.
 Q = heat capacity.
 Q_{cu} = " " of conductor.
 Q_d = " " " dielectric.
 R = ohmic resistance.
 s_{cu} = sectional area of conductor.
 s_d = " " " dielectric.
 $t_1 t_2$ = time intervals.
 t_{total} = duration of a series of duty cycles.
 t_o = time-constant.

Introduction.

IN recent years, much attention has been paid to the heating of motors and apparatus when intermittently loaded. The usual listing of motors in simple groups of half-hour, one hour and one-and-a-half hour rating has, in many respects, been found insufficient, as it does not take any account of the effect which the size and the type of the machine have upon its short-time rating.

In this connection a proposal¹ was submitted some time ago to the "Verein Deutscher Elektrotechniker" (V.D.E.), according to which lists of motors for intermittent rating should contain information regarding the output of each machine with a given "intermittence", that is, the ratio of the duration of the load period (a) to that of the duty cycle (P) — the latter being made up of the load period plus the rest period. For ordinary requirements, it is sufficient to classify the motors in four rating categories

which take account of three intermittences $\left(\frac{a}{P}\right)$, namely: 0.15, 0.25 and 0.35, and two degrees of loading: full load and variable load; the latter applies to motors which do not have to develop on the average more than 60% of their normal output. The intermittence is frequently called the operating factor, and expressed as a percentage of the duration of the duty cycle, in the present case, therefore, 15%, 25% and 35%.

¹ Elektrotechnische Zeitschrift (E.T.Z.), 1920, Vol. 41, pp. 485 and 508.

In view of the increasing endeavour to utilise to the fullest extent motors and apparatus employed for intermittent working, it will be of interest to consider in detail the current-carrying capacity of the cables necessary for such installations.

(a) Continuous rating.

The permissible current which a cable may carry continuously is determined by:

1. The maximum temperature to which the dielectric may be subjected.
2. The thermal resistivity of the dielectric.
3. The thermal characteristics of the medium in which the cable is laid.

According to the Standard Rules of the V.D.E., rubber-insulated cables can be used for the following maximum currents:—

Section	4	6	10	16	25	35	50 sq.mm.
Current	25	31	43	75	100	125	160 A.

The temperature rise of the conductor, that is to say of the copper core, will then be 20° C.

It might have been expected that these currents — in the determination of which the above three

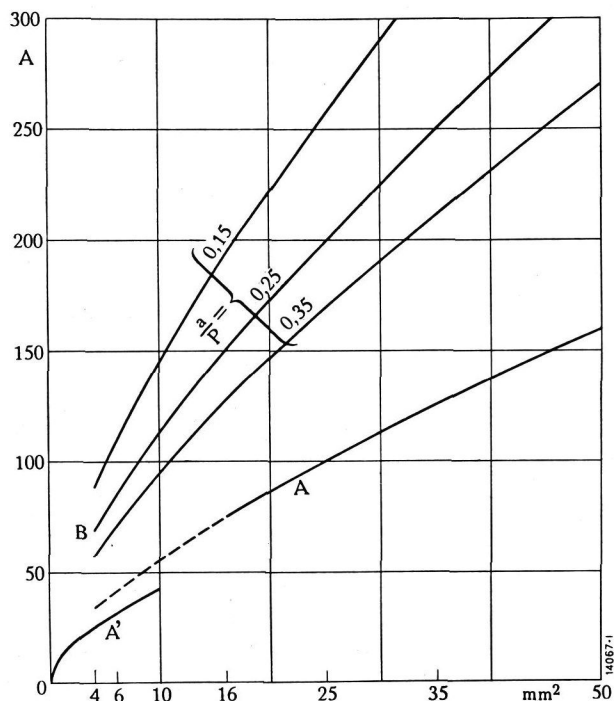


Fig. 1. — Current-carrying capacity of rubber-insulated cables.

Ordinates: Current in amperes. Abscissæ: Cable section in sq. mm.

A. Continuous rating with cables laid in air.

A'. Continuous rating with cables laid in tubing.

B. Intermittent rating with various intermittences

$p = \frac{\text{load period}}{\text{load period} + \text{rest period}}$

based on the root-mean-square current I_p (See Fig. 2).

points were taken into consideration — would lie on a regular curve when plotted as a function of the area of the conductor. This, however, is not the case, as will be seen from the curves A and A' in Fig. 1. The apparent irregularity can be explained by the fact that the permissible load for sections of 16 sq. mm and over holds good for cables laid in air, whereas the values for the smaller sizes were determined on the assumption that these cables would be placed in tubing, this containing two cables and not merely one.

In most cases, the cables used for machines working intermittently, such as cranes, etc., are provided with a covering of galvanised iron wire, and laid without further protection. In consequence of this latter fact, it is possible to increase the continuous load for cables up to 10 sq. mm. The higher values allowable can be obtained from the tests¹ which form the basis of the German Rules. For a temperature rise of 20° C, they amount to 34, 42 and 56 A for cables with sections of 4, 6 and 10 sq. mm, as indicated in the dotted portion of curve A, Fig. 1.

(b) Loading on the basis of the effective current.

When the cable is loaded intermittently, the value fixed by the Rules can be exceeded, on condition that the temperature rise is at no time above 20° C. Consequently, it is very often possible to use a smaller cable for an intermittently-rated motor than would be necessary for carrying the same current continuously.

The choice of the size of cable is usually made on the basis of the effective load, that is, the root-meansquare value of the various loads it has to carry during a series of duty cycles. This effective value is the current which the cable could carry continuously with the same temperature rise, and is found by the usual formula:

$$I_{\text{eff}} = \sqrt{\frac{I_1^2 \cdot t_1 + I_2^2 \cdot t_2 + \dots}{t_{\text{total}}}} \quad (1)$$

From this it can be seen that the heating due to a current of 75 A which only flows during one-third of the total time is the same as that caused by a current of 43 A continuously,

since $\sqrt{\frac{75^2 \times 1}{3}} = 43$ A. It is therefore possible to use in this case a cable of 10 sq. mm instead of one of 16 sq. mm.

In order to fix definite figures for the load capacity of cables used for plants working intermittently, such as cranes and transport appliances,

¹ E. T. Z., 1907, Vol. 28, p. 475.

etc., let it be assumed that the machine operates on a regular cycle, and also that the normal running current after the acceleration period is over amounts to 0.8 of the normal full-load current of the motor. It has been found from experience that the load period (a) lasts 30—120 seconds and that the starting time, which is included in this figure, takes about 3—10 seconds according to the working conditions. For present purposes, the starting period can be taken as one-tenth of the load period. The mean starting current is, as a rule, equal to twice the normal full-load current, which corresponds to a maximum starting torque of about 2.5 times the normal full-load torque in the case of polyphase slip-ring motors, and a somewhat higher torque with direct-current series motors, which are the two types most commonly used for the kinds of installation in question. These load conditions are indicated in Fig. 2 for an intermittence of 0.35 and $a = 35$ seconds. The effective current during the latter period is found from formula (1) to be

$$I_a = \sqrt{\frac{2^2 \times 3.5 + 0.8^2 \times 31.5}{35}} \approx 1$$

Since

$$I_a^2 \cdot a = I_p^2 \cdot P$$

it follows that

$$I_p = \sqrt{\frac{I_a^2 \cdot a}{P}}$$

In the present instance, the effective current I_p during the duty cycle, or in fact continuously, is equal to

$$\sqrt{\frac{1^2 \cdot a}{P}} = \sqrt{\frac{a}{P}}$$

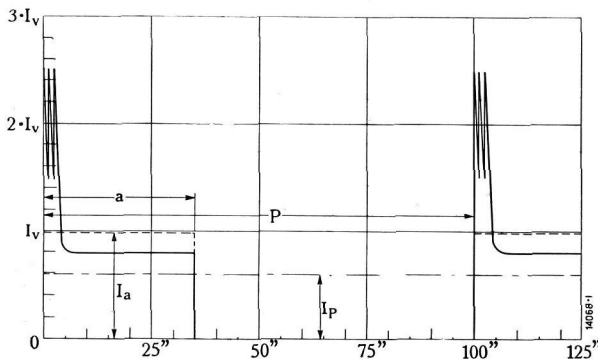


Fig. 2. — Current-time diagram of a motor on intermittent load.

Ordinates: Current as a multiple of the full-load motor current I_v .

Abcissæ: Time in seconds.

Load period $a = 35$ seconds.

Starting period = 3.5 seconds.

Duty cycle $P = 100$ seconds.

Mean starting current = 2

Intermittence $\frac{a}{P} = 0.35$

Steady load current = 0.8

Effective (root-mean-square) value I_a of the currents during the load period ≈ 1 .

Effective current I_p during the duty cycle = 0.59.

that is to say, the square root of the intermittence. For the standard intermittences of 0.15, 0.25 and 0.35 the effective current I_p will consequently be 0.39, 0.5 and 0.59. The reciprocal value of these figures, namely 2.6, 2.0 and 1.7, represents the short-time overload factor of the cable reckoned on the basis of the root-mean-square value I_p of the currents flowing in a given period. The overload factor refers here to the amount by which the current normally allowable can be increased in the case of intermittent working without the specified temperature rise being exceeded. The three curves B in Fig. 1 show the full-load motor current for which freely-laid cables of 4 to 50 sq. mm can be used under such conditions.

(c) Loading on the basis of the time-constant.

It is obvious that there is a limit to the short-time overload allowable, as the pressure drop has to be considered, and, in the case of very small sections, the mechanical strength must not be overlooked. Further, the duration of any one load period is a most important point which is very frequently not allowed for sufficiently. It is evident that, even with the intermittence remaining unchanged, a cable could become too warm if instead of 30—120 seconds the load period lasted the same number of minutes. The curves B, Fig. 1, must therefore be used with caution.

For determining exactly the permissible intermittent current for a given cable, it is necessary to know in what measure the latter as a whole can store up part of the heat developed. This property of the cable is expressed by a factor called the *thermal time-constant*. This latter is the time which it would take to reach the final temperature with a given current if none of the heat developed were dissipated to the surroundings. In reality, when starting from cold, the temperature rise of the cable is at first almost directly proportional to the heat supplied, that is, to the watt losses; gradually, however, the heat given off increases until a condition is reached where the heat developed and the heat emitted are equal to one another. (Certain secondary effects are here neglected, such as the variation of the specific resistance of copper and also of the emissivity coefficient with increasing temperature, as well as the fact that the heat developed is taken up more slowly by the dielectric than by the conductor itself). Theoretically, an infinitely long time would be required until the steady condition above mentioned is reached. The time t at the end of which the temperature reaches ϑ_t per cent. of the final tempe-

perature is given as a function of the time-constant t_0 by the formula

$$t = t_0 \cdot \log_e \left(\frac{100}{100 - \vartheta_t} \right) \quad (2)$$

When $t = t_0$ the value of ϑ_t is 63.2%. The time-

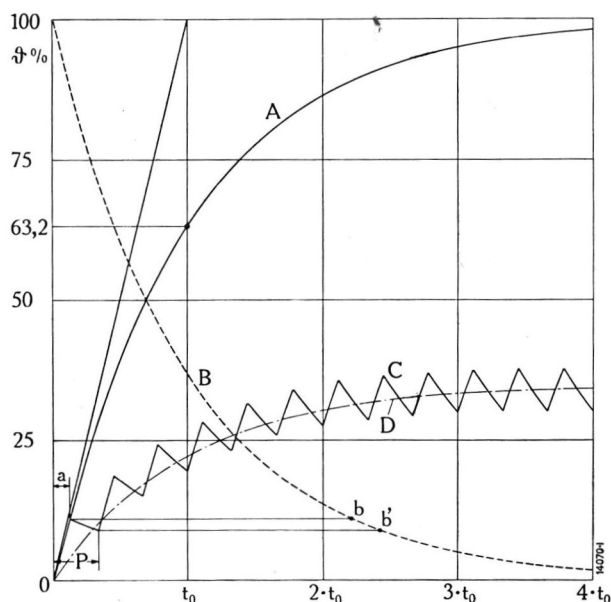


Fig. 3. — Heating and cooling curves.

Ordinates: Temperature rise ϑ as a percentage of the maximum rise.
Abscissæ: Time as a multiple of the time-constant t_0 .

A. Heating with full-load current I_v .

B. Corresponding cooling curve.

C. Heating and cooling with the load conditions of Fig. 2 and a time-constant $t_0 = 5$ minutes.

D. Heating with the corresponding effective current $I_p = 0.59$.

constant is therefore the time required for the temperature to rise to 63.2% of its final value.

These conditions are shown clearly in the curves of Fig. 3. Curve A shows the way in which the temperature rises with normal full-load current I_v , while curve B — which is the reflected image of curve A — shows how the cable cools down. The gradual increase of temperature with the working conditions given in Fig. 2 is indicated by the zigzag curve C, which is for a cable with $t_0 = 5$ minutes. The dotted curve D refers on the other hand to the same cable carrying the corresponding effective current $I_p (= 0.59 I_v)$ continuously. Since the mean current I_a during each load period is equal to $1 \times I_v$, it follows that the zigzag curve is made up of portions of the main heating and cooling curves A and B. For instance, after first switching in, the temperature rise mounts from 0 to 11% before the load is switched off. During the rest period, the cable cools down according to curve B from the

point corresponding to the latter value — that is to say from point b — to b', to rise again during the next load period from this reduced temperature according to curve A, and so on.

As mentioned above, the time-constant depends on the heat-storage capacity of the cable, and this, expressed in calories per unit volume and degree of temperature difference, is the product of specific weight and specific heat

$$\left(\frac{g}{\text{cub. cm}} \times \frac{\text{Cal}}{\text{kg} \cdot ^\circ\text{C}} = \frac{\text{Cal}}{\text{cub. dm} \cdot ^\circ\text{C}} \right)$$

In the case of the copper conductor the heat capacity amounts to $8.9 \times 0.094 = 0.84$. If the twist of the cable is allowed for, it will be about 2—3% higher with stranded conductors.

The specific weight of the dielectric is about 1.65, while its specific heat can be taken as 0.35, so that the specific heat capacity is 0.58. As the surrounding air has a heat capacity of only 0.0003

$\frac{\text{Cal}}{\text{cub. dm} \cdot ^\circ\text{C}}$ it is evident that it need not be considered when determining the time-constant of a cable laid in air.

The total heat capacity of a conductor of section s_{cu} sq. mm for a temperature rise of 20°C is $Q_{cu} = 0.84 \times 20 \times 0.001 \times s_{cu}$ Cal per metre or, since 1 Cal = 4180 watt-seconds

$$Q_{cu} = 70 s_{cu} \text{ Ws per m.} \quad (3)$$

The average temperature rise of the dielectric will, of course, be somewhat less than 20°C . The temperature falls from the conductor to the surface of the cable according to a logarithmic law, and reaches a value somewhat above the temperature of the surrounding air, which is taken as 15°C . This heat drop depends on the thermal resistivity of the various component parts of the dielectric and also on the surface resistivity of the cable. As these two latter factors have really been taken into account in the determination of the permissible continuous load corresponding to a temperature rise of 20°C , it is possible to calculate by means of a suitable formula the temperature at the outside surface of the insulation. With the relatively low temperatures entering into consideration, the effect of direct radiation can be neglected. The heat drop between the cable surface and the surrounding air takes place in the air film, which has a high resistivity, directly surrounding the cable. The air is continually changed by convection and the heat thus carried off. The colour and the texture of the cable surface are of

no great importance; a rougher surface presents a somewhat greater area to the stream of cooling air, but, at the same time, retards its speed. The emissivity coefficient in watts per unit of area and degree of temperature difference is not a constant, but varies with the difference of temperature and the diameter. In the case of a cylindrical cable with an outer diameter D cm, the heat emitted in still air is given by the following formula:¹

$$\text{Heat emitted} = 0.0029 D^{0.6} \vartheta_s^{1.18} \text{ watts per cm.}$$

The temperature rise of the surface is therefore:

$$\vartheta_s = \sqrt[1.18]{\frac{\text{Watt losses per cm}}{0.0029 D^{0.6}}}$$

since the heat emitted is equal to the heat energy supplied after a steady temperature has been reached.

For cables of 4 and 50 sq. mm ($D = 0.64$ and 1.6 cm), the surface temperature rise ϑ_s is found to be 15°C and 15.5°C respectively, assuming the specific resistance of copper to be $0.019 \frac{\text{ohms} \cdot \text{sq. mm}}{\text{m}}$. (As the effective section of the conductor is fixed by the German Rules accord-

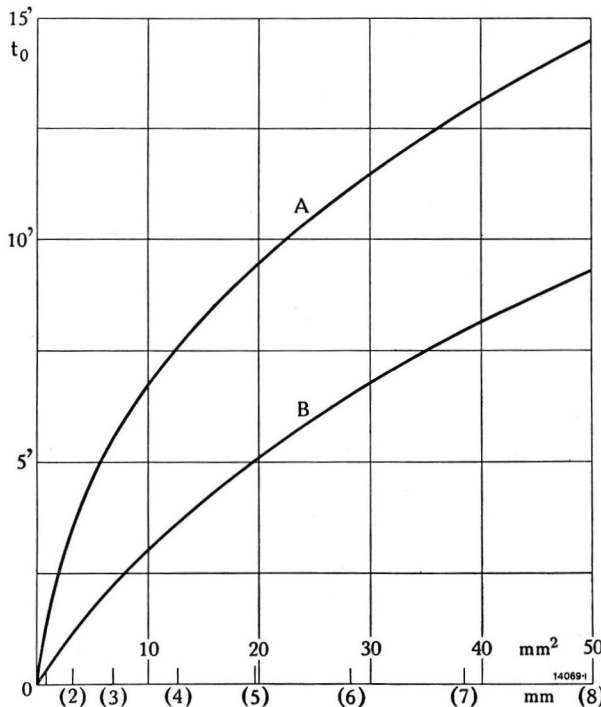


Fig. 4. — Time-constant of copper conductors laid in still air. Ordinates: Time-constant t_0 in minutes. Abscissæ: Section of conductor in sq. mm (Diameter of conductor in mm). A. For rubber-insulated cables up to 50 sq. mm. B. For bare copper wires up to 8 mm diameter.

¹ Electrician, 1920, Vol. 85, p. 202.

ing to its resistance on the basis of a specific resistance for copper of 0.01784 at a temperature of 20°C , it follows that the resistance at 35°C , corresponding to 15°C air temperature plus 20°C temperature rise, is 0.019 .) The average temperature of the dielectric — in which the temperature gradient follows a logarithmic law — is found to be 16.5 and 17°C above that of the air for the two sizes of cables mentioned.

Reckoning on the basis of the lower value, the heat capacity of the dielectric with a sectional area s_d sq. mm is $Q_d = 4180 \times 0.58 \times 16.5 \times 0.001 \times s_d = 40 s_d$ Ws per metre. (4)

It can be shown that

$$t_0 = \frac{\text{heat capacity}}{\text{heat emitted}} = \left(\frac{\text{watt secs. per unit of length}}{\text{watt losses per unit of length}} = \text{secs.} \right)$$

For vulcanised indiarubber cables the time-constant in minutes is (formulae 3 and 4) therefore

$$t_0 = \frac{70 s_{cu} + 40 s_d}{I^2 R \times 60}$$

In the case of a cable of 50 sq mm it amounts, for instance, to

$$t_0 = \frac{70 \times 50 + 40 \times \frac{\pi}{4} (16^2 - 10^2)}{160^2 \times 0.019 \times 60} = 14.5 \text{ min.}$$

The time-constants for other sections are given in Fig. 4, curve A, which refers to cables laid in still air. In other cases — for buried cables or cables subjected to a current of air — it is necessary to take special account of the medium surrounding them. The draught would, for instance, increase the emissivity coefficient with a given load, and consequently the time-constant would be lower.

Curve B, Fig. 4, gives the time-constants for bare copper wires calculated in a similar manner to the above.

The time-constant permits the allowable overload factor of a cable for intermittent as against continuous loading to be determined in a reliable manner, which, as has been seen, is not the case when merely the effective current is taken into account.

Without deducing in detail the formula for the overload factor, it is sufficient to state here that the latter — with reference to the watt load of the cable — is given by the ratio $\frac{\vartheta_P}{\vartheta_a}$. In the present case, it is more suitable to express it with respect

to the current flowing, so that the overload factor

$$p \text{ is equal to } \sqrt{\frac{\vartheta_p}{\vartheta_a}}$$

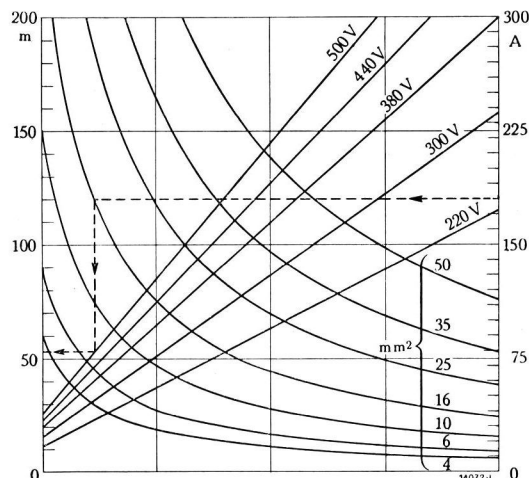


Fig. 6. — Permissible length of copper conductors based on a 10% pressure drop at starting with a maximum torque of 2.5 times the normal full-load torque.

Ordinates: Right hand:
Full-load current of motor in amps.
Left hand:
Maximum length between motor and mains in metres.
These curves hold good for both direct current and three-phase current.
This figure can be considered as completing Fig. 5.

As seen from the zigzag curve C, Fig. 3, the temperature rises during the first load period (a) from 0 to 11% under the running conditions given. During the whole cycle (P), the cooling curve falls, or the heating curve rises, 28% altogether. The overload factor of a cable carrying the working currents indicated in Fig. 2 would therefore be

$$p = \sqrt{\frac{28}{11}} = 1.6$$

This figure holds good, of course, only for a cable with a time-constant of 5 minutes, as assumed, and will rise with increasing values of the time-constant. Although it would probably only vary be-

tween 1.58 and 1.65 for ordinary cranes and similar installations, and consequently not differ greatly from the overload factor of 1.7 found on the basis of the effective current in Fig. 2, it must be pointed out that with a larger load period (a), and

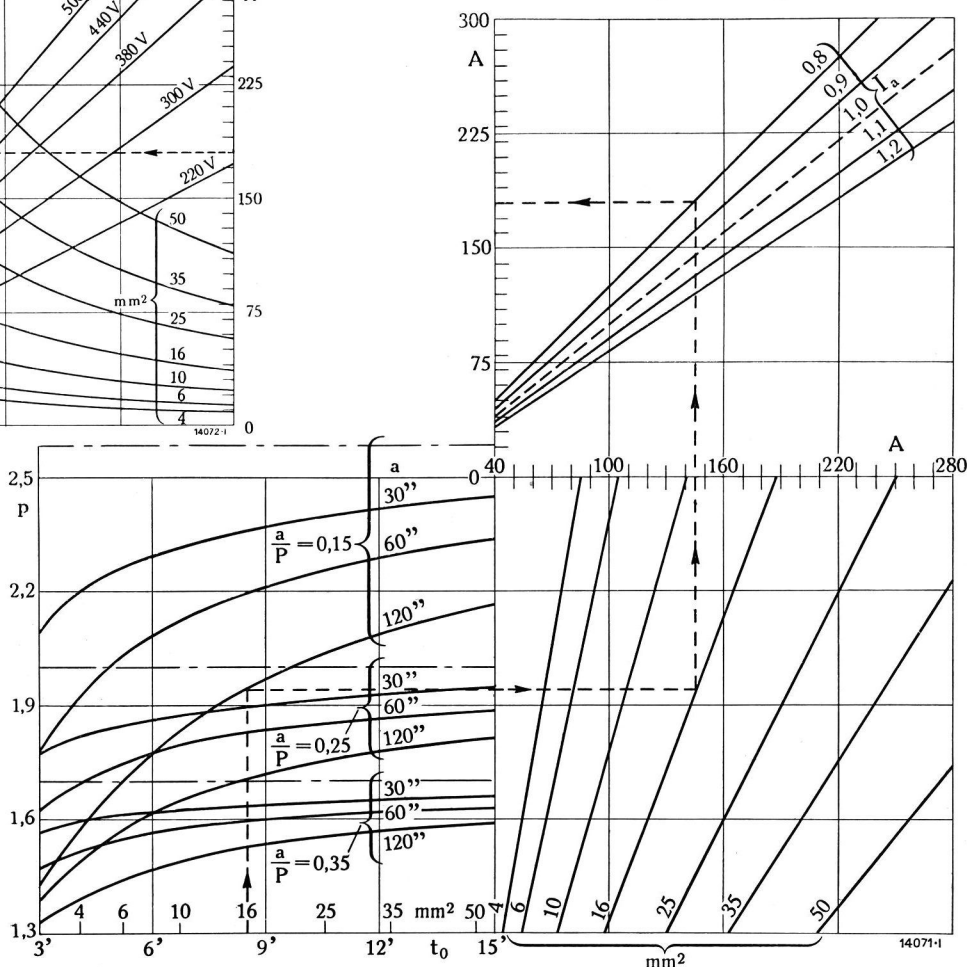


Fig. 5. — Current-carrying capacity of intermittently-loaded rubber-insulated cables based on the time-constant.

Left hand:
Ordinates: Overload capacity p compared with the normal continuous rating (curve A, Fig. 1) for load periods of 30, 60 and 120 seconds with intermittences of 0.15, 0.25 and 0.35.
Abscissae: Cable section in sq. mm. Time-constant in minutes.
The chain-dotted horizontal lines in the left-hand portion indicate the overload capacity corresponding to curve B, Fig. 1, on the basis of the effective current I_p .
Right hand: Abscissae (middle): Full-load current of motor in amps for which the cable can be used.
Ordinates (above): Full-load current of motor in amps.
The upper part is to be used when the mean current I_a during the load period is different from unity.

especially with a lower intermittence, the difference would be considerably greater, as can be seen from the left-hand portion of Fig. 5. With an intermittence of 0.15 and $a = 120$ seconds, the factor p for a cable of 4 sq. mm, for instance, would only be 1.6 instead of 2.6 as found on the basis of the effective current.

As the explanation given to Fig. 5 is very complete, it is not necessary to describe here in

detail what the various curves mean. Those for the overload factor p can be obtained from the curves A and B of Fig. 3 in the manner indicated above, or from formula (2). The latter should then be written in the form

$$\vartheta_t = 100 \left(1 - \varepsilon^{-\frac{t}{t_0}} \right)$$

where t is to be substituted by the values of (P) and (a) in turn. Such calculations can, however, be avoided by using the well-known nomographic chart¹ of G. Gut, which enables all kinds of heat problems to be solved in a simple manner.

From what has been mentioned above, it is clear that, from the point of view of heating, the smallest allowable cable section for any given working conditions should be chosen only on the basis of Fig. 5, or of similar curves, and not according to curves B, Fig. 1. The dotted lines in Fig. 5 show that a cable of 16 sq. mm can be used, without the allowable temperature being exceeded, for a motor having a full-load current of 145 A if the latter flows during 120 seconds with an intermittence of 0.15. If the mean current I_a during the load period is not 1, but 0.8 times the full-load current of the motor, the same cable is sufficient for a machine which takes 180 A on full load, as can be seen from the upper portion of the figure.

The following rough rule can be established on the basis of the curves giving the values of p :—

Intermittently-loaded rubber-insulated cables laid freely can be used for machines whose normal full-load current — corresponding to the power they are designed for on intermittent rating — is 50% higher than the steady current permissible for cables of the same section according to the German Rules.

Since the values according to the latter refer to cables laid in tubing in the case of sections of 4—10 sq. mm, such an overload amounts to only about 10—15% above the current which these cables can carry continuously when laid freely. In consequence of this, the extra margin advisable with small cables, that is those with a low time-constant, in case of short periods of heavier duty, which might take place due to a temporary increase in current or in the duration of the load period, is allowed for. When calculating the effective current I_a during the load period, it is of course advisable to take the steady running current as being not less than the full-load current

of the motor, if there is any chance of the latter having to develop full power for several successive duty cycles.

(d) Pressure drop.

The loading of a cable up to the value found from the curves Fig. 5, or even up to the continuous value allowed by the German Rules, will only be done in practice if the pressure drop is not excessive.

Since the starting torque of an induction motor falls as the square of the pressure, it is evident that the pressure drop, which increases as the current rises, must not be too high during the starting period. The foregoing calculations are based, as already mentioned, on a mean starting current of $2 \cdot I_v$. The peak necessary to overcome the static friction of the machine and to accelerate the moving parts will be about $2.5 I_v$ — corresponding to the starting torque of 2.5 times the normal full-load torque — and the pressure drop with this current should not be more than about 10% of the no-load terminal pressure E , i.e. 4% drop on normal full load.

The type of plant in question is generally provided with a brake-lifting magnet, and it is also necessary to keep the pressure drop within moderate limits on account of this apparatus. The current taken by the magnet on switching in has a power factor of perhaps 0.5 and amounts to roughly 30 times the current necessary to hold the core when once lifted; the peak at switching in is in some cases as much as 50% of the normal full-load current of the motor. As, however, the controller is mostly arranged so that the current taken by the motor on the first notch is only about normal full-load current, and the magnet lifts on this step, it is sufficient — since the current taken by the magnet at once falls to a low value — to reckon with the pressure drop due to the peak taken at starting by the motor alone. In order to calculate exactly the drop for any given induction motor, it is necessary to make use of formulæ which are comparatively complicated, as they take account of the inductive as well as the ohmic drop. A graphical method of determining at the pressure drop has already been given in these pages¹. For installations like those considered here it is, however, usually sufficient to calculate the pressure drop Δe in volts for a given line of L metres length between motor and mains by the approximate formula

$$\Delta e = \sqrt{3} \times IR = \frac{\sqrt{3} IL \times 0.019}{S_{cu}}$$

¹ Bulletin of the Schweizerischer Elektrotechnischer Verein, 1918, Vol. 9, p. 42.

¹ Revue BBC or BBC Mitteilungen, 1921, No. 11.

The maximum allowable length of line is therefore

$$L = \frac{0.1 E \times s_{cu}}{\sqrt{3} \times 2.5 I_v \times 0.019} = \frac{1.2 E \times s_{cu}}{I_v} \quad (5)$$

In the case of direct current the question is somewhat simpler, and, for a core temperature of 35° C, the pressure drop is

$$\Delta e = IR = \frac{I \times 2L \times 0.019}{s_{cu}}$$

Although the starting torque of a direct-current series motor, unlike that of an induction motor, does not depend on the terminal pressure, and reaches the desired value of 2.5 times normal full-load torque with only 2.2 times normal current or even less, it is advisable to limit the pressure drop at starting to 10%. The maximum allowable distance L between motor and mains is therefore

$$L = \frac{0.1 E \times s_{cu}}{2 \times 2.2 I_v \times 0.019} = \frac{1.2 E \times s_{cu}}{I_v}$$

that is to say, the same as in the case of the induction motor (equation 5).

The curves in Fig. 6 have been prepared to enable the length L of a cable chosen according to the particulars of Fig. 5, which is used for connecting a motor with a normal full-load current I_v , to be easily determined. As shown in the dotted example, the value for I_v is traced horizontally until it meets the curve representing the area of the cable, from here to the pressure curve and then to the left side of the figure, where the maximum value for L is given directly. As shown, L, that is the distance between motor and mains, should not exceed 53 m when a cable of 16 sq. mm is used for a 500-volt

motor with a normal full-load current of 180 A, (compare the dotted example in Fig. 5).

If Fig. 6 is placed in the space at the top left corner of Fig. 5, thus making the latter into a square, a very complete table of curves is obtained, which permits the necessary cable section for any given intermittently-rated equipment to be determined in a reliable manner.

Conclusion.

The size of the cable should be chosen on the basis of the time-constant and not of the root-mean-square current. The time-constants for standard rubber-insulated cables have been obtained mathematically, and curves (Fig. 5) prepared for determining the short-time overload factor. The pressure drop, however, must not be overlooked. A set of useful curves (Fig. 6) has been made for finding the maximum allowable length of the line.

SUPPLEMENTARY NOTE.

After going carefully into the proposal mentioned at the beginning of the above article, the V.D.E. has published its definite suggestions¹ for new standards as regards the rating of motors destined for intermittent service. According to these, the standard intermittences will be 0.15, 0.25 and 0.40 (instead of 0.35). Further, it shall be allowable to use larger fuses in conjunction with a cable of given section than has been permitted hitherto by the German Rules; fuses for intermittently-rated motors shall no longer be chosen with a view to protecting the cables, but shall be based directly on the motor current.

J. F. Lochhead.

¹ E.T.Z., 1921, Vol. 42, p. 1081.

NOTES.

The hydro-electric power station at the Lungern Lake (Switzerland).

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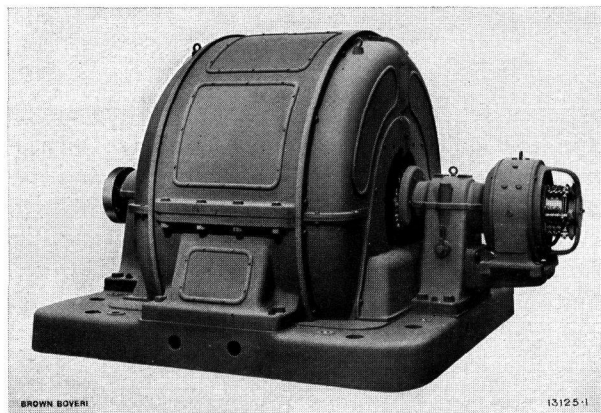
THE first portion of the hydro-electric scheme for utilising the waters of the Lungern Lake was completed in the middle of December, 1921. When finished, the total output will amount to 70 000 H.P.; at present only 8 000 H.P. are installed.

This power station has been built by the owners, a company in Lucerne which supplies electrical energy to the central part of Switzerland (Centralschweizerische Kraftwerke A.-G.), and the plans were worked out by the S.A. Motor, Baden.

The power station was built and completed in record time for an undertaking of this magnitude — the building operations were started on March 1, 1921, and the plant was ready for service about ten months later. This rapid construction was only rendered possible by the existence of a gallery which had been built over one hundred years ago by the peasants of the village of Lungern for tapping the waters of the lake. The work on this tunnel, which was an undertaking of considerable importance for the time, was started on November 25, 1790, — much opposition having had to be faced before the assent was given to start the construction thereof. It had to be abandoned after eight years of uninterrupted work, on account of financial, technical and political difficulties (occupation of Switzerland by the French). The tunnelling operations were resumed in 1806, after subscriptions had been taken in the

whole of Switzerland in order to raise the necessary funds. Altogether 160 hectares (about 395 acres) were reclaimed for cultivation.

The old gallery, which was built for draining off the waters of the lake, is now utilised as a pressure tunnel for the new power station. For this purpose, the cross-section was rendered more even, and certain portions lined with



Three-phase alternator for the Lungern Lake power station.
4000 kVA, 8400 V, 0.7 power factor, 50 cycles.

concrete. Adjustable sluices have been provided at the intake. The level of the lake will be raised 16 metres for the time being in order to increase the head, thus giving a fall of 166 metres. All the land reclaimed 100 years ago will therefore be gradually submerged.

The power station is situated directly below the Kaiserstuhl cliffs, and lies in the same valley as Giswil. For the first part of the scheme, two horizontal Francis turbines have been supplied by Messrs. Theodor Bell & Co., Ltd., Kriens (near Lucerne). Each turbine and its corresponding alternator are rigidly coupled together, and form a set carried by three bearings. The two bearings on either side of the alternator are designed as journal bearings only, whereas the turbine has a thrust bearing in order to take up the axial load.

The two three-phase alternators were supplied by Brown, Boveri & Co., Baden, and the chief particulars of these machines are as follows:—

Continuous output: 4000 kVA, or 2800 kW with a power factor of 0.7. Normal pressure: 8400 V, which can be regulated down to 6930 V. The output remains constant for pressures between 8400 and 8000 V, but decreases proportionally with the pressure below the latter value.

The alternators have eight poles, and are designed for a speed of 750 r.p.m., to which corresponds a frequency of 50 cycles. The speed may rise to 1350 r.p.m. should the turbine run away. In order to ascertain whether this speed could be safely withstood, the rotors were run up to it in the overspeed testing plant before leaving the works. Not the slightest deformation was found to have taken place after this test. The cooling air is led to and

from the lower part of the alternator — which is of the totally enclosed type — in ducts.

Each alternator is connected to a step-up transformer of 4500 kVA which raises the pressure from 8700 to 57 000 V. The transformation ratio has been temporarily altered to 8700/47 000 V by cutting out a number of coils in the high-tension windings; the output in this case is 3800 kVA. The low-tension windings are delta connected and have two tappings for 8400 and 8100 V, whereas the high-tension windings are star connected, with neutral point brought out. A dissonance extinguishing coil is to be placed between the latter and the earth in order to afford a protection against groundings.

The first and last coils of the high-tension windings are specially well insulated, as the outgoing lines are not provided with either choke coils or any other protective devices against lightning, so that undamped surges can enter the transformer. Furthermore, the windings are held in place by the Brown Boveri patent support with springs, in order to protect the transformer from the effects of short circuits.

External cooling of the oil is employed, for which purpose two cooling sets are provided, each comprising an oil cooler, and a hot oil pump which is driven by a three-phase motor.

The switchgear has been designed and erected by the S. A. Motor. Brown, Boveri & Co. supplied all the necessary apparatus, such as, oil-switches, current transformers, potential transformers, knife switches, automatic quick-acting pressure regulators, etc.

G. Fisler. (D. M.)

Two-frequency alternators.

Decimal index 621.313.1.

Two three-phase alternators are being built by the Tecnomasio Italiano Brown Boveri, Milan, for the Italian State Railways which will be installed in the Bardonecchia power station. These machines can generate current having a frequency either of $16\frac{2}{3}$ cycles for traction purposes or of 50 cycles for feeding industrial systems. Their chief particulars are the following:—

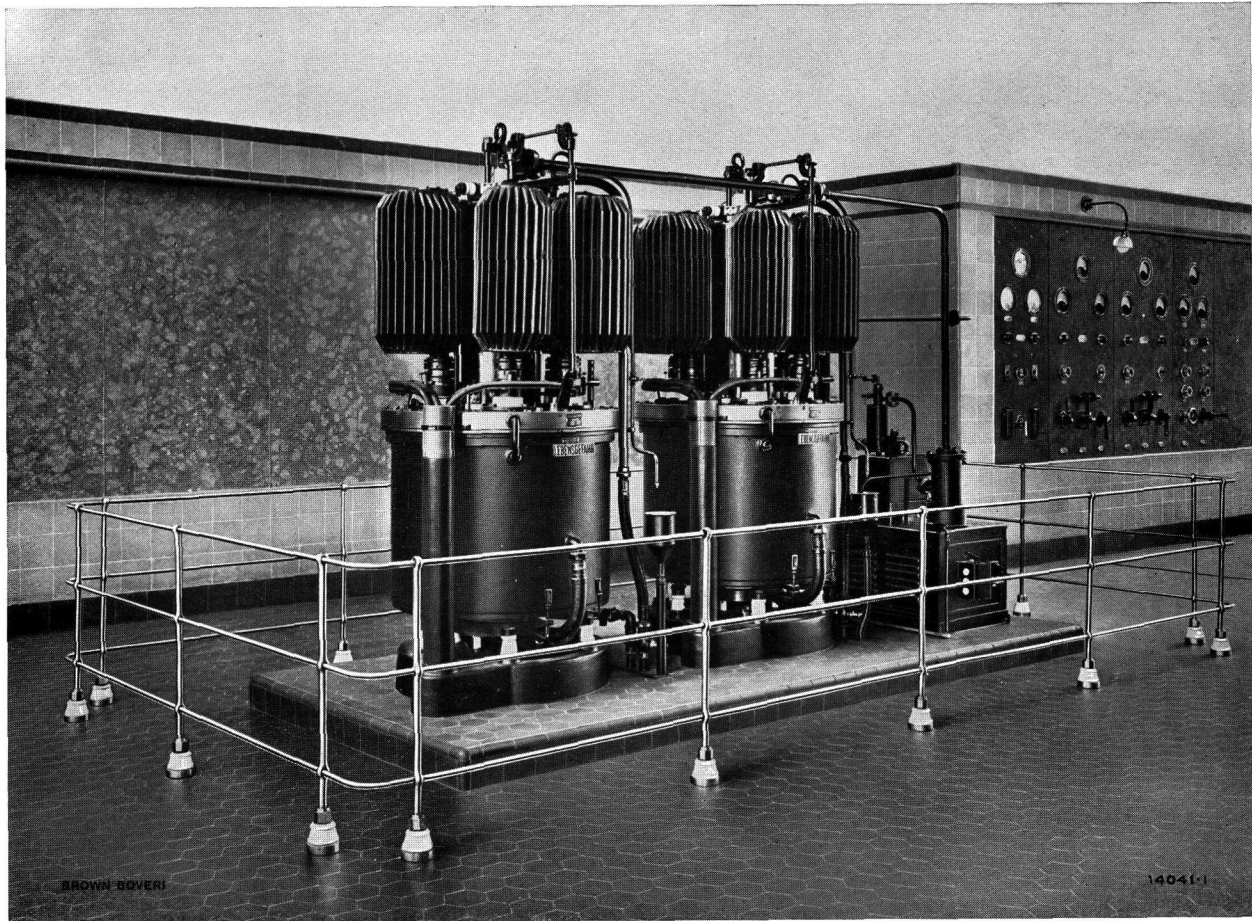
Frequency	$16\frac{2}{3}$	50 cycles.
Output	7000	6000 kVA.
Power factor	0.75	0.75
Pressure	4000	7000 V.
Speed	500	500 r.p.m.
Number of poles	4	12

Each alternator is directly coupled to a water turbine of 7600 H.P., and is capable of withstanding a runaway speed of 900 r.p.m. The weight of an alternator amounts to about 100 tons, inclusive of the built-on exciter. These machines are, as far as known, the first large two-frequency alternators ever built. Such machines will probably be extensively used in the future for plants which supply both railway and industrial systems — as well as for tidal power stations, where the periodicity of the supply must remain constant although the speed of the turbines changes with the varying head.

G. Hunziker. (D.M.)

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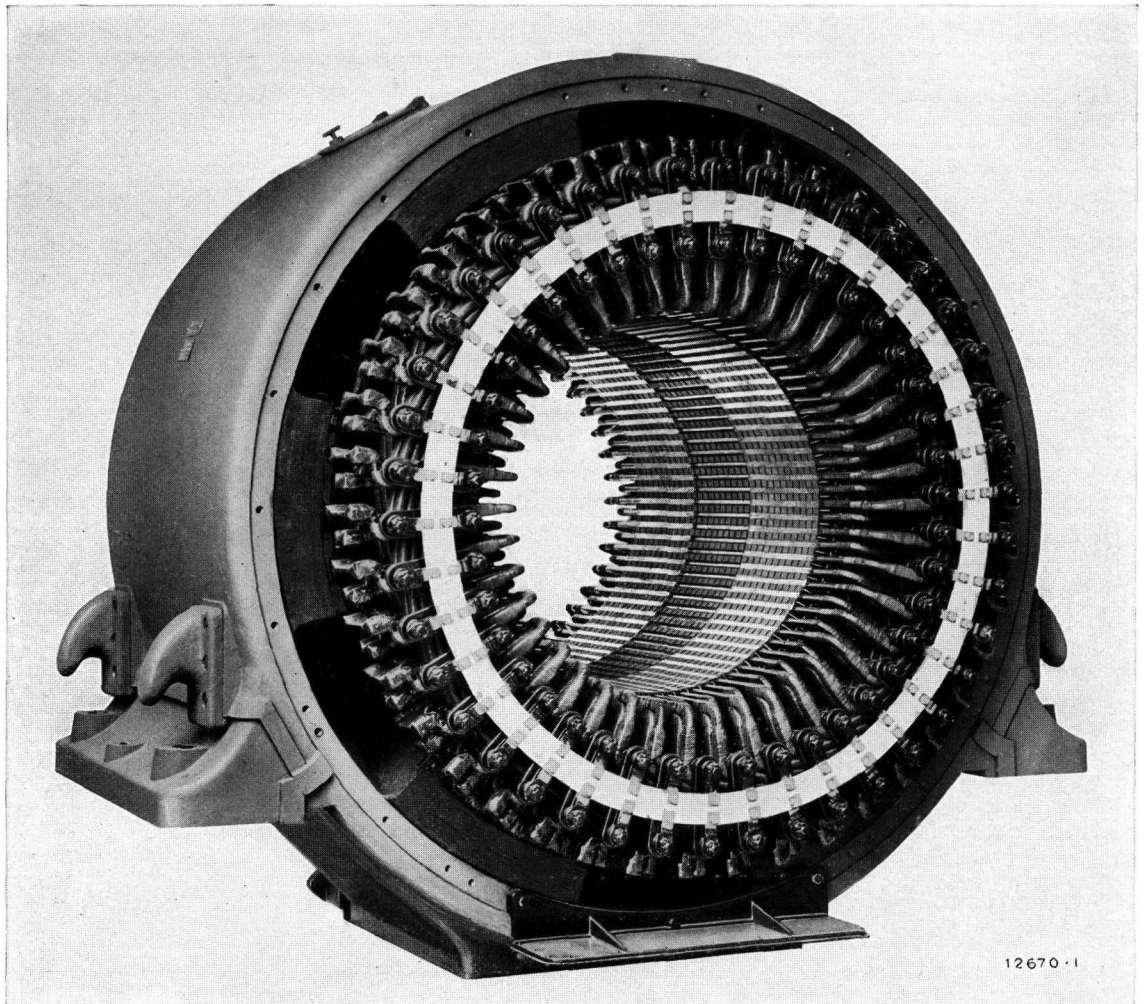
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