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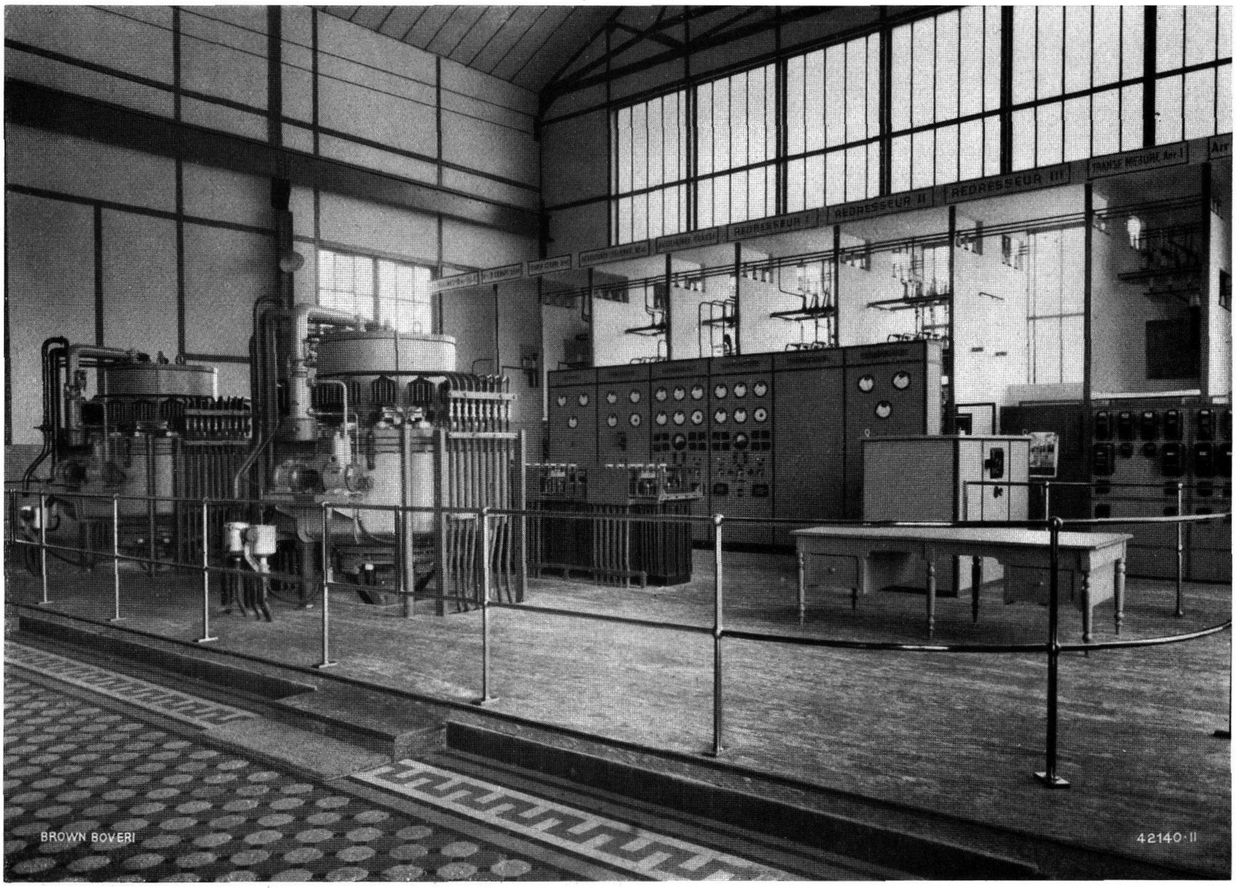
THE BROWN BOVERI REVIEW

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



THE MUTATOR PLANT OF THE USINES DE LA PROVIDENCE IN HAUTMONT (FRANCE).

CONTENTS:—

Printed in Switzerland

WATER-JET ELECTRIC BOILER

Zuckerfabrik & Raffinerie Aarberg A.-G.

Nebenbetriebe:
Melassebrennerei, Melassefutterfabrik
Kunstdüngerfabrikation
Trocknung von Rübenschnitzeln
Eigene Landwirtschaftsbetriebe

Telegramme: Raffinerie. Telephon Nr. 40 & 117
Postcheck-Konto Nr. III/2460 R/S.

AARBERG, den 29. Januar 1936.
(Schweiz)

Brown, Boveri & Co. A.G.,

Bern.

Betr. Elektrokessel- Anlage.

In Beantwortung Ihres Schreibens vom 27. d.M. teilen wir Ihnen mit, dass der von Ihnen im Oktober v.J. unserem Garbekesselhaus angegliederte Elektrokessel bisher in ununterbrochenem Tag- und Nachtdienst zu unserer vollsten Zufriedenheit gearbeitet hat. Wir haben die Absicht, solange wir Strom zur Verfügung haben werden, mit dem Elektrokessel unsern Dampfverbrauch mitherzustellen.

Er hat die Aufgabe unsere mit Steinkohlen beheizten Steilrohrkessel zu entlasten mit ausserordentlicher Wirtschaftlichkeit und aller nur wünschbaren Betriebssicherheit dauernd erfüllt. Obgleich seine Nennleistung mit 8000 kg Stundenleistung bei 6000 KW. Stromaufnahme gewährleistet war, konnten wir vorübergehend bis auf 10000 kg gehen, ohne dass weder an der Schaltarmatur noch am Kessel selbst sich die geringste Störung zeigte.

Besonders befriedigte uns der Kessel inbezug auf die Speisewasser- Beschaffenheit. Es liegt in der Eigenart unseres Betriebes, dass wir grosse Menge Kondensat zur Verfügung haben, dass in dem Wasser aber manchmal u.zw. vorübergehend Spuren von Zucker auftreten können. Während in den kohlengeheizten Kesseln der Kesselinhalt in einem solchen Ausnahmefall unverzüglich behandelt werden muss, reagiert der Elektrodenkessel in einer betriebsgünstigen Weise durch Senkung der Stromaufnahme, ohne dass die Verdampfungsleistung sich verändert.

Der Elektrodenkessel kann dank seinen sehr gut durchgearbeiteten Kontroll- und Regelapparaten hinsichtlich Dampfspannung, Verdampfungsleistung und Stromverbrauch sich vollkommen selbst überlassen bleiben, gelegentliche Kontrollbesuche eines Aufsichtsorganes vorbehalten.

Unser Personal hat sich mit dem Kessel sehr schnell vertraut gemacht, was hervorgehoben werden muss, weil dieser Kessel der erste elektrisch geheizte Dampfkessel in unseren Anlagen ist. Die Sauberkeit der Elektrodenkessel- Anlage, ihre Geruchlosigkeit, der Wegfall jeden An- und Abtransportes von Heizmaterial und dessen Rückstände, sowie der hohe Nutzeffekt von 97- 99 % macht den Elektrodenkessel zum idealen stationären Dampferzeuger. Nach dem Vorstehenden brauchen wir seine Empfehlenswürdigkeit nicht noch besonders zu erwähnen.

Hochachtend:
Zuckerfabrik & Raffinerie Aarberg A.G.

42215

BROWN BOVERI DESIGN
RELIABLE - ECONOMICAL - STRONG

Translation of the above letter from:—

Zuckerfabrik & Raffinerie Aarberg A. G.

Aarberg (Switzerland), 29th Jan., 1936.

To Brown, Boveri & Co., Ltd.,
Berne Office.

Re:— Electric-boiler plant.

Dear Sirs,

In reply to your letter of the 27th inst., we beg to inform you that the electric boiler built by you, and installed in our boiler house, has been in continuous day and night operation since it was put in and has given us entire satisfaction. It is our intention to cover our steam consumption by means of steam generated in the electric boiler, as long as we have electric power available.

The duty of the electric boiler is to take over part of the load from our inclined-tube, coal-fired boiler, and it has done so with great economy and perfect reliability. Although its rated output is 8000 kg of steam per hour with a power input of 6000 kW, we are able to get 10 000 kg of steam per hour from it, for short intervals, without in any way damaging the electric equipment or the boiler proper.

The boiler is particularly satisfactory because of the quality of feed water available. The nature of the process work produces a big quantity of condensate, but the water often contains traces of sugar. While, with the coal-fired boiler, we are obliged to treat the boiler filling without loss of time when the said traces became apparent, the electric boiler reacts in a way which does not affect the service of the plant, namely by a slight drop in the power input without its efficiency as a steam generator being impared.

The electric boiler can be left quite to itself, thanks to the thoroughly reliable control and regulating apparatus acting on steam pressure, evaporation output, and current consumption. All that is required is an occasional inspection by a skilled operator.

Our personel got familiar with the boiler in a very short time, and this should be stressed, because this is the first electric boiler to be put into our works. The cleanliness in operation, noiselessness, elimination of any conveyance, to and fro, of fuel and its waste products combined with the high efficiency attained of 97—99% all go to make the electric boiler an ideal stationary type of steam generator. The above appreciation should suffice, without further words, to prove what a recommendable type of apparatus it is.

Yours faithfully,
Zuckerfabrik & Raffinerie Aarberg A. G.

THE BROWN BOVERI REVIEW

THE HOUSE JOURNAL OF BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND)

VOL. XXIII — APRIL, 1936 — No. 4

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BROWN BOVERI TURBO-COMPRESSORS[1] IN MARINE AND HARBOUR INSTALLATIONS.

Decimal index 621. 635. 5 : 629. 12.

INTRODUCTION.

THE utilization and latest designs of Brown Boveri turbo-compressors on board ship and in harbour installations will be considered, namely:—

(1) Turbo-blowers for scavenging and charging Diesel engines.

(2) Turbo-blowers for boiler plants.

(3) Turbo-compressors as heat pumps in evaporating and refrigerating plants.

(4) Turbo-blowers for emptying ballast tanks in submarines and for ships with activated stabilizing tanks.

(5) Turbo-blowers for pneumatic conveying plants.

To begin with, a number of characteristic properties of turbo-compressors will be recalled, as these have to be taken into account when an installation is made with these machines.

I. FUNDAMENTAL CONSIDERATIONS.

This heading includes single or multi-stage, centrifugal or axial blowers and compressors. They may be designated as *flow compressors* in opposition to the *positive-displacement compressors* (e. g. reciprocating, rotary, Roots compressors).

It is essential that the operating characteristics of turbo-compressors should be clearly understood if they are to be properly utilized. Experience shows time and again, however, that a considerable amount of misapprehension still exists in this respect, and that much too little attention is paid to the properties of turbo-compressors in so far as they differ from those of reciprocating machines[2].

In particular, the following points should be exactly known:—

(a) Limitations, i. e. within what pressure and volume limits are turbo-compressors an economical proposition.

(b) Influence of the resistance of the system on the operation of turbo-compressors.

(c) The fundamental advantages of turbo over reciprocating compressors.

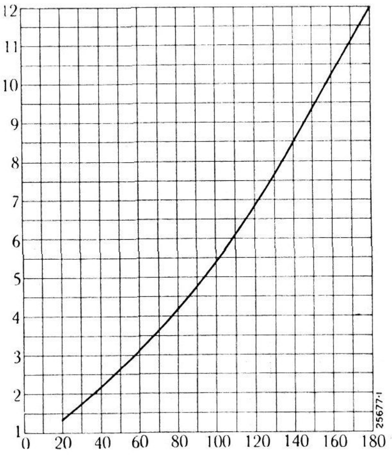

Fig. 1. — Smallest indrawn volumes in function of the pressure ratio for turbo-compressors for air under normal conditions.

Abscissæ: volume of indrawn volume of air in m³/min at 15° C, 1·0 kg/cm² abs, specific weight $\gamma = 1{\cdot}185$ kg/m³.

Ordinates: Pressure ratio (delivery to inlet pressure). With gases other than air or for other suction conditions, account must be taken of the differences of the specific weight.

Example: superheated steam having a specific weight $\gamma_{steam} = 0{\cdot}45$ kg/m³ is to be compressed from 1·0 to 4·0 kg/cm² abs. Pressure ratio $\frac{p_e}{p_a} = 4{\cdot}0$, $Q/_{min}$ for air $= 76$ m³/min. The ratio $\frac{\gamma_{air}}{\gamma_{steam}} = \frac{1{\cdot}185}{0{\cdot}45} = 2{\cdot}65$. Hence, the smallest volume for steam under the conditions considered is $76 \times 2{\cdot}65 = 200$ m³/min.

(a) *Limitations of turbo-compressors.*—Turbo-compressors are inherently suitable for delivering or compressing relatively large volumes under moderate pressure ratios. The greater the pressure ratio (i. e. ratio between pressure after and before compression) the greater becomes the smallest volume for which it is still possible to construct a turbo-compressor. Fig. 1 shows, for different pressure ratios, the smallest volumes for which it is advisable to build these machines under normal conditions. It is evident that exceptional cases can arise, for which they can be employed with advantage for still smaller volumes, e. g. whenever oil contamination must be avoided, or very little space is available, etc. It must not be overlooked, however, that the power consumption of a turbo-compressor is then less advantageous than that of a positive-displacement compressor.

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[1] The term turbo-compressor is utilized here in its widest sense, and refers to all possible pressure conditions.

[2] The complete theory of turbo-compressors has appeared in a number of publications, one of the best of these being the series of articles in French or German which were published in the Revue BBC or BBC Mitteilungen in 1919 and 1920.

The pressure ratio which can be produced by a single impeller is generally dependent on the maximum permissible peripheral speed, which is limited by the allowable stresses in the materials employed. As a general rule, peripheral speeds of 250—275 metres per second are not exceeded except for quite exceptional conditions, such as ballast-tank blowers for sub-marines, for instance, where peripheral speeds as high as 350 metres per second have been reached. This means that with air at 15° C and 1·0 kg/cm^2 absolute (specific weight 1·185 kg/m^3), and a good compressor efficiency, the corresponding pressure ratio will not exceed 1·3—1·4 under normal, and about 2 under exceptional conditions. With specially-designed rotors with radial impellers for charging airplane engines, pressure ratios exceeding 2 have been obtained per impeller. Furthermore, this pressure ratio increases with the density of the gas handled, i. e. it increases as the temperature becomes lower.

To obtain a high pressure ratio a number of impellers must be necessarily connected in series. When the number of impellers becomes considerable, considerations due to the critical speed of the shaft, render unavoidable the multiplication of the number of cylinders (Fig. 2). As a general rule, turbo-compressors are seldom employed for pressure ratios exceeding approximately 10, because the volume of air or gas, particularly in the last stages, becomes too small. Nevertheless, turbo-compressors have been built for pressure ratios of 20 and more.

(b) *Influence of the resistance of the system on the operation of turbo-compressors.*—It is essential that whenever a turbo-compressor is contemplated, the exact resistance characteristics of the system on which it will have to work should be known. The resistance or back-pressure characteristic of a system is neither more nor less than a pressure-volume curve, just like the pressure volume characteristics of a turbo-compressor; it shows for any indrawn volume the static pressure necessary to force this volume through the system on to which the turbo-compressor has to work.

It sometimes happens that complaints are made after a turbo-compressor has been installed that it does not produce the pressures and volumes for which it has been ordered. This is due to the overlooking of the fact that a turbo-compressor only delivers the volume stipulated under the required pressure when the back-pressure of the system on to which it operates exactly corresponds to the figure given for the volume when it was ordered. The right thing to do would be if those passing a contract always indicated the pressure-volume (back-pressure) characteristic of the system, just as the compressor builder supplies the pressure-volume characteristics of the machine which he measures on his test bed. If these two characteristics are drawn on the same scale on a common diagram, their intersection will show the exact conditions under which the turbo-compressor will operate on the system (Figs. 4 and 5).

It may be recalled that the back-pressure characteristics of a system can fall under three headings, namely:—

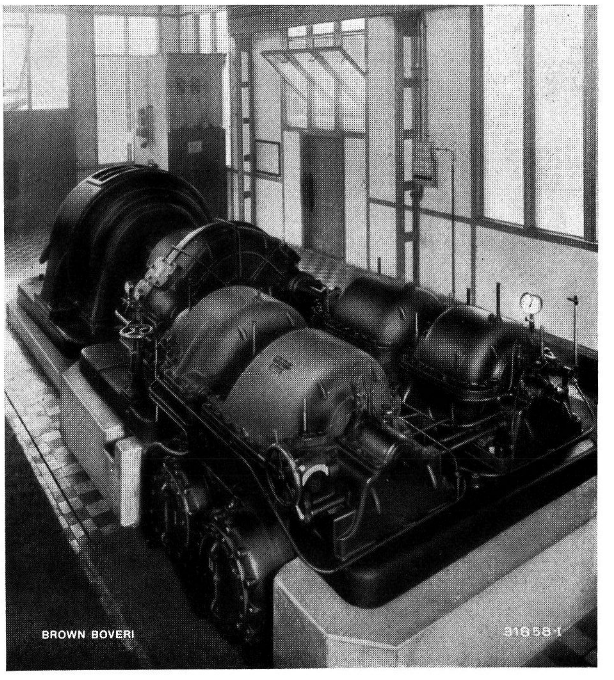


Fig. 2. — Brown Boveri two-cylinder turbo-compressor for high efficiencies and large regulation range, for supplying compressed air in shipyards.

The compressor is designed for 200 m^3/min indrawn air, pressure ratio 8, speed 8400 r. p. m., driven by three-phase motor over gearing having a ratio of 8400/1000 r. p. m.

The compressor has 13 stages, and is provided with movable diffusers and external intercooling. The 13 stages are distributed over a h.-p. and a l.-p. cylinder, which can run at different speeds, in a similar manner to marine turbines, in order to obtain best efficiencies, Brown Boveri also constructs single-cylinder turbo-compressors for these conditions, having only 9 stages but a somewhat lower efficiency.

1. *Dynamic resistances,* also called hydraulic resistances (Fig. 3 a). With given, invariable cross sections, they increase approximately proportionally to the square of the volume, and consist essentially of the resistance to flow in the pipework, losses in apparatus and valves, losses due to bends, etc. An example of this form of resistance is afforded by a scavenging or charging turbo-blower, which forces air through a Diesel engine followed by an exhaust silencer or waste-heat boiler. A system of this description could be replaced by a constant-section contraction orifice: for this reason, the turbo-compressor is said to operate against a constant opening in such cases.

2. *Static resistances,* which are independent of the volume (Fig. 3 b). An example is afforded when

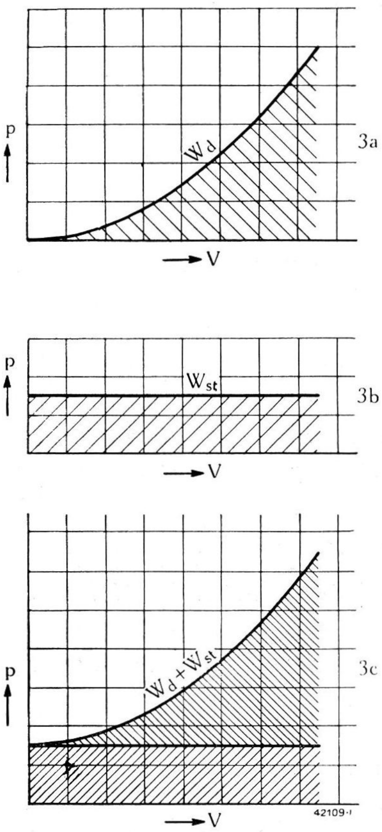


Fig. 3. — Different kinds of system resistances.

3a. Dynamic or hydraulic resistance, W_d (operation against a constant aperture).
3b. Constant, static resistance, W_{st}.
3c. Combined static and dynamic resistance, $W_d + W_{st}$.

The resistance characteristic (W_d, W_{st} or $W_d + W_{st}$) gives for different volumes V, what pressures p are necessary to force these volumes V through the system.

a gas has to be forced through a constant head of liquid. Pure static resistances do not occur in practice but only:—

3. *Combined static and dynamic resistances* (Fig. 3 c), which are obtained when the two forms of resistance just mentioned are present simultaneously. They can occur, for instance, for scavenging turbo-blowers on board submarines when the Diesel engine exhausts under water, so that the exhaust gases have to overcome, in addition to the dynamic resistance of the system, an additional back pressure due to the head of water.

If the resistance of the system undergoes a change during operation, the volume delivered by the turbo-compressor will also undergo a corresponding variation, constant speed being assumed. An example taken from practice illustrates this point:—

Complaints were made that, on board a ship, turbo-blowers supplied gave less and less air as the duration of the voyage increased, until finally very bad combustion occurred in the Diesel engines. At first sight, the fault lay with the scavenging turbo-blowers, which gave less air than the quantity for which they were ordered. A closer examination showed, however, that the exhaust ports of the Diesel engines and the silencers in the exhaust mains got more and more choked up during the voyage with solid residues, which, evidently, caused the resistance of the system to increase, day by day. Consequently, the operating point on the pressure-volume curve moved more and more to the left, so that it is understandable that with time the turbo-blowers necessarily delivered less air (Fig. 4).

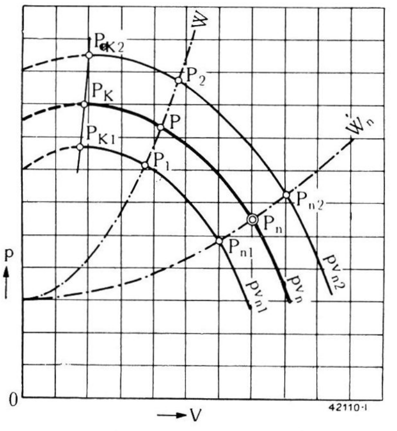


Fig. 4. — Influence of the resistance of the system on the operating point of a turbo-compressor.

pv_n, pv_{n1}, pv_{n2}. Pressure volume characteristic of a turbo-compressor at normal speed n, and at fractional and overload speeds n_1 and n_2.
W_n. Normal resistance characteristic of system.
W. Increased resistance of system.
P_n, P_{n1}, P_{n2}. Operating points with normal resistance of system and the different blower speeds.
P, P_1, P_2. Ditto, but with increased resistance of system.
P_k, P_{k1}, P_{k2}. Pumping limit of turbo-compressor.
V. Volume (abscissae).
p. Pressure (ordinates).

Another similar case occurred on board a ship when a spark arrestor with quite an appreciable resistance was subsequently fitted into the exhaust mains. Here again, the resistance of the system was increased, whereby the volume of air delivered by the turbo-blower was diminished. The best way to counteract resistance variations of this description is to alter the speed of the turbo-blower. Consequently, motors driving turbo-blowers should be liberally dimensioned both with respect to output and to speed range.

Whilst discussing this subject, it will not be out of place to examine, with the aid of an example, how turbo and reciprocating blowers behave under similar circumstances (Fig. 5). Let W_n be the resistance curve assumed by the purchasers: the blower would be dimensioned accordingly for the normal operating point Pn; pv_n is the pressure-volume characteristic of the turbo-blower at normal speed, and pv_{nk} the corresponding characteristic of the reciprocating blower. It subsequently turned out, that the resistance of the system was in reality much larger than assumed. It corresponded to curve W_b, and the amount of air required was v_b under a pressure p_b (operating point P_b). With constant speed, C will be the operating point of the turbo-blower, i. e. the intersection of its pressure volume characteristic pv_n with the real resistance curve W_b of the system. For the reciprocating blower on the other hand, the operating point will be B. The turbo-blower delivers, therefore, less air than required, and it produces insufficient pressure. Due to its almost vertical pressure-volume characteristics, the reciprocating compressor can overcome without difficulty the increased resistance, but under certain circumstances the pressure at B may be dangerously high. For this reason reciprocating compressors have to be always provided with pressure-relieving devices. At all events, both

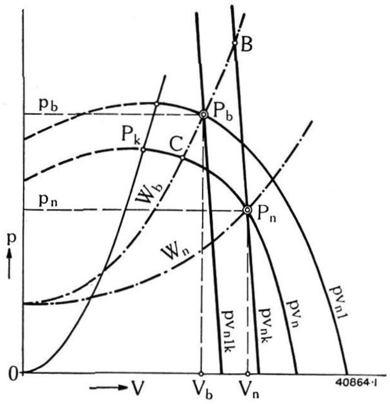


Fig. 5. — Comparison of the behaviour of a turbo-compressor and a reciprocating compressor when the resistance of the system changes.

W_n. Computated resistance of system.
W_b. Resistance subsequently obtained in reality.
P_n (p_n, V_n). Point for which the compressor was determined.
P_b (p_b, V_b). Real operating point.
pv_n, pv_{n1}. Pressure-volume characteristics of turbo-compressor at speeds n and n_1.
pv_{nk}, pv_{n1k}. Ditto for reciprocating compressor.
P_k. Pumping limit of turbo-compressor.

the pressure and volume at B are higher than necessary, with the result that the power consumption of the reciprocating compressor has an extremely prejudicial effect on the overall efficiency of the plant. In order to obtain operating conditions corresponding to point P_b, the speed of the turbo-compressor must be increased (pressure-volume characteristic pv_{nl}), whereas that of the reciprocating compressor must be reduced (curve pv_{nlk}).

This example also serves to recall a very valuable property of turbo-compressors, namely that they can never produce excessive pressures—as it is the case with reciprocating compressors — and consequently do not require any safety devices in this connection.

(c) *Inherent advantages of turbo-compressors over reciprocating compressors.* — Although these advantages are generally known, they can be briefly summarized as follows:—

1. *Considerably smaller dimensions and weight.* Both of these factors are very important on board ship. Due to the continuous acceleration and retardation of the masses, mean piston speeds do not exceed 10 m/s with reciprocating compressors, whereas with turbo-compressors peripheral speeds up to 275 m/s (in exceptional cases even up to 350 m/s) can be allowed. Turbo-compressors are, therefore, particularly advantageous as regards weight and dimensions when large volumes have to be compressed to low pressures. It must also not be overlooked that the prime movers for turbo-compressors are as a general rule, smaller, lighter and cheaper than those for reciprocating compressors.

2. *Great reliability* due to the much more simple design — no rubbing glands but only labyrinth glands, no valves and valve gear, no rubbing parts, consequently no internal lubricated parts in the air path.

3. *Air uncontaminated with oil and reduced oil consumption.*

4. *Minimum attendance and practically no upkeep expenses,* because no parts are exposed to wear.

5. *Vibrationless operation,* consequently light foundations and continuous delivery of air.

With regard to the *power consumption,* the turbo-compressor is, when under favourable conditions — i. e. large volumes and moderate pressure ratios — better or, at least, as good as a reciprocating compressor. Even when it is less advantageous as regards power consumption, preference is given to the turbo-compressor in a great many cases due to its valuable advantages.

II. UTILIZATION OF BROWN BOVERI TURBO-COMPRESSORS IN MARINE AND HARBOUR PLANTS.

1. *Scavenging turbo-blowers for two-stroke marine Diesel engines.*

The use of turbo-blowers to supply scavenging air for two-stroke Diesel engines was originally advocated by Brown Boveri in 1915—16, and the first firm to adopt this idea was Messrs. Sulzer Bros. of Winterthur (Switzerland). The initial installations were on board submarines; later on, after the war, they were also employed for merchant vessels (MS "Handicap" in 1921).[1]

The supply of air for scavenging two-cycle Diesel engines can be obtained either by positive-displacement blowers of the reciprocating or rotary type, driven off the main engines, or by independent turbo-blowers.

In addition to the general advantages already alluded to, the turbo-blower has for this application the following advantages:—

(a) Simplified layout of the main Diesel engine; the whole output becomes available for propulsion.

(b) Possibility of adjusting the volume and pressure of the scavenging air in a very economical manner to the momentary load of the Diesel engine. The resistance characteristic of a Diesel engine is

[1] For full particulars regarding the development of Brown Boveri scavenging turbo-blowers see publication 792 E "Centrifugal scavenging blowers for two cycle marine Diesel engines" as well as The Brown Boveri Review of 1927, p. 51 "New motor ships equipped with Brown Boveri turbo-blowers for scavenging and supercharging". Further particulars have also appeared in periodic articles regarding installations carried out, appearing in The Brown Boveri Review in 1925, 1928, 1929, and 1935.

purely dynamic: under these conditions varying the speed of the turbo-blowers affords the most logical and efficient method of regulation.

(c) As the turbo-blowers are independent of the main engines and require moreover very little space, they can be often installed in subsidiary compartments, which ensures a better overall utilization of the space available. It may be recalled at this juncture that quite a number of large Brown Boveri scavenging turbo-blowers are even placed athwartships, and in no single instance after many years operation have any bearing troubles occured due to gyroscopic action.

The following arguments have been advanced by the advocates of built-on reciprocating scavenging pumps:[1]

(d) The complete installation is more simple and requires less supervision, because the Diesel engine forms a single, self-contained unit (this argument applies evidently to a certain extent to single-screw cargo vessels).

(e) Smaller overall fuel consumption, because the electrical drive of the turbo-blower entails approximately 15 % energy losses in the dynamo and electric motor.

(f) Smaller electrical generating plant, and consequently slightly lower initial outlay.

With regard to point (d) it may be added that this advantage no longer applies to Diesel engines for large outputs. For these, the reciprocating scavenging pump assumes unwieldy proportions unless a subdivision over several cylinders is resorted to. At all events, driving the scavenging pump by the main motor means an additional complication — e. g. lengthening the crankshaft with additional cranks, drive by levers from the main connecting rods, or by chains from the main shaft — which is all the less desirable the greater the Diesel engine output. Furthermore, with a large Diesel engine, which is utilized to its fullest extent, quite an appreciable output is taken up for driving the scavenging pump off the main shaft which output is no longer available for propulsion. All these considerations show that, at least for Diesel engines of larger outputs, the adoption of independent turbo-blowers is fully justified, both on the grounds of design and operation.

Coming now to points (e) and (f) it may be pointed out that so far, the use of direct-current turbo-motors for electrical drives of scavenging blowers has predominated. This does not necessarily imply an appreciable increase in the size of the electrical generating plant, particularly for those installations where all auxiliaries are already driven electrically, in accordance with the most modern practice for both cargo and passenger vessels. With an electrical drive, transmission losses of approximately 15 % cannot be avoided between the auxiliary Diesel engine and the scavenging blower. In reality, however, the greater part of these losses are recuperated by the more efficient adaptation of the turbo-blower to the momentary demands for scavenging air of the main Diesel engine. In order to obviate these losses, large scavenging blowers have been driven recently by their own auxiliary Diesel engines; high-speed, four-cycle engines, with exhaust-gas turbo-charging blowers being particularly suitable for this purpose.

Under these conditions, the consumption of fuel for scavenging is, at all events, no higher than with a built-on reciprocating pump. Fig. 6 shows a scavenging turbo-blower of this description, driven by an auxiliary Diesel engine. While the blower set shown can be taken as an example that separate scavenging blower sets with auxiliary Diesel drive can be used for relatively small two-cycle Diesel engines, it should be said that such scavenging sets have been chiefly utilized, on recent years for marine Diesel engines of very big outputs. In such cases the driving power for the scavenging blower can attain 1000 H.P. and more and it is understandable that, particularly, with such big units, direct drive by an auxiliary Diesel engine is especially advantageous.

Another economical form of drive is by a steam turbine fed from a waste-heat boiler through which flows the exhaust from the Diesel engine, provided of course, that no appreciable amount of additional firing is necessary. Such steam-driven scavenging turbo-blowers have been recently used as stand-by or to supplement the built-on scavenging pumps. Fig. 7 shows a stand-by scavenging turbo-blower, driven by a steam turbine for the new Diesel-engine plant of the M. S. "Vulcania", which is equipped with two double-acting two-stroke Fiat Diesel engines, each for 13,000 H.P.

A continuous rise in the scavenging pressure has taken place during recent years. For many years the scavenging pressure remained around 1200 mm w. g., and pressures lower than 1000 mm w. g. were often sufficient; much higher values are now required, which vary from 1600 to 2400 mm w. g. for merchant vessels, and can be as high as 4500 mm w. g.

[1] See Schor: — "Spülluftgebläse oder angehängte Spülluftpumpe?", Werft, Reederei, Hafen, 1929, p. 131.

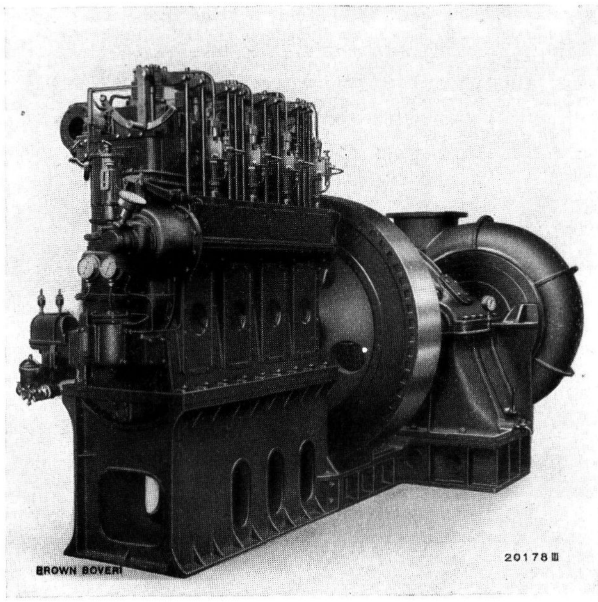


Fig. 6. — Brown Boveri scavenging turbo-blower, driven by an auxiliary Diesel engine over gearing.

The Diesel engine runs at 500 r.p.m. and the blower at 3600 r.p.m. Between both units a reduction gear is lodged. To compensate the fluctuations in torque of the driving Diesel engine the big gear wheel has an oscillation-damping spring device.

for warships. This rise may be attributed in part to the increasing use of double acting engines; furthermore, in addition to scavenging a certain amount of charging is attempted. Finally, the resistance is still further increased by waste-heat boilers, which have been employed more and more frequently of late. The pressures required can be produced by single-stage blowers, unless other considerations, such as the limitation of the speed which cannot be avoided with direct drives by electric motors render a two-stage turbo-blower compulsory.

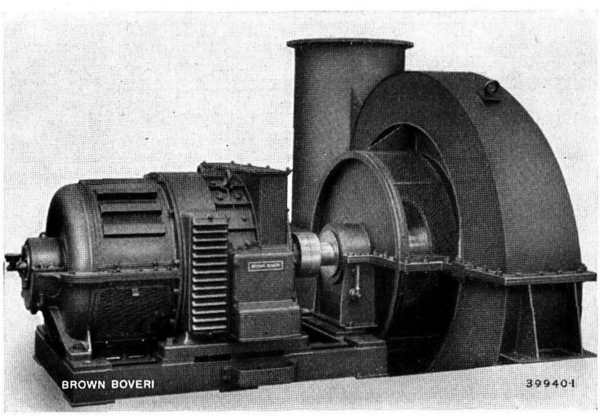


Fig. 8. — Scavenging turbo-blower set, driven by D. C. motor for the motor liner "Saturnia", which is equipped with Sulzer double-acting, two-stroke Diesel engines 2 × 13,000 B.H.P., built by the Cantieri Riuniti dell'Adriatico, Trieste.

Volume of indrawn air 1800 m³/min, delivery pressure 1800 mm w. g., 2350 r. p. m., 700 kW power input at motor terminals.

Examples of recent installations with motor-driven, scavenging turbo-blowers are afforded by the Cross-Channel motor ship "Prince Baudouin" [1] and the rebuilt liner "Saturnia", the former Diesel engines of which have been replaced by double-acting Sulzer two-stroke engines for 2 × 13 000 H.P. Scavenging air is supplied by three turbo-blowers, of which two are in operation together. Each turbo-blower handles 1800 m^3/min under 1800 mm w. g. scavenging pressure, the corresponding speed being 2350 r. p. m. The power input at the motor terminals then amounts to 700 kW (220 V, 3180 A), the D. C. turbo-motors being the largest that have ever been built. Another notable feature is that these scavenging blower sets are placed athwart-ship. This large amount of scavenging air is drawn directly through the complete engine room to ensure thorough ventilation and cooling of same.

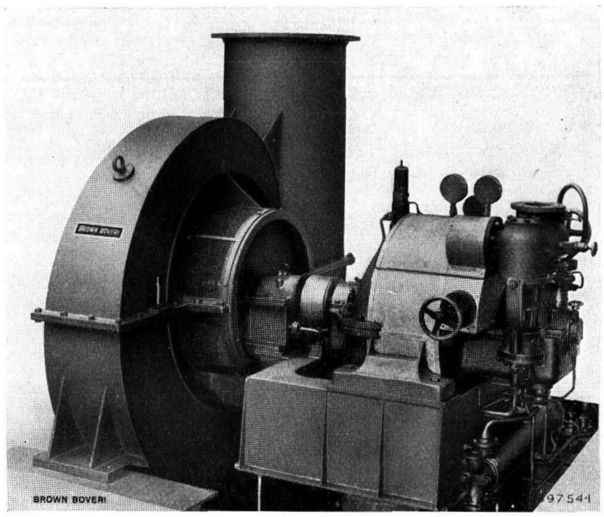


Fig. 7. — Scavenging turbo-blower set with steam turbine drive (steam from waste-heat boilers), for the motor liner "Vulcania", which is equipped with Fiat double-acting, two-stroke Diesel engines, 2 × 13,000 B.H.P.

Volume of indrawn air 1200 m³/min, delivery pressure 2600 mm w. g., 4400 r. p. m., 620 kW power input.

Up to the end of 1935, 265 Brown Boveri scavenging turbo-blowers, with an aggregate volume of indrawn air of 186,700 m^3/min have been supplied. Taking a mean demand of 0·14 m^3/min of scavenging air per B.H.P., it will be seen that the total Diesel output of 1·33 million B. H. P. is scavenged by Brown Boveri turbo-blowers. The mean volume per turbo-blower is 700 m^3/min to which corresponds 5000 B.H.P. Diesel engine output.

[1] A detailed description of the scavenging turbo-plant for this ship appeared in the Brown Boveri Review No. 4, 1935, p. 96.

2. *Exhaust-gas turbine-driven charging turbo-blowers for raising the output of marine Diesel engines.*

Charging four-cycle Diesel engines represents a more recent application for turbo-blowers than scavenging. Its development has been greatly furthered by the researches of Mr. Alfred Büchi, dipl. engineer, in Winterthur and by Brown Boveri. At the present time, there are practically no four-cycle engines which do not utilize some form of charging or after charging. Charging according to the Büchi system possesses the following advantages over methods which have been subsequently evolved:—

(a) Greater efficiency because the energy necessary for driving the blower is obtained from the exhaust gases, the useful heat of which can be still further recuperated after the turbine in waste heat boilers.

(b) The design of the Diesel engine requires no modification whatsoever, because the blower set runs as an independent unit, and may be said to form part of the exhaust mains. For this reason, charging according to the Büchi system can be very easily added to existing Diesel engines.

In a comparative study [1] based on first-hand experience on a large number of existing machines charged according to various systems, Dr. Pflaum, chief engineer of the MAN Augsburg Works, comes to the following conclusions:—

(a) Exhaust gas turbo-charging according to the Büchi system gives the best results with regard to fuel consumption, this advantage being the more pronounced the more the output is raised.

(b) By subdividing the exhaust mains in accordance with the Büchi process, an efficacious scavenging of the combustion space can be obtained, whilst the back-pressure conditions for the Diesel engine are so favourable that they cannot be surpassed by any other charging process.

(c) It is only when the power increase reaches 70 % that the same amount of heat is taken off in the cooling water of a Diesel engine charged according to the Büchi system as with an ordinary uncharged engine. This is due to the large amount of air for scavenging and to the greater amount of excess air at which these machines operate.

(d) It is invariably noticed that charged Diesel engines run more smoothly to the ear.

[1] Werft, Reederei, Hafen, Vol. 12, June 15, 1935 "Auflade-Dieselmaschinen u. Schiffantrieb" by Dr. Pflaum.

(e) Graphical research confirms that the bearing loads and torque diagram become more uniform with charging.

(f) Exhaust-gas charging enables the output to be increased with the smallest expenditure of weight. With a favourable arrangement of the charging set, practically no additional floor space is required.

It is, therefore, hardly surprising that leading Diesel engine builders all over the world are now employing exhaust gas turbo-charging according to the Büchi system, and that its use is becoming more and more widespread.

Recently, notable developments with Büchi charging have been taking place [1] which have enabled its use to be extended to small, high-speed Diesel engines. Until quite a short time ago an output as large as 400 B.H.P. was considered to represent the lowest limit for exhaust gas turbo-charging. Thanks to increased efficiencies of the turbo-blowers and exhaust-gas turbines, this limit has been now brought down to about 200 B.H.P., and an experimental plant for 100 B.H.P. is now under construction. Consequently exhaust-gas charging can be now applied not only to main propulsion engines, but also to the small auxiliary engines which are now used on board all ships for driving dynamos.

Single-stage turbo-blowers are employed for pressure ratios up to about 1·45, mean effective pressures around 10 kg/cm^2 being then obtainable. For greater pressure ratios, as come into consideration at high

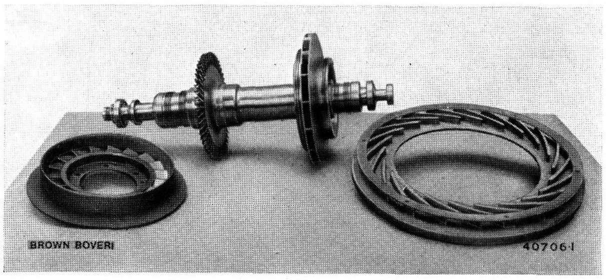


Fig. 9. — Parts of a Brown Boveri exhaust-gas charging turbo-blower.
Blower impeller. Turbine disc.
Diffuser. Turbine nozzle ring.

altitudes, two-stage turbo-blowers are necessary. Fig. 9 shows the moving and guiding parts of a charging turbo-blower set driven by exhaust-gas turbine, while Fig. 10 gives an idea of how the exhaust-gas turbo-set forms one with the Diesel engine, both as regards design and operation. Up to the end of 1935, Brown Boveri has supplied altogether 220 charging turbo-

[1] The Brown Boveri Review, 1935, No. 1/2, pp. 56—57; also year 1936, No. 1/2, pp. 17—18.

blower sets for an aggregate Diesel-engine output of 480,000 B.H.P; these figures including 128 sets for marine plants. These installations comprise the large liner "Reina del Pacifico" with a total engine output of

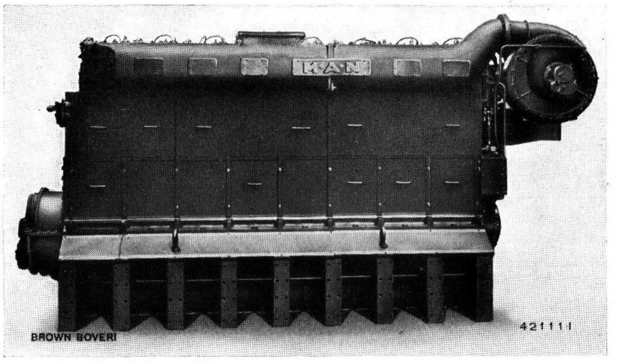


Fig. 10. — M. A. N. four-stroke marine Diesel engine with built-on Brown Boveri exhaust-gas charging turbo-blower for increasing the output according to the Büchi system. Continuous output 1400 H.P., 700 r. p. m., mean effective pressure 8·4 kg/cm².

22,000 B.H.P., as well as a large number of cargo and passenger ships, and of late an increasing number of submarines as well as other light ships for navies.

Now that charging four-cycle engines has become recognized practice, the charging of two-cycle engines is being tackled. Considerable possibilities are offered if the output of existing two-cycle marine Diesel engines can be raised, and in this connection, the most promising way to approach the problem appears to be according to the Brown Boveri-Curtis arrangement (Fig. 11), which consists of connecting a charging turbo-blower driven by an exhaust gas turbine in series with the existing scavenging blowers — which can be either built on pumps or electrically-driven turbo-blowers. In other words, the charging turbo-blower may be said to boost the existing scavenging blower.

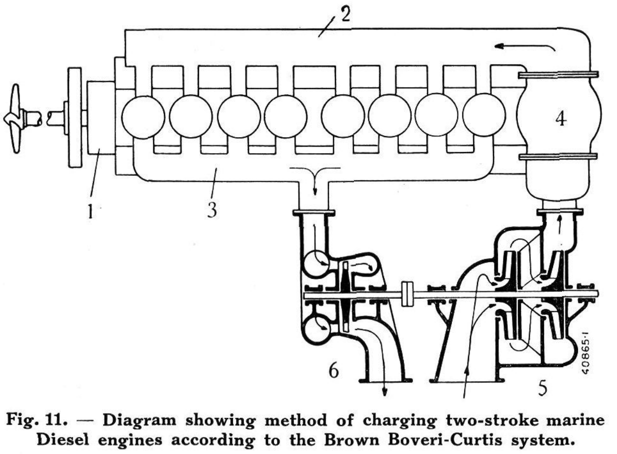


Fig. 11. — Diagram showing method of charging two-stroke marine Diesel engines according to the Brown Boveri-Curtis system.

The charging turbo-blower (5) is driven by an exhaust-gas turbine (6) and connected in series with the existing reciprocating scavenging pump (4), i. e. the scavenging pump is charged; (2) is the scavenging-air pipe, and (3) the exhaust-gas pipe.

3. *Turbo-blowers for marine boiler plants.*

The earliest application of turbo-compressors on board ship was for inducing combustion air, i. e. producing forced draught, because relatively large volumes of air have to be handled under low pressures, conditions for which reciprocating blowers are not suitable. The pressures coming into consideration, here, vary between approximately 40 mm w. g. for merchant vessels with Howden's system up to 300 mm w. g. for warships with closed stokeholds and oil firing. With Velox steam-generator plants on board warships, pressures up to 25,000 mm w. g. are actually reached. For the conditions first mentioned, even the centrifugal blower does not represent the most favourable solution, because with such small pressures it must run at low speeds if good efficiencies are to be obtained, with the result that its dimensions as well as those of its drive are liable to become unwieldy. In such cases *axial blowers* are more suitable. Fig. 12 shows the design of a single-stage vertical-shaft axial blower, driven by a steam turbine, for a warship boiler plant. Axial blowers are a new development and are derived from the aerodynamical theories developed in connection with airoplane wings. They are, therefore, typical flow machines, the air going through the blower axially. With single stage designs, the impeller has only a few vanes resembling propellers. Compression is produced by the impulse given to the air by the vanes, which impart an axial acceleration and a twist. The kinetic energy is then converted into

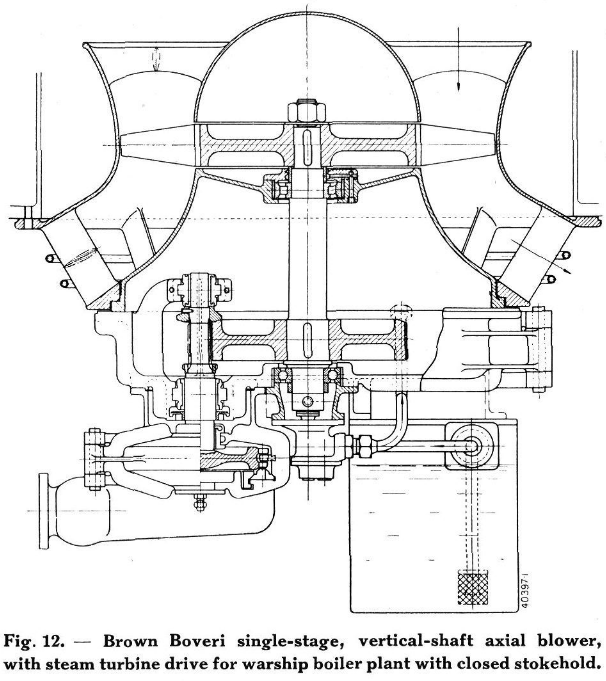


Fig. 12. — Brown Boveri single-stage, vertical-shaft axial blower, with steam turbine drive for warship boiler plant with closed stokehold.

pressure in the diffuser casing following the impeller. If, according to Keller[1], the term of speed coefficient for single stage axial blowers is defined as

$$\sigma = 2 \cdot 105 \cdot Q^{\frac{1}{2}} \left(\frac{\Delta p}{\varrho}\right)^{-\frac{3}{4}} \cdot n$$

where

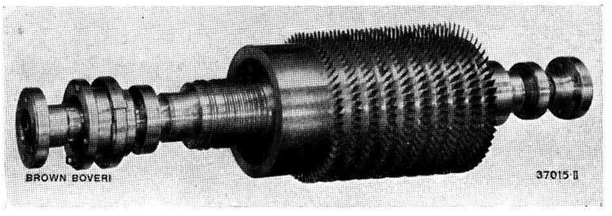
Q is the volume handled in m^3/s.

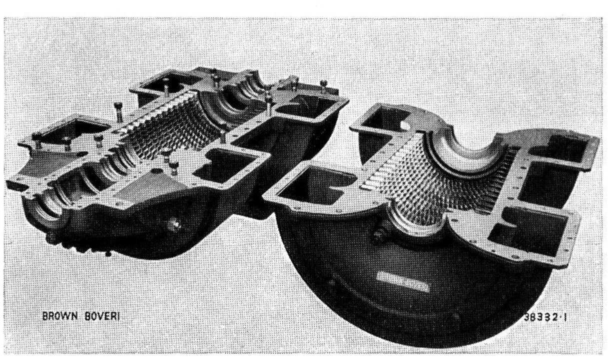
Δp is the static pressure rise in the blower in kg/m^2.

ϱ is the gas density in $kg \cdot s^2 \cdot m^{-4}$.

n = number of revolutions per second.

Then the speed coefficient for ordinary centrifugal fans amounts to 0·2—0·5, whereas for axial blowers the corresponding figures are 0·5—4. It will be seen, therefore, that the latter may be immediately classed as high-speed machines. They are consequently smaller and lighter than centrifugal compressors and can be frequently coupled directly to high-speed drives. The pressure-volume curve of axial compressors is steeper than that of centrifugal compressors and





Figs. 13a and 13b. — Rotor and casing of a Brown Boveri multi-stage axial compressor.

The compressor is for charging a Velox steam generator, and is driven by a gas turbine.

the pumping limit is somewhat less favourable, i. e. closer to the operating point having best efficiency, which incidentally can amount to 80% and more notwithstanding the high speed coefficient. Due to their characteristics, axial blowers are only suitable for applications where the resistance of the system is purely dynamical (delivery against an invariable aperture), as is precisely the case in marine boiler plants.

Figs. 13a and 13b show the rotor and casing of a multi-stage axial compressor as used for Velox steam generators, which, it may be recalled, are fired under pressures of 2·5—3·5 kg/cm^2, and have been already adopted in a number of instances for ships. Externally, an axial compressor bears a close resemblance to a reaction turbine, except that the flow takes place in opposite directions. Parsons attempted to build multi-stage axial blowers as long ago as 1903. It was, however, only on the basis of recent aerodynamical research that suitable blade profiles could be evolved. Brown Boveri can undoubtedly claim the distinction of having been the first to construct a serviceable axial compressor.

4. *The turbo-compressor as a steam compressor and heat pump on board ship.*

Yet another application of the turbo-compressor on board ship is afforded by heat pumps in evaporating and refrigerating plants. According to the second law of thermodynamics, heat cannot flow without expenditure of energy from a lower to a higher temperature state. Consequently if heat (energy) is available under a low temperature, it can only be utilized if energy is expended to pump it to a higher temperature state — hence the term heat pump — and it is then allowed to give up work by an energy drop to the ambient conditions.

With an evaporator as shown in Fig. 14, the heat pump enables the steam given off to be utilized for heating the solution, in that its latent heat is pumped to a higher temperature level, and is thus employed usefully instead of being thrown away in a condenser. In this manner, evaporation can take place without drawing to any appreciable extent on an external source of heat. If there were no heat losses ($Q_v = 0$) and if the heat exchanging surfaces of the evaporator were infinitely great (te = ta), it would be possible to keep the evaporator going without any addition of heat, once started up. However, as such conditions cannot be realized in practice, heat has to be added from an external source:— in the present case it is in the equivalent form of mechanical energy expended to drive the heat pump which serves to create the temperature difference necessary for heating, i. e. Qv + Qa = AL. The use of heat pumps in evaporator plants is recommended only if no possibility exists for utilizing in another manner the latent heat of the steam given off.

[1] Keller „Axialgebläse vom Standpunkt der Tragflügeltheorie". Communication by the Aerodynamical Institute of the Swiss Federal Institute of Technology, Zurich 1934.

Such possibilities are almost always available on board ships with steam plants, where the steam given off can be employed for heating feed water. Consequently there is no justification for a heat pump in such cases. On the other hand, it is conceivable that for large motor liners which require considerable quantities of fresh water, evaporators with heat pumps can represent quite an attractive proposition. As can be seen diagrammatically in Fig. 14, an installation of this description would be exceedingly simple. It would consist essentially of the evaporator proper, with preheater and turbo-compressor for steam, which has been assumed electrically driven and fed from a Diesel generating set on board. An evaporator of this

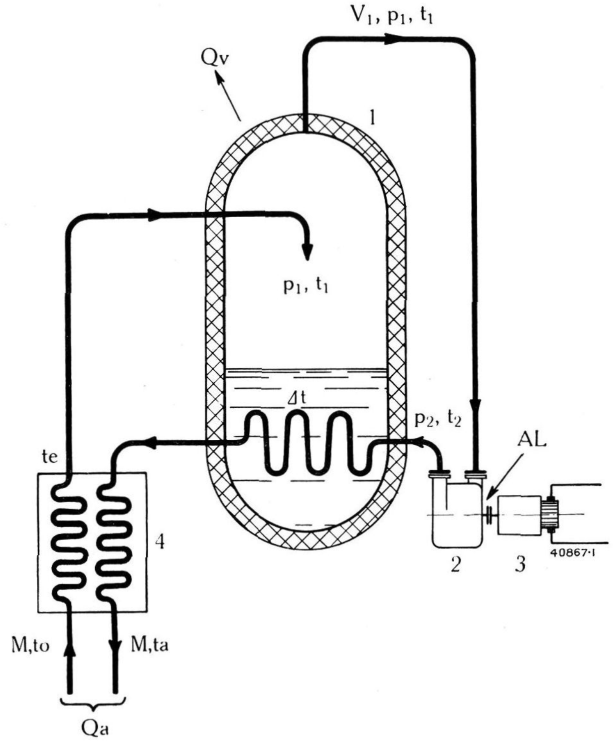


Fig. 14. — Diagram of a feed-water evaporator with heat pump.

1. Evaporator.
2. Turbo compressor for steam.
3. Driving motor.
4. Preheater for make-up water.

Q_a. Heat losses due to imperfect heat exchange.
O_v. Heat losses due to radiation and leakage.
AL. Heat addition by work of compression.

Example: Evaporator output: M = 80 tons per day = 3330 kg/h.

t_o. 20° C
t_e. 90° C
t_1. 101·7° C
Heat drop: t = 11° C
t_a 40° C.
Q_a. 66,600 kcal/h.
A_L. 82,000 kcal/h.

t_2. 112·7° C
p_1. 1·1 kg/cm² abs
p_2. 1·6 kg/cm² abs
$\frac{p_2}{p_1} = 1{\cdot}46$
V_1. 86·5 m³/min.
L. 95·5 kW.

Three-stage blower, approximately 12,000 r. p. m.

Fuel-heat consumption for evaporating 1 kg of make-up water:

$$\frac{95{\cdot}5 \times 860}{3330 \times \eta_d \times \eta_{el}} = \underline{83 \text{ kcal/kg.}}$$

of which approximately 25 kcal/kg are available for the evaporator, whereas the remainder is lost in the Diesel engine and electric transmission.
η_d. 0·37 % = Diesel-engine efficiency.
η_{el}. 0·81 % = Electrical-transmission efficiency between Diesel engine and steam compressor.

description would be operated preferably under pressures exceeding that of the atmosphere in order to eliminate difficulties due to air leaking in. The temperature difference in the evaporator between the heating steam — i. e. the steam given off after compression — and the sea water which has to be evaporated would have to amount to at least 10° C. However, the heat pump and particularly its motor should be so liberally dimensioned that they are capable of producing, if necessary, a greater temperature difference, so as to be able to cope with all contingencies (dirty heat exchanging surfaces, raised boiling temperatures with increased concentration, steam losses due to gland leakage and radiation). For the sea water to be evaporated, the warm water leaving the jackets of the Diesel-engine cylinders can be used to advantage. It is first of all preheated in a heat exchanger by the condensate from the evaporator. Fig. 14 contains figures based on conditions with an evaporator for 80 tons per day. The efficiency of this process must be obviously examined for each individual case.

Another form of heat pump is afforded by the *refrigerating machine.* In this case, heat is removed under a low temperature, and its state is raised until its temperature is higher than that of the cooling water, which carries its heat away. Up to the present, reciprocating compressors have been used as heat pumps in such cases, and ammonia (NH_3) or carbon dioxide (CO_2) as refrigerants. Without a doubt, for larger capacities exceeding 75,000 kcal/h or 25 tons ice capacity, turbo-compressors will prove in the future a serious competitor to reciprocating compressors, on account of the considerable advantages as regards space and operation afforded by the former. Fig. 15 gives an idea of the appearance of such a refrigerating plant: the turbo-compressor with its drive, together with the evaporator and condenser are united together to form a single closed unit, without any glands, which has been called Frigibloc, and which requires about one third of the space taken up by an ordinary refrigerating plant. The oil-free delivery of the refrigerant vapour by the turbo-compressor is of importance, because an oil film on the heat exchanging surfaces has a harmful influence on the heat transfer. The gas-tight casing prevents all loss of refrigerant. The refrigerants used are those haloid hydrocarbons, the vapours of which have a sufficiently large specific volume and a moderate pressure ratio — i. e. conditions which are favourable for turbo-compressors. The most suitable

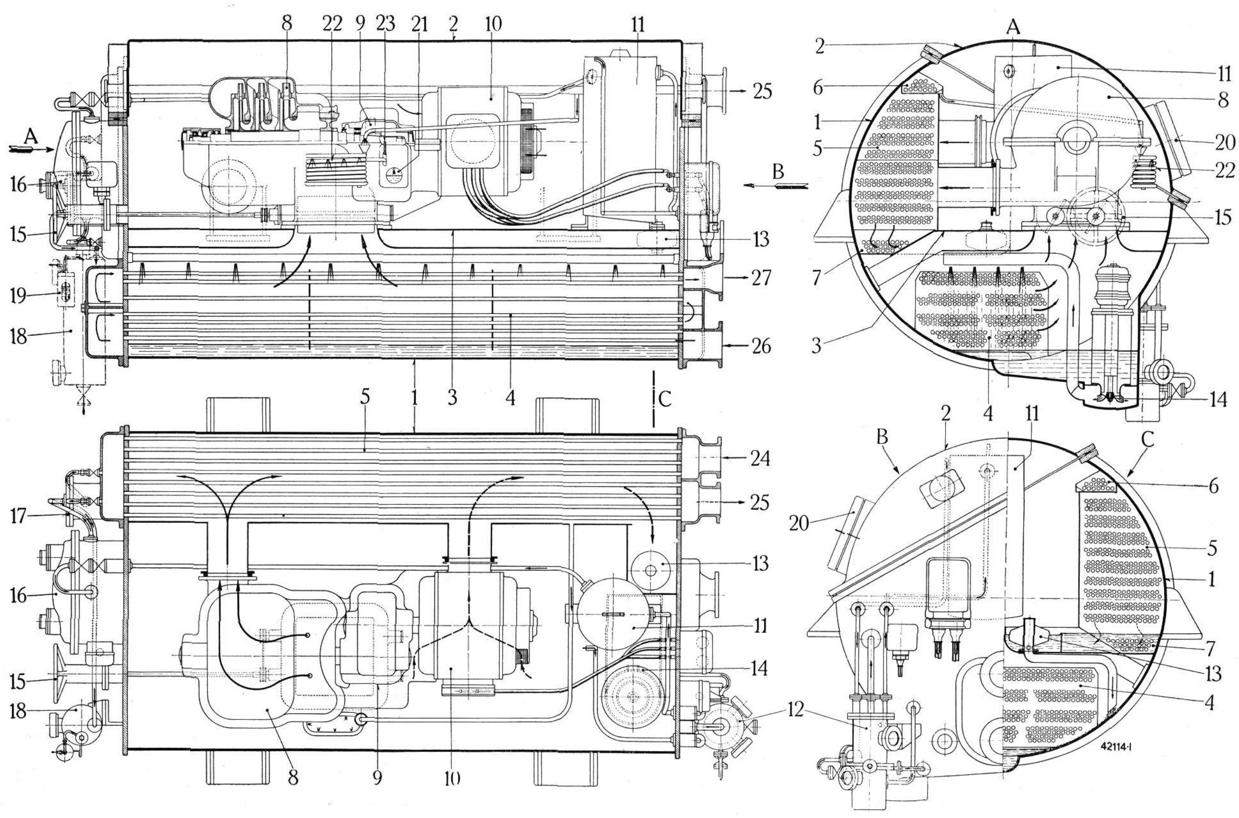


Fig. 15. — Brown Boveri Frigibloc as marine refrigerating unit.

1. Casing.
2. Cover.
3. Floor.
4. Evaporator.
5. Condenser.
6. Auxiliary condenser.
7. Undercooler.
8. Turbo-compressor.
9. Gearing.
10. Motor.
11. Air collector.
12. Water and air separator.
13. Float valve.
14. Circulating pump.
15. Drive of compressor suction throttle valve.
16. Vacuum pump.
17. Air after-cooler.
18. Container for 17.
19. Inspection glass.
20. Porthole.
21. Oil level.
22. Oil cooler.
23. Oil thermometer.
24. Cooling-water inlet.
25. Cooling-water outlet.
26. Brine inlet.
27. Brine outlet.

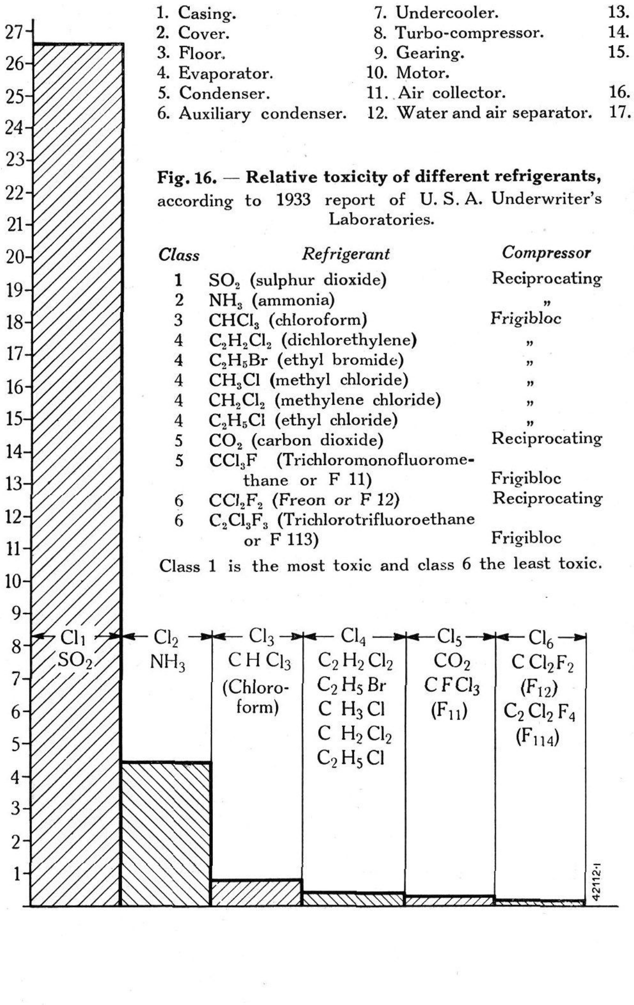


Fig. 16. — Relative toxicity of different refrigerants, according to 1933 report of U. S. A. Underwriter's Laboratories.

Class	*Refrigerant*	*Compressor*
1	SO_2 (sulphur dioxide)	Reciprocating
2	NH_3 (ammonia)	"
3	$CHCl_3$ (chloroform)	Frigibloc
4	$C_2H_2Cl_2$ (dichlorethylene)	"
4	C_2H_5Br (ethyl bromide)	"
4	CH_3Cl (methyl chloride)	"
4	CH_2Cl_2 (methylene chloride)	"
4	C_2H_5Cl (ethyl chloride)	"
5	CO_2 (carbon dioxide)	Reciprocating
5	CCl_3F (Trichloromonofluoromethane or F 11)	Frigibloc
6	CCl_2F_2 (Freon or F 12)	Reciprocating
6	$C_2Cl_3F_3$ (Trichlorotrifluoroethane or F 113)	Frigibloc

Class 1 is the most toxic and class 6 the least toxic.

refrigerants for use in Frigiblocs are methylene chloride ($CH_2\ Cl_2$), ethyl chloride ($C_2\ H_5\ Cl$), ethylene chloride ($C_2\ H_2\ Cl_2$), ethyl bromide ($C_2\ H_5\ Br$), as well as of a number of similar fluorine compounds, etc. Fig. 16 shows the relative degree of toxicity of various refrigerants, chloroform having been also included for comparison purposes. As will be seen, the new refrigerants as used in the Frigibloc, are less harmful than those commonly employed formerly. No refrigerant known is absolutely harmless (except water vapour), and it should, therefore, be the duty of every designer to strive to ensure that no leakage of refrigerant can occur. Whenever possible, refrigerants are adopted for Frigiblocs which have pressures lower than that of the atmosphere in the whole operating cycle. *Consequently no gas* can escape outwards, at the worst only air can penetrate in, and this can be effectively prevented by the simple hermetic seal adopted for the flanges of the casing. The new refrigerants are quite neutral as regards their chemical action on the materials employed, this applying in particular to motor insulating materials. Consequently the motors for driving the turbo-compressor as well as for auxiliary purposes can be all enclosed inside the Frigibloc, and be cooled with refrigerant vapours. On account of their simple and robust design, squirrel-cage induction motors are best suited for this purpose. In this manner all glands for moving parts can be done away with and the only external openings of the Frigibloc are for electric cable leads, and, in addition to these, the only external connections to the Frigibloc are for water and brine. It may be objected that up to the present, direct-current is employed almost exclusively for ships auxiliary drives. It may be safely asserted, however, that the advent of alternating current is only a question of time; in the meanwhile either a converter set must be resorted to, or, if a direct-current drive is adopted, the main motor must be located outside the Frigibloc, in a similar manner to that employed for steam turbines, and use be made of a gland. As the latter has to tighten only a supported shaft of small diameter, which is only subjected to torsional stresses, a reliable and simple design can be adopted. Finally, it may be mentioned that the Frigibloc forms a complete unit, which can be tested before leaving the works, and is erected as such on board ship. The power consumption of a Frigibloc for outputs exceeding 200,000 kcal/h is equal to or better than that of plants with reciprocating compressors, whereas for smaller outputs it is, on the other hand, slightly higher, which, however, is of no very great importance, as the magnitude of the excess should be around 5 kW for the smallest units, and 15 kW for the larger units under the most unfavourable conditions.

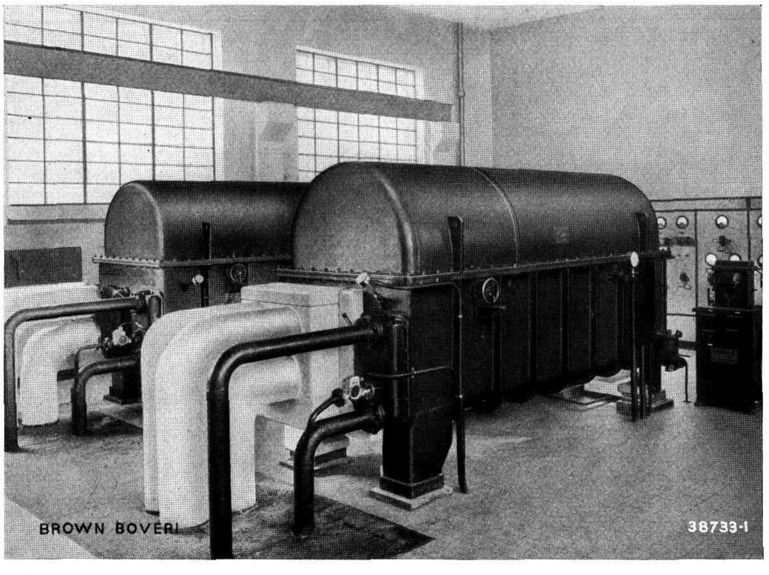


Fig. 17. — Two Frigiblocs each for 300,000 kcal/h for a slaughter house and fish freezing plant in Helsingfors harbour.

Each Frigibloc has two evaporators of which one supplies brine at − 15·5° C (60,000 kcal/h) and the other at −8° C (240,000 kcal/h.)

Fig. 17 shows an installation with two Frigiblocs for the slaughter house in Helsingfors harbour. The Frigiblocs run quite automatically, just like a household refrigerator. Besides the saving in weight and space already alluded to, as well as automatic operation, the Frigibloc is characterized in comparison with reciprocating machines by its silent and absolutely smooth running. It is also possible to subdivide a Frigibloc internally so that several evaporator temperatures can be obtained simultaneously, which is an advantage when there are a number of refrigerated rooms in which different temperatures are required. The two Frigiblocs in Helsingfors, for example, are designed in this manner; each has a double evaporator, of which one cools brine to −15·5° C and the other to −8° C.

In the United States, water vapour refrigerating machines have been recently revived. Water serves here as refrigerant, but such installations are only suitable for air-conditioning plants, due to water freezing when the temperature becomes lower than 0° C. However, air-conditioning plants will become in the future a necessity for ships which operate in the tropics. The difficulties which have to be overcome with water vapour as a refrigerant may be ascribed to the very low saturation pressures (about 0·02 kg/cm^2) at low temperatures, which occur concomitantly with very large specific volumes. Consequently, the turbo-compressors will have also very large dimensions, and will be accordingly expensive. The maintenance of very high vacua gives rise to very great difficulties, which must necessarily limit the scope of water-vapour refrigerating machines.

For conditioning plants, for dehumidifying and cooling air, the *Brown Boveri air expansion refrigerating machine*[1] should prove in certain cases attractive, as it requires no refrigerant whatsoever, the air itself undergoing the required temperature variations. Although the power input of such installations is higher

[1] Brown Boveri Review, 1930, volume 9, page 271, Ad. Baumann: "Cooling and drying air (air conditioning) with particular reference to the air expansion process".

than that of vapour-compression machines, they have over the latter the undisputed advantage of simplicity and absolute harmlessness. The process as such has been already used for years on board submarines. It

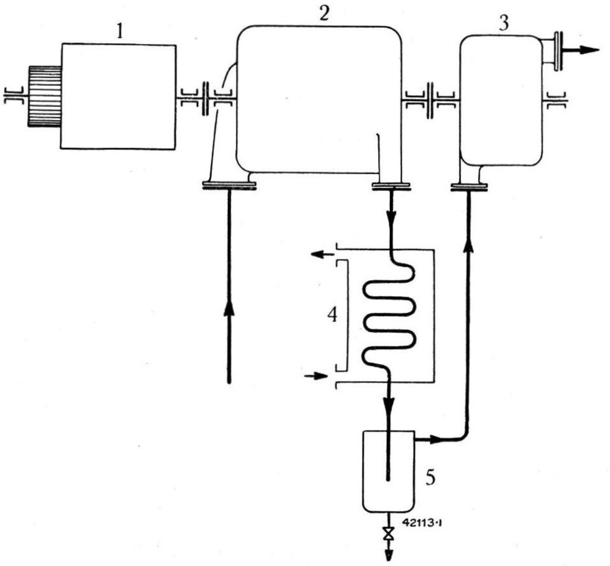


Fig. 18. — Diagram showing the operating principles of an air-conditioning (drying and cooling) plant according to the air-expansion process.

1. Driving motor. 2. Turbo-compressor. 3. Expansion turbine. 4. Air-cooler. 5. Water separator.

operates in principle in the following manner (Fig. 18): — the air to be treated is compressed first of all by a turbo-blower, then cooled by ordinary water in a surface cooler, and finally expanded in a turbine where the air gives up useful energy and is cooled at the same time to a temperature lower than that of the surrounding atmosphere. At the same time, the humidity in the air is precipitated as water (tests carried out on such an installation gave a water precipitation of 95 % of that theoretically possible).

For the sake of completeness, mention must be also made of the use of turbo-compressors on board ship for compressing steam, as adopted for instance for the Götaverken system for improving the efficiency of reciprocating steam engines. As with the Brown Boveri exhaust turbine system, the purpose of this arrangement is to make use in a turbine of the energy of exhaust steam from a reciprocating engine which would be otherwise lost due to incomplete expansion. With the Brown Boveri system, the mechanical energy recuperated is transmitted directly to the propeller shaft, whereas with the Götaverken system, the exhaust-steam turbine drives a steam compressor, and the recuperated energy is returned to the steam in the form of heat of compression[1]. Practically, this is carried out in such a manner, that the steam leaving the high-pressure cylinder is compressed before it enters the middle-pressure cylinder, and at the same time superheated by the work of compression. A condition sine qua non for the efficiency of this system, which is inherently lower than that of the Brown Boveri exhaust-steam turbine system owing to the numerous energy transformations, is that the steam to be compressed must be absolutely dry when it penetrates into the compressor, because otherwise if water is present, part of the energy recuperated is thrown away in the latent heat absorbed to re-evaporate water. A steam turbo-compressor with exhaust-steam turbine, as used for the Götaverken system, has great similarity with a Büchi charging turbo-blower with exhaust-gas turbine drive, even as far as the assembly with the steam turbine is concerned, so that one is tempted to speak of "exhaust-steam turbo-charging of reciprocating steam engines."

5. *The turbo-compressor as tank blower in submarines and in plants with activated stabilizing tanks.*

Fig. 19 shows a recent design of a diving-tank blower for submarines[2]. The design is interesting in so far that these blowers furnish an example of the

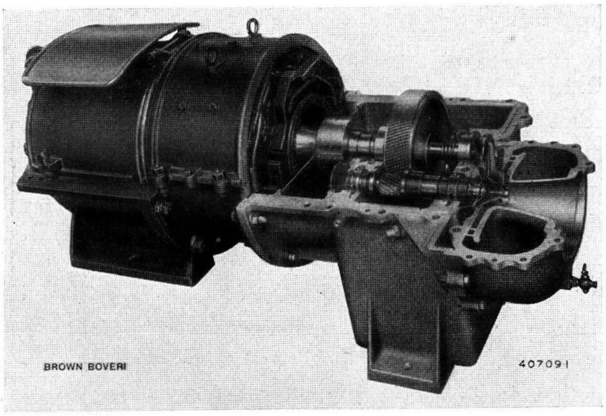


Fig. 19. — Brown Boveri submarine diving tank turbo-blower.

Volume of indrawn air 30 m^3/min.
Pressure ratio 1·8.
Speed 33,000 r. p. m. (peripheral speed 345 m/s).
Drive by D. C. turbo-motor for 5500 r. p. m. over gearing.

[1] The basic idea to connect a steam turbine after a reciprocating engine plant, and to couple the former with a steam compressor which takes steam from a place in the system ahead of the turbine and then returns it to the system after compression appears to have been originally propounded by B. Graemiger, Zürich (DRP 313842 of 22. IX. 1917).

[2] The purpose and method of operation of these blowers has been described in detail in The Brown Boveri Review, 1929, No. 12, p. 319 "Brown Boveri turbo-blowers on submarines".

extreme saving of weight and bulk obtainable. These blowers have to run for about only five minutes when the submarine emerges:— during the remainder of the time they remain idle. The smallest weight possible and extreme reduction in space taken up are consequently conditions which the designer of these blowers is compelled to meet. The turbo-blower shown is built to deliver 30 m^3/min of air under a pressure of 1·8 kg/cm^2 absolute: it runs at 33,000 r.p.m. to which corresponds a peripheral speed of approximately 350 m/s for the impeller. It will be noticed that the pressure is produced by only a single impeller, which is provided with open radial blades. For these high speeds, this impeller design must be necessarily adopted. Their efficiency is unfortunately somewhat lower than that of standard impellers with blades bent backwards, but in the present case the efficiency is a secondary consideration. The turbo-blower is driven by a direct-current turbo-motor running at 5500 r.p.m., over gearing. The turbo-blower almost vanishes when its size is compared to that of the gearing and motor. It is evident that extensive use is made of light-metal alloys for such blower sets. Quite a large number of these turbo-blowers have been supplied.

A similar application to that just examined is afforded by *stabilizing-tank blowers,* which are required in connection with the activated stabilizing tanks which have been introduced of late. As known, they serve to dampen the rolling motion of a ship. Whereas formerly the water level in these tanks was converted by natural means by the movement of the ship into oscillations, the movement of the masses of water has been more recently forcibly controlled. Compressed air is used for this purpose, which is produced by centrifugal blowers. The blower operates in such a manner that it is loaded and unloaded by rotary valves, located in the suction and delivery mains between the blower and stabilizing tanks. The movement of the masses of water in the tanks is controlled by alternatively drawing in air from one of them and raising the pressure in the other. Existing systems comprise those of Frahm (Blohm and Voss), SSW and Flamm, the first two having been already been installed and operated on board ships. The turbo-blowers used for these purpose are of single-stage design, electrically driven, and are similar to scavenging blowers also with respect to pressure and volume conditions.

6. *Turbo-blowers for pneumatic conveying plants.*

In conclusion, a brief description may be given of turbo-blowers for pneumatic conveyors[1]. In this

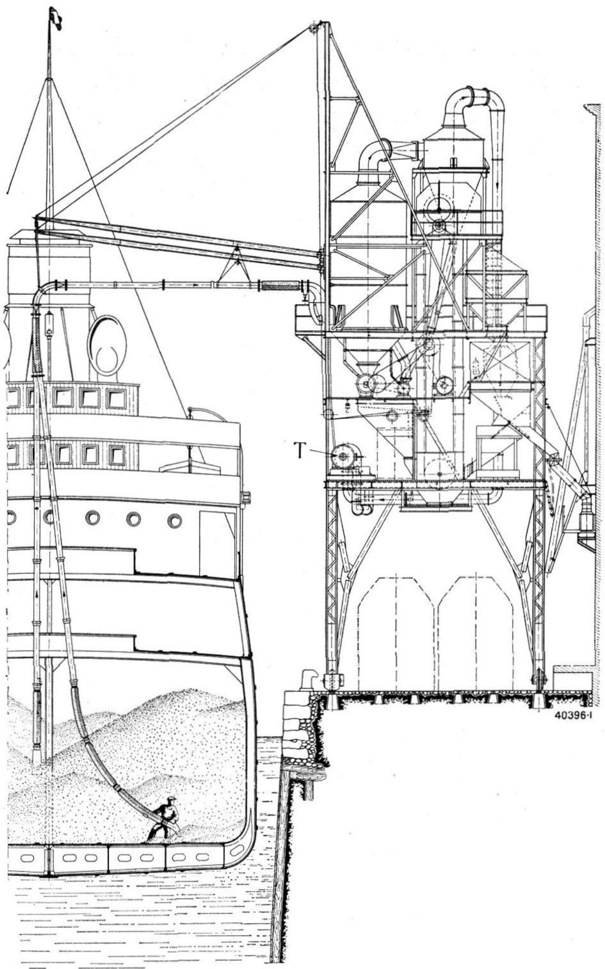


Fig. 20. — Arrangement of a mobile, pneumatic grain-conveying plant in the free port of Copenhagen for 220 tons per hour, by Bühler Brothers, Uzwil (Switzerland).

The air is exhausted by a Brown Boveri three-stage turbo-blower.

case, the blower operates as an exhauster, and evacuates air so as to obtain suction pressures of 0·4 to 0·5 kg/cm^2 abs, and thus produce a draught having velocities of 20—40 m/s, which carries along the granular material to be conveyed—e.g. grain, small pieces of coal, etc. The amount thus transported weighs approximately 10 to 15 times the weight of air exhausted. Reciprocating and Roots blowers are extensively used for this purpose, but in recent years turbo-blowers have found increasing favour. The Swiss firm of Bühler Brothers in Uzwil has to be credited with extensive pioneering work in this connection. Turbo-blowers are suitable for conveyor capacities exceeding 30 tons per hour. The property of the turbo-blower to ensure continuous delivery is particularly valuable here. In addition, the small space required and smooth

[1] Full details appeared in The Brown Boveri Review, 1926, No. 12, p. 289.

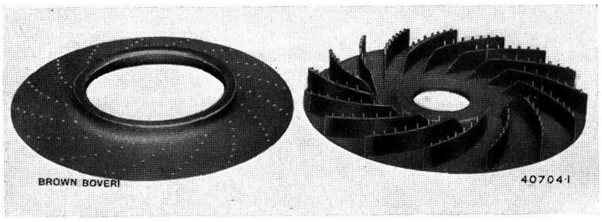


Fig. 21. — Impeller for a Brown Boveri turbo-compressor.
The rivets uniting the blades to the hub and covering discs are milled solid out of the blading material. There are consequently no rivets in the air passages exposed to erosion and corrosion. The air passages are perfectly smooth with no projecting rivet heads. The covering disc with inlet ring and the hub and hub disc are forged in one piece for highly-stressed impellers.

running are also precious properties. This accounts for the preference given to turbo-blowers for movable plants, as they can be mounted on same, whereas the large reciprocating pumps have to be installed as a general rule in a separate stationary machine house, which necessitates disconnecting the air piping whenever the conveyor moves away. Fig. 20 shows a recent installation having a capacity of 220 tons per hour installed by Messrs. Bühler in the free port of Copenhagen, use being made of a Brown Boveri turbo-blower. For reliable operation, no matter whether a reciprocating or turbo-blower comes into consideration, it is essential that adequate means should be taken to ensure dust precipitation before the blower, in order to avoid undue wear. For this purpose means are taken to ensure dust precipitation in the grain separator, and in addition, a cyclone for separating out the dust is fitted before the blower. It is very important to adopt impellers of substantial design, as shown for instance in Fig. 21. Alloy steel is used throughout and the rivets, machined solid out of the blades, bind these to the hub and coverning discs. No rivet heads are, therefore, exposed to erosion in the impeller passages, which are smooth and free from any obstructions.

(MS 944) *E. Klingelfuss. (D.M.)*

BROWN BOVERI A.C.-D.C. MUTATORS IN THE SERVICE OF THE CONSOLIDATED MINING & SMELTING COMPANY OF CANADA, LTD.

Decimal index 621. 314. 652. 2 : 621. 357.

THE Consolidated Mining & Smelting Company of Canada, Ltd. is one of the largest mining concerns and the largest producer of electrolytic zinc and lead in Canada. In 1928 the demand for zinc was such that the existing rotary converter equipment of the Company was being used to full capacity for the electrolytic production of zinc and cadmium. It, therefore, became necessary to install additional conversion equipment so as to be in a position to meet the increasing demands of the zinc market. An order was accordingly placed with Brown, Boveri & Co., Ltd., in December 1928 for mutator equipment. Three 10,000-A double mutator units, each of 5600 kW at 560 V, were installed giving a total D.C. output of 16,800 kW.

A description of this plant will be found in The Brown Boveri Review of October 1930, but it may be of interest here to recapitulate, briefly, the reasons which spoke in favour of the application of mutators as opposed to rotary converters:—

Small floor space.
Imperviousness to acid-laden gases and fumes.
Absence of commutators, slip-rings and windings requiring periodic cleaning.
Noiselessness.
Insensitivity to voltage fluctuations and frequency variations in the 60-kV primary supply line.
Absence of heavy foundations.

Fig. 1. — Zinc-plant substation.
In foreground, three double mutator units each for 5600 kW and, in background, ten rotaries each for 2500 kW.

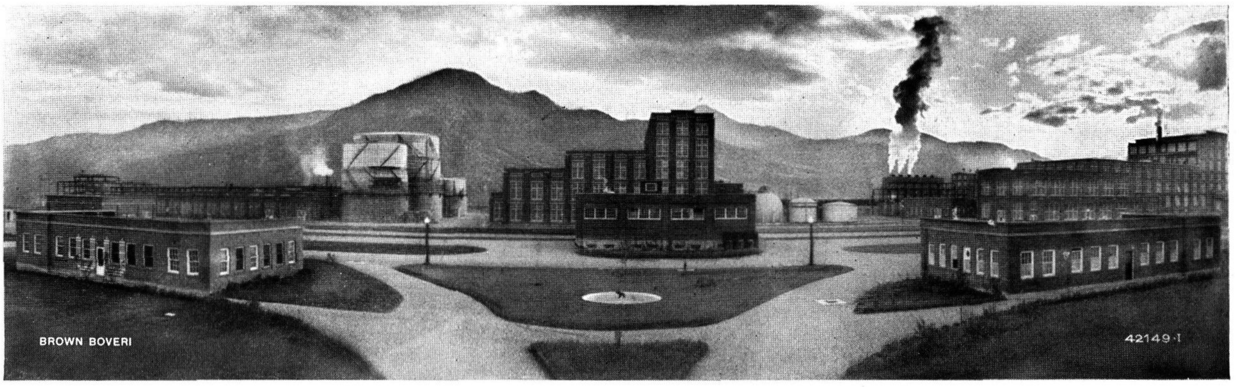


Fig. 2. — Consolidated Mining & Smelting Co. of Canada, Ltd. Warfield fertiliser plant.

A general view of the machine room of this plant is shown in Fig. 1.

In 1929, the Consolidated Mining & Smelting Company decided to undertake the manufacture of artificial fertiliser and proceded to build for this purpose its imposing Warfield plant, shown in Fig. 2. This plant is situated in the Rocky Mountains of Canada at an altitude of about 2200 ft. above sea level and is some two miles distant from the zinc and smelting plant previously referred to in this article.

The artificial fertilisers produced by the Consolidated Mining & Smelting Company are ammonium sulphate, ammonium phosphate and triple superphosphate. The ammonia required for this purpose is obtained by the combination of nitrogen and hydrogen, in the presence of a catalyst, the nitrogen being produced by the liquefaction of air and the hydrogen by the electrolytic decomposition of water in cells. The sulphuric acid is obtained from the main smelting plant where it is recovered from the smoke-stacks as a by-product, while phosphate rock, for the manufacture of phosphates, is imported.

The direct current necessary for the electrolytic production of hydrogen from water is supplied by mutators at a D.C. voltage of 670 V. When deciding to employ mutators for this purpose the engineers of the Consolidated Mining & Smelting Company were not only influenced by the advantages previously cited but also took into consideration the high efficiency of mutators at 670 V and the impossibility of the mutator polarity becoming reversed during service. This latter feature, which is inherent to mutators, is of inestimable value in a hydrogen plant as it eliminates the danger of hydrogen being generated at the anodes of the electrolytic cells, instead of at the cathodes, and hence removes the danger of an explosive mixture being formed in the storage tanks.

The mutator equipment for the Warfield plant was ordered in July 1929, and comprised a total D.C. output of 20,100 kW. This output is supplied by three 10,000-A double mutator units, each of 6700 kW at 670 V, of which one was manufactured by the General Electric Company and two by Brown, Boveri & Co., Ltd. Part of the mutator room is shown in Fig. 3, the two General Electric mutators being visible in the background and three of the four Brown Boveri mutators being visible in the foreground.

Energy for the supply of the Warfield substation is, as in the case of the zinc plant substation, taken from the West Kootenay Light & Power Co.'s network at 60,000 V, 60 cycles per second. In the zinc plant regulation of the D.C. voltage between 460 and 560 V is performed by varying the voltage fed to the mutators by on-load tap-changers. For this purpose, the 60,000-V supply is stepped down to 13,200 V at which voltage tap-changing is effected. In the Warfield plant, however, tap-changing is effected in regulating transformers at 60,000 V without resort to a step-down of the voltage. The D.C. voltage of each double mutator unit is regulated in this way to suit the requirements of the cell room between 600 and 670 V, the D.C. current

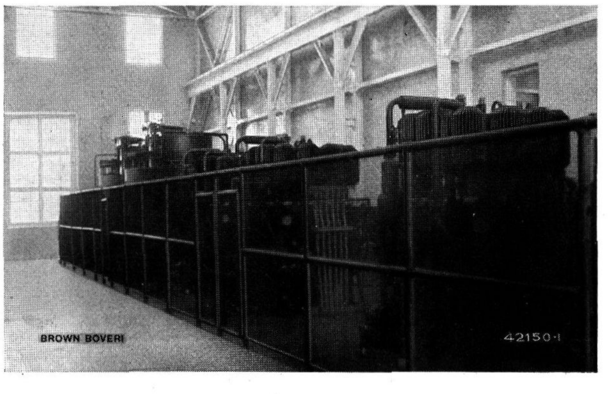


Fig. 3. — Part of Warfield mutator substation 1930,
showing, in background, two General Electric mutators each 3350 kW, and, in foreground, three Brown Boveri mutators each 3350 kW.

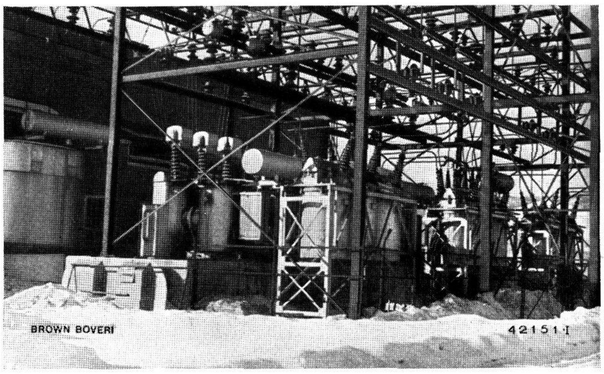


Fig. 4. — Warfield open air substation — 1930,
showing, in foreground, General Electric oil circuit breakers, one Brown Boveri regulating transformer and, in background, one Brown Boveri mutator transformer.

remaining constant at 10,000 A over this range. One of the Brown Boveri regulating transformers with built-on 60-kV tap-changer is shown in Fig. 4. A 60-kV mutator transformer, in series with the regulating transformer, is to be seen on the left.

In 1935 the Consolidated Mining & Smelting Company decided to increase their production of fertiliser, and required for this purpose approximately 16,600 kW of additional direct-current power. This will be supplied by two 10,000-A Brown Boveri double mutator units, each supplying 8300 kW at 830 V. The order for this equipment was placed on the first of July 1935 for delivery within four months ex works for the first unit, five months being allowed for the second unit. Special workshop organisation was necessitated to ensure manufacture of units of this size within such extremely short periods; the first unit was ready for shipment on time on the first of October 1935 and the second unit was completed two weeks ahead of time.

Each unit comprises, in the main, a bank of oil circuit breakers, a regulating transformer, a mutator transformer, two mutators, two high and one slow-speed D.C. breakers, two D.C. smoothing coils and one switchboard.

The oil circuit breakers, shown in Fig. 5 consist of three outdoor single-pole breakers per bank with a guaranteed rupturing capacity of $1^1/_2$ million kVA at 60,000 V, 60 cycles per second. In order to avoid all danger of bushing flash-overs due to lightning, dust or other deposits, the bushings are designed for a rated voltage of 87,000 V although the service voltage only attains 60,000 V. An interesting feature of these bushings, provided at the express wish of the West Kootenay Light & Power Co., is a suction device enabling oil to be withdrawn from the lower end of the bushings without in any way disturbing the oil in the breaker. The breaker tanks and control pedestals are equipped with resistance heaters thereby ensuring service in the winter months when temperatures down to and below minus 30 ° C are liable to occur.

The 60,000-V regulating transformers with built-on tap-changers vary under load the voltage fed to the mutator transformers, thereby varying the D. C. voltage furnished by the mutators. A D.C. range of 740 to 830 V at 10,000 A is required for operation of the cells. The regulating transformers have been designed to cover this range in 36 steps under the assumption that the line voltage remains within the limits of 59,000 and 61,000 V. This is normally the case but the current carrying capacity of the transformers is such that, even if the line voltage should sink to 54,600 V, it is still possible—by using the 54,600-V tap on the mutator transformer, to maintain and regulate the D.C. voltage between 740 and 830 V under 10,000 A load. The regulating transformers, as may be seen, are of the self-cooled, outdoor type and here again 87 kV bushings and tap changers have been provided as a precautionary measure.

The mutator transformers, on account of their design and size, are a noteworthy feature of the plant. Each transformer feeds two mutators and forms with them a double mutator unit of 8300 kW D. C. output; the mean transformer capacity required for this output is 11,400 kVA, which represents in itself a substantial unit. The size of the transformer is, however, considerably greater than that of a three-phase transformer of the same capacity on account of the requirements of mutator service. The secondary winding of the transformer is connected in six phase and from this

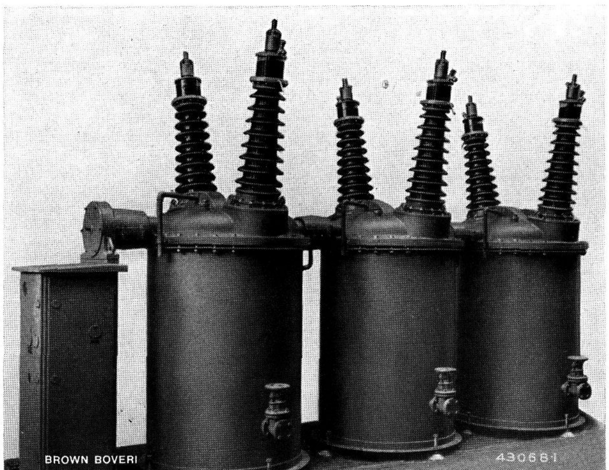


Fig. 5. — Three single-pole oil circuit breakers, rated voltage 87,000 V, service voltage 60,000 V, rupturing capacity $1^1/_2$ mill. kVA.

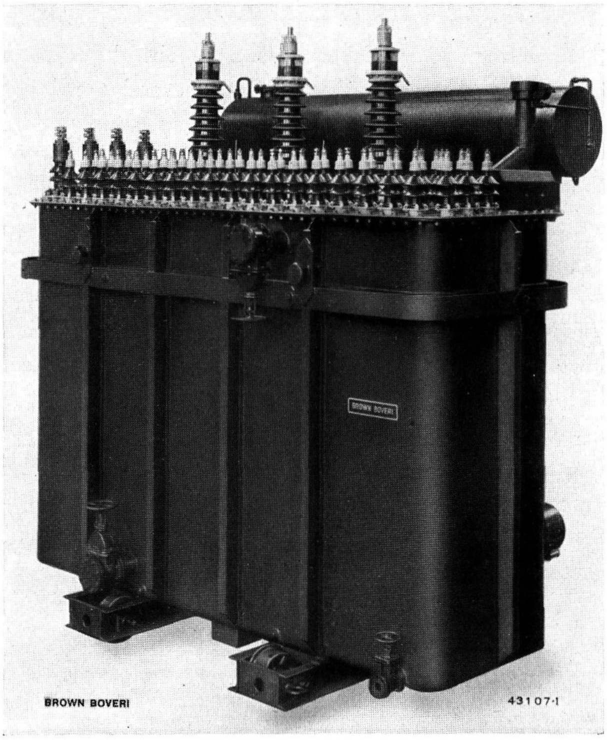


Fig. 6. — 60,000-V mutator transformer with built-in interphase reactor and anode choke coils for feeding 8300-kW double mutator unit.

winding leads are taken through anode choke coils to the 36 secondary terminals; these, in turn, are connected to the pair of 18 anode mutators fed by the transformer. The neutral points of the two component stars of the six-phase winding are joined through the interphase reactor, the middle point of which forms the 10,000-A negative pole of the double mutator unit. The 36 secondary terminals are clearly visible in Fig. 6, which shows, on the left, the four parallel terminals for connection to the 10,000 A busbar.

The mutator transformers, each of which, with oil, weighs thirty-three tons, are cooled by oil, circulated through a small pump set to a counter-flow water cooler and back to the transformer. The interphase reactor and anode choke coils are incorporated in the transformer tank so as to eliminate unnecessary bushings, tanks and cabling and are thus cooled with the main transformer.

The primary windings of the Brown Boveri mutator transformers supplied to Warfield in 1930 are connected in delta whereas the primary windings of the new transformers shown in Fig. 6 are connected in star. The latter connections were especially chosen so that the combination of the delta and star-connected transformers would reduce the 5th, 7th, 17th, 19th, etc. (series) harmonic currents which would otherwise flow in the primary network as a result of six-phase mutator operation. In this way, the advantages of twelve phase operation are attained whilst maintaining, on the other hand, the advantage of simple and robust six-phase transformer design. In order to prevent the star-connected transformers from creating third harmonics in the primary supply voltage, a small delta-connected tertiary winding is provided.

The four mutators installed in the Warfield extension are of the latest design in every respect. In this connection it is interesting to note the progress made in recent years in heavy-current mutator design. For purposes of comparison, the mutator supplied in 1929 to the zinc plant is shown in Fig. 7, the mutator supplied in 1930 to the Warfield Plant is shown in Fig. 8, whilst Fig. 9 shows the 1935 mutator execution for the extension of the Warfield Plant. A cursory glance, bearing in mind the outputs dealt with by the different mutators, suffices to reveal the great progress which has been made.

The mutators are equipped with grid control for protection against backfires and external short circuits. Grid voltage control is also provided enabling the voltage while starting the cells to be raised gradually from zero to full voltage; current surges are, thus, eliminated. Regulation of the voltage between 740 and 830 V is usually carried out by the regulating transformer as a better power factor and a smaller ripple in the D. C. are obtained by this method than

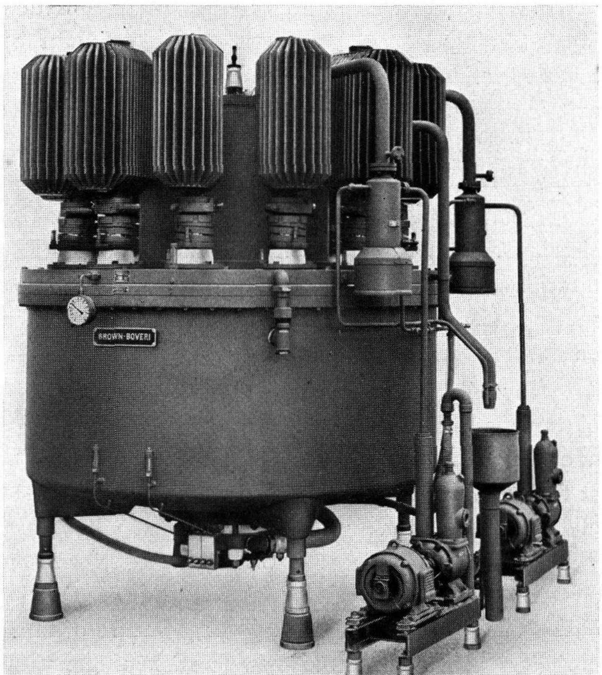


Fig. 7. — Zinc plant mutator, 2800 kW — 1929 design.

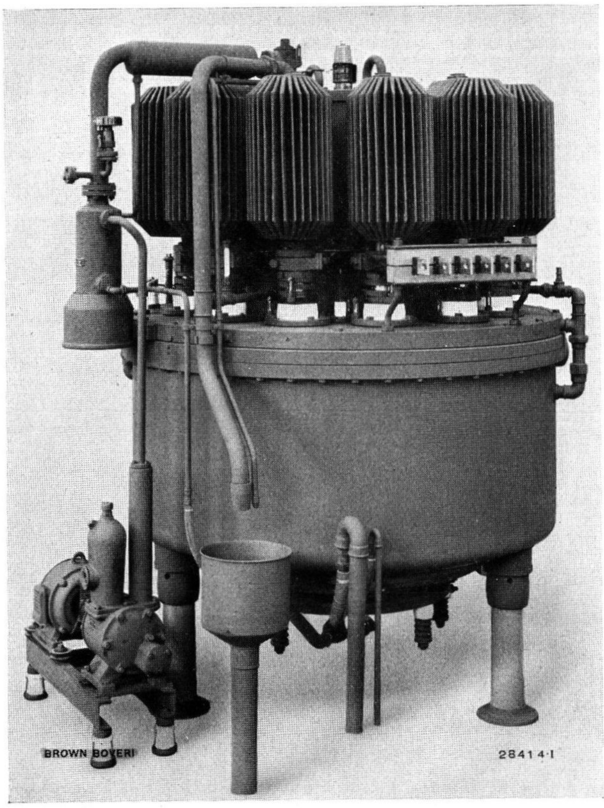


Fig. 8. — Warfield mutator, 3350 kW — 1930 design.

by grid voltage control. The grid control equipment is, however, designed to cope with continuous regulation of the voltage between 740 and 830 V, thereby presenting a valuable standby for the regulating transformers with built-on tap-changers.

Cooling of the mutators, like that of the transformers, is effected by circulating the water of the mutator cooling jackets through a counterflow cooler forming part of a totally enclosed system thereby completely eliminating the possibility of impurities coming continuously into contact with the cooled surfaces of the mutators. Formation of deposits on the cooling surfaces is thus prevented and corrosion reduced to a minimum. The mutators are cooled in tandem, one cooler sufficing for a double mutator unit. The counterflow coolers are alive as they are connected with the mutators through the circulating-water piping. The coolers are, therefore, mounted on insulators and fresh water is lead to them through insulating rubber piping. Any corrosion which may take place will, thus, occur in the coolers and not in the mutators. A zinc plate is installed in each cooler and acts as a "corrosion electrode"; this plate can easily be replaced from time to time if necessary.

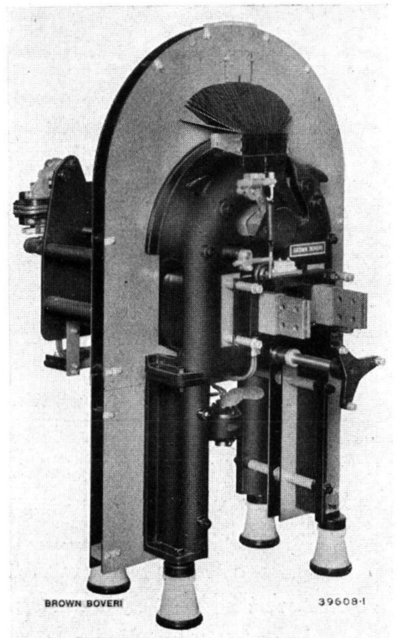


Fig. 10. — High-speed circuit breaker, rated current 6400 A.

The design of modern heavy-current mutators is such that backfires are an extremely rare occurrence. It is, nevertheless, necessary to provide high-speed D. C. breakers to protect the mutators from the effects of the heavy reverse currents which would flow from the electrolytic cells during a backfire. It is estimated that this reverse current would attain about 35,000 A and it is evident that a direct current of this magnitude could work havoc unless cut off in the shortest possible time. Fig. 10 shows the high-speed breaker which affords the requisite protection. The second mutator of the double mutator unit would feed a heavy current into the backfiring mutator but this current is immediately cut off by the grid relay which applies negative potential to the grids.

At this juncture, mention may be made that, in the plants supplied in 1929 and 1930, insufficient

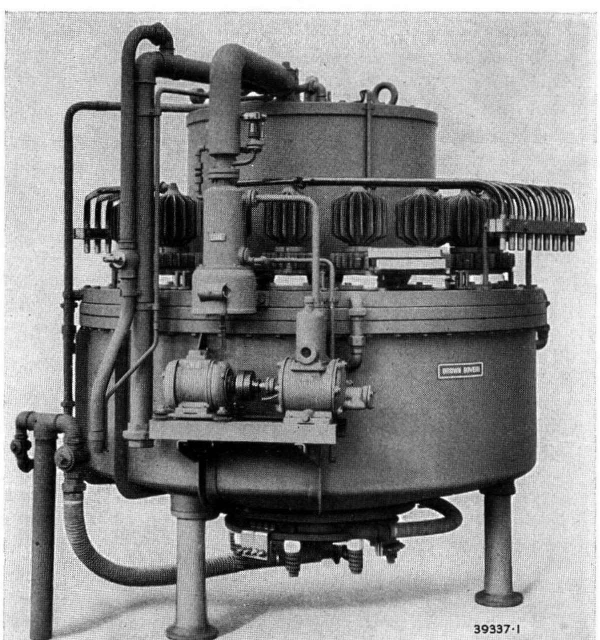


Fig. 9. — Warfield mutator, 4150 kW — 1935 design.

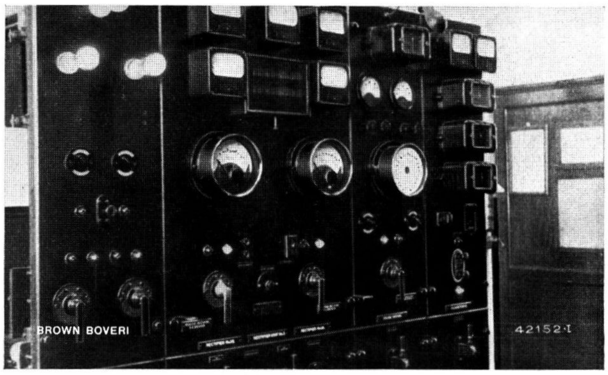


Fig. 11. — Warfield mutator switchboard — 1930 design.

attention had been paid to the operating time of the D.C. breakers. Slow speed breakers of American design had been installed and until this fact was realized, very considerable operating inconvenience was occasioned. Brown Boveri high-speed breakers, as shown in Fig. 10, were subsequently installed and satisfactory operation was immediately obtained.

All circuit breakers and tap-changers are motor-operated, so that control of each double mutator unit may be effected from a switchboard installed in the mutator room. It is interesting to compare the switchboard supplied in 1930 (shown in Fig. 11) with that supplied in 1935 (shown in Fig. 12) and to note the progress in design. It must, however, be stated that the difference between the two switchboards is partly to be attributed to the fact that the board shown in Fig. 11 was built in the U.S.A. in accordance with American practice, whereas the board shown in Fig. 12 is built in accordance with European practice. The centre panel of the switchboard carries the control switches, instruments and alarm devices for the incoming 60,000-V apparatus, whereas the side panels carry the controls for each of the mutators of the unit.

In conclusion it may be said that the total output of Brown Boveri mutators installed in the plants of the Consolidated Mining & Smelting Company now attains 46,800 kW. On large traction systems such as those of the Southern Railway, England, and the Berlin Suburban Railway, Germany, mutators of Brown Boveri design attain total outputs of between 100,000 and 200,000 kW on each of the systems in question. The above figure of 46,800 kW represents, however, the largest mutator output ever supplied by Brown Boveri to industry and is a striking example of the application of mutators to electro-chemical processes.

Fig. 12. — Warfield mutator switchboard — 1935 design.

(MS 964) *H. C. Beck.*

NOTES.

A Brown Boveri electric boiler in the Zuckerfabrik[1] & Raffinerie Aarberg A. G., Aarberg (Switzerland).

Decimal index 621.181.646 : 664. 1.

THE accompanying illustration shows the Brown Boveri electric boiler which was put to work for the first time in October 1935 in the Zuckerfabrik und Raffinerie Aarberg A. G., Aarberg (Switzerland). This boiler is built for a rated power input of 6000 kW and for a three-phase supply at 16,000 V. It was built to produce a pressure of 18 kg/cm^2 gauge. When working with feed water at 80° C the full load corresponds to a production of approx. 8600 kg/h of steam.

This plant is a typical example of a Brown Boveri high-voltage electric boiler. The water is sprayed out from a central ejection pipe and impinges on metal electrodes. Both the ejection pipe and the electrodes are so designed that there is no splashing of water, which allows of avoiding short circuits and trouble in service. The special shape of the electrodes has been patented. The passage of the electric current and the consequent heating of the water takes place during the passage of the water jets from the ejection pipe to the electrodes and also during the flow off, below, of the water from the electrodes to the lower part of the boiler.

This electric boiler has been in continuous 24-hours-a-day service ever since it was taken over, including Sundays and holidays and the output has, occasionally, been increased to 10,000 kg/h of steam.

Formerly, steam generation in this sugar mill was by four inclined-tube boilers with coal firing and each of these is built for an output of 7—8 tons of steam per hour. It

[1] See translation of letter on the second page of this number.

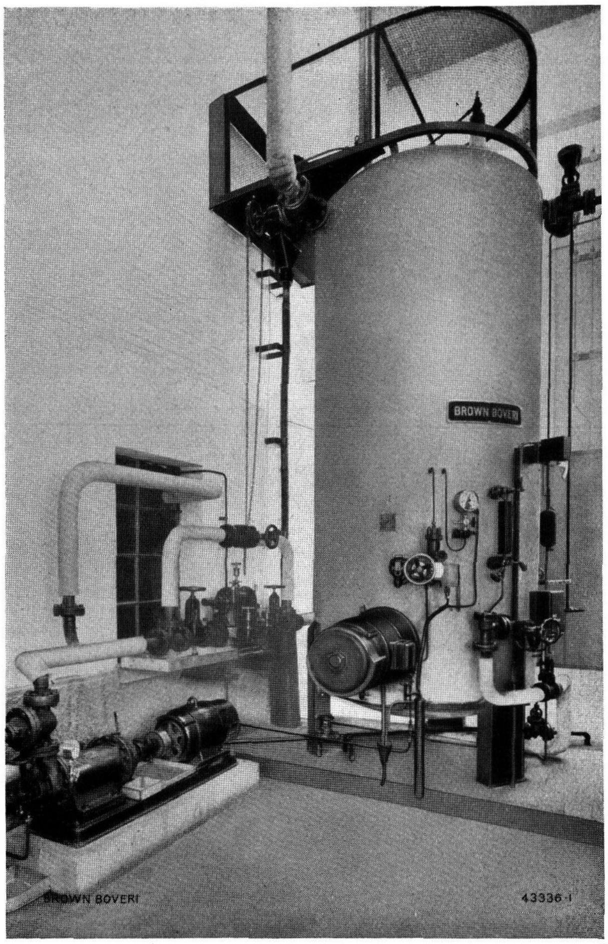


Fig. 1. — Zuckerfabrik und Raffinerie Aarberg A. G., Aarberg (Switzerland). Electric boiler 6000 kW, 16,000 V, 50 cycles, 18 kg/cm² gauge, for 8600 kg of steam per hour.

became necessary, last year, to enlarge the boiler plant; work which had to be carried out before the beet-root harvest of 1935. It would have been impossible to install boilers of the ordinary type in the time available and this caused the owners to purchase an electric boiler. This unit was delivered and put to work within four months and was in perfect working order when the beet-root harvest begun.

The electric switchgear was also delivered by Brown Boveri. It is composed of a high-tension framework with sheet-metal covering and a separate switchboard for the low-voltage part.

The Bernische Kraftwerke Co. supplies the requisite electric power.

(MS 982) *W. Roth. (Mo.)*

110-kV circuit breakers with convectors for outdoor erection, in Tasmania.

Decimal index 621.316.57.064.25.

THE Brown Boveri Review reported, lately, on the delivery of generators of large output for the Tarraleah Power Station, which is, at present, in course of erection on the island of Tasmania. The extra-high tension system of the country is being extended and altered in connection with the building of this big power station. 25 Brown Boveri oil circuit breakers, 110 kV for outdoor erection, Type OKF 22, were ordered for the equipment of the said system. In this type of circuit breaker, the arc is extinguished in convector chambers, the operation of which has been explained in various publications on Brown Boveri convector circuit breakers and should be well known. The breakers of Type OKF have the advantageous qualities of the latter, as, for example, extraordinary short duration of arc. Thanks to the small amount of gas generated at breaking, it is possible to lodge all three phases in one tank despite the high-rated voltage, which means considerable saving in space, reduction in oil filling, and in freight charges. The illustration shows a similar circuit breaker for 87 kV with its drive.

The material delivered in the present case comprises circuit breakers for current-ratings of 400 A and 640 A. Some of these will be inserted on the existing 88-kV system or else on the newly-built 110-kV system. Condenser-type bushings are used as terminals, these having porcelain covers. There are six bushing-type current transformers built into each breaker for system-protective purposes, of which all give the same three ratios of transformation which can be adjusted to on the control pedestal in order that the current transformers may be made to suit the rated current flowing at the various points on the system.

There are spring-type power-storage devices, with electric winding-up gear, for the drive of the breakers. There is a heating resistance in the control pedestal to

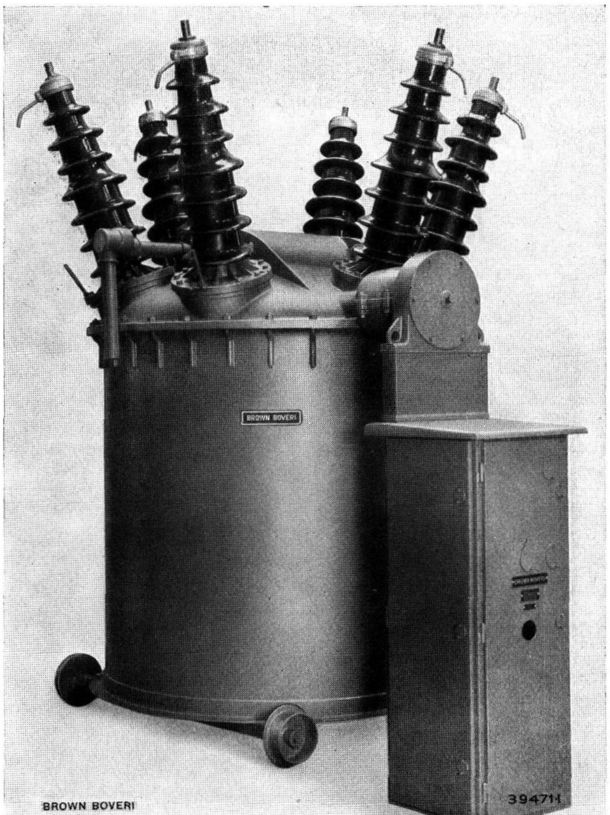


Fig. 1. — Oil circuit breaker with convector chambers, Type OKF 18, 87 kV, with control pedestal.

prevent condensate forming even under rapid falls in temperature.

Some of the circuit breakers have electrostatic voltage dividers built into the bushings, which are used to supply synchronizing instruments. Two sets of each one electrostatic synchronoscope of the Sieber type, one frequency meter and a voltmeter were delivered to the Tarraleah power station and the Creek Road Substation respectively; in the latter, the coupling of the 110-kV system to the 88-kV system is carried out.

(MS 965) *H. Vetsch. (Mo.)*

Mutators for rolling-mill service.

Decimal index 621.314.652.2 : 621.771.

In the month of April, 1935, two mutator sets each of 2500 kW were put to work in the plant of the Société des Hauts-Fourneaux, Forges et Usines de la Providence, in Hautmont (France).

This mutator plant is intended to strengthen the power plant available, consisting of old turbo-dynamo sets. The chief characteristics of the new mutator plant are:—

Output . . . 2×2500 kW,
D. C. voltage . . 520 V.
D. C. current . . 4800 A.
Overload capacity 5300 A, during 60 min.
6000 A during 30 min.
7200 A during 5 min, every 15 min.
9600 A during 1 min, every 10 min.

The output given here and the very severe overloads are delivered by mutators of the A 918 type each having 18 anodes (Fig. on cover), with anode choke coils to assure a proper distribution of current between the anodes (these coils are seen in the center of the photograph of the substation, being located between the mutators and the control switchboard).

These converter sets, designed specially for the supply of rolling-mill motors of big output, have got to stand up to heavy overloads occurring every 10 to 15 minutes. Thanks to its quality of being able to carry big overloads, the mutator is a very suitable type of machine for supplying rolling-mill motors.

The protection of mutator sets is always a problem of great importance and the more so the greater the output of the mutators. Much study was devoted to this point, in the present case, and the protective equipment employed is described herewith.

Taking into account the power of the high-voltage plants of the Usines de la Providence, in Hautmont, circuit-breakers Type OH 12, of reinforced design and capable of rupturing 500 MVA, were used for coupling up the mutator equipments to the 10,000-V bus-bars. These circuit breakers are equipped with over-current tripping gear and are remote-controlled by motor. Tripping can be effected by push-button from the control board through a tripping coil on the breaker.

There are extra-high speed breakers Type JCB inserted in the cathode leads of the mutators; these have a reverse-current automatic trip and are also remote-controlled.

Further, each mutator is protected against short circuits by polarized grids. This special protection by the Brown Boveri method makes use of a very high-speed

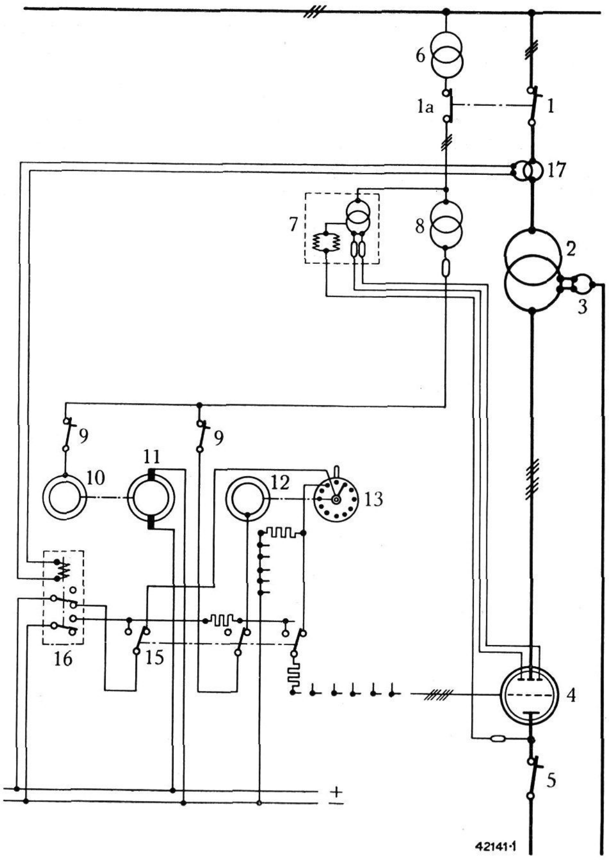


Fig. 1. — General diagram of connections. Voltage regulating devices and protective devices against short circuits by polarized grids.

relay 16 which reverses the polarity of the grid (Fig. 1). If a short circuit occurs in the mutator tank itself or on the D. C. side, this relay intervenes instantaneously, under the influence of the over-current from the transformers 17, and applies negative polarity to the anode grids thereby preventing the arc reigniting. The time required to suppress a short circuit does not exceed that of one full cycle, at the most.

One of the particular conditions stipulated by the Société des Usines de la Providence was regulation of the D. C. voltage by polarized grids within the following ranges.

Progressive regulation of D. C. voltage from zero to the rated value, allowing a motor and mutator set to start service under special conditions on the main D. C. bus-bars.

Continuous regulation of D. C. voltage at all loads, from the rated voltage down to 10% below it, to allow of adjusting the D. C. voltage when the mutator sets are to work in parallel with turbo-dynamo sets and, also for compensating fluctuations in the primary voltage.

The equipment required for voltage regulation by polarized grids is shown in the diagram in Fig. 1. This apparatus consists, in the main, of a small set composed of an induction motor and a dynamo, 10 and 11, a distributor 13 driven by a synchronous motor 12, running in synchronism with the A. C. system to which the mutator is connected. By regulating the moment the arc strikes during the positive half wave, the R. M. S. value of the voltage is regulated, as desired, which means, practically, regulation of the D. C. voltage available on the D. C. side of the mutator set.

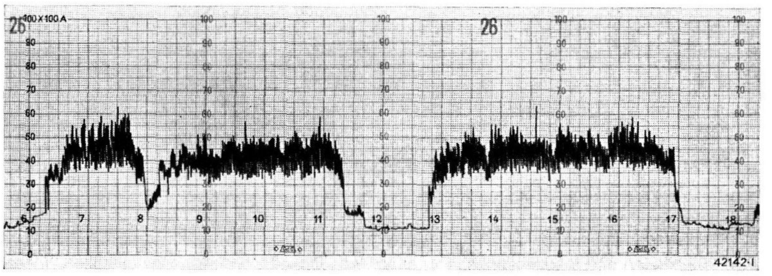


Fig. 2. — Load diagram of a mutator set.

The control apparatus for voltage regulation by polarized grids has been designed to allow of voltage regulation either from the control board of the mutators themselves or else from the control desk of the rolling-mill motors.

The devices for protection against short circuits, by means of polarized grids are co-ordinated with the apparatus regulating the voltage.

The voltage-regulating apparatus can be cut out by means of change-over switch 15, while maintaining in service the protective devices by polarized grids.

Fig. 2 gives a fragment of the load diagram of one of the mutator sets, which is characteristic of operating conditions with sudden and heavy load fluctuations:— these are conditions for which the mutator is peculiarly fitted.

The number of kW produced by all the Brown Boveri mutators used in rolling mills is increased by the addition of this new plant to a total of 40,000 kW.

(MS 963) *M. Rossé. (Mo.)*

Three-phase shunt commutator motor to drive a high-power sugar centrifugal.

Decimal index 621.34 : 664.1.057.55.

Fig. 1 shows a three-phase shunt commutator motor delivered for the drive of a high-power sugar centrifugal.

By means of very simple control, through three push-buttons, only, this motor very quickly brings the centrifugal up to the running or process speed of 1000–1450 r. p. m., without stressing the supply system by current surges. For stopping the centrifugal, the motor is retarded by electric braking down to a speed of about 500 r. p. m., so that the mechanical brake, only intervenes in the lower speed range and is, thus, saved from wear. Apart from the simplicity of control, the economical operation of the drive proved very advantageous, this in spite of the relatively low cost of power in the sugar mill. This economy is due to the practical elimination of the usual starting losses and, also to a great part of the power stored up in the rotating masses being recuperated through electric braking. As compared to drives by squirrel-cage or slip-ring motors, whether with a slip coupling or not, the ratio of the total power consumptions is about 100:175 as is shown by the two current consumption comparisons of Fig. 2.

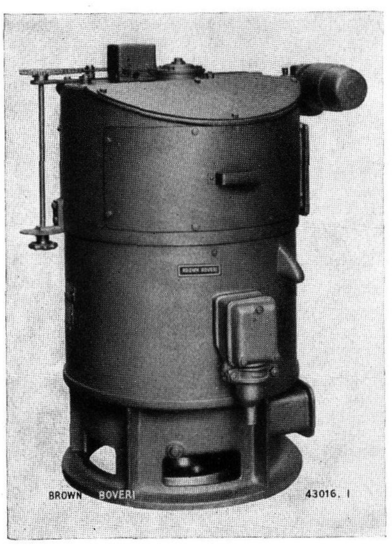


Fig. 1. — Three-phase shunt commutator motor, 37 kW, 430—1450 r. p. m., in totally-enclosed design with forced-draught ventilation.

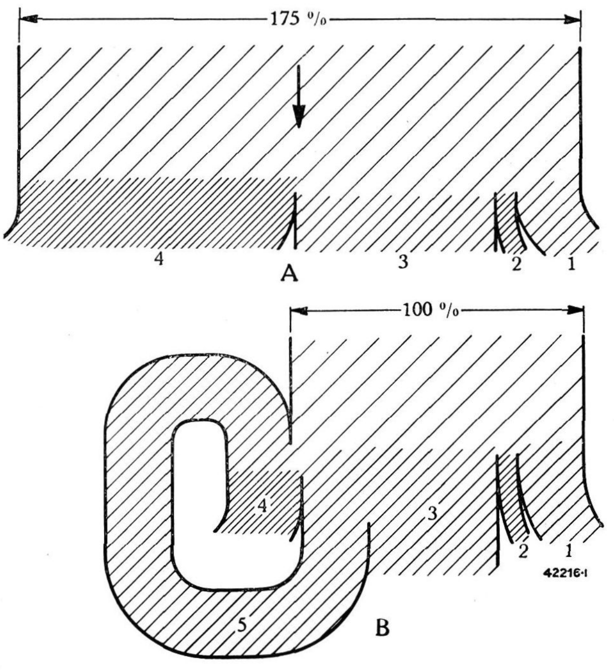


Fig. 2. — Current consumption comparison for the drive of a centrifugal.

A. By Induction motor.
B. By shunt commutator motor.
1. Effective work done by motor during the process.
2. Losses of motor during the process.
3. Effective work done by motor at starting.
4. Losses of motor at starting.
5. Power recuperated by electric braking.

From the mechanical point of view, as well, excellent results were attained with this motor which has a coupling of a new design with very flexible but tough rubber disc as transmission organ.

(MS 984) *S. Hopferwieser. (Mo.)*

Electric drives for sanforising machines.

Decimal index 621. 34 : 677. 021.

UNEQUAL tensions in warp and weft are set up in tissues in the course of manufacture and are due to the various stresses to which they are subjected during the weaving process proper and the subsequent processes, such as dyeing washing and bleaching. The result is that these stuffs shrink when washed. The process known as sanforising has as object the removal of the unequal tensions from the tissue by shrinking and, thus, preventing the stuff shrinking later on again. The amount of shrinkage necessary depends on the kind of cloth handled and the speed with which it has to be passed through the sanforising machine is dependent on this.

For the reasons first given, it is necessary to vary the speed of the driving motor smoothly, without steps, and over a wide range, independently of the load. Supervision of the motor must be made as simple as possible so that the operator can give his full attention to the sanforising machine. These conditions are best fulfilled by the three-phase shunt commutator motor with electric remote-control equipment (Fig. 1). D. C. motors in Ward-Leonard or in positive and negative booster connection can also be used, but this means using a converter set and the consequent conversion losses, which are unavoidable, must be reckoned with. This second solution has the additional disadvantage of requiring more apparatus. For these reasons, the three-phase shunt commutator motor deserves to be given preference. Brown Boveri has already equipped a whole series of sanforising machines with drives of this type and all have given the most satisfactory results. The push-button control is especially appreciated as it makes for easy and certain control of all the processes and allows the machine to be used to greatest advantage, in accordance with the different conditions it can be called on to work under. The main switch and contactor are lodged in a switch cubicle along with the control apparatus and fuses of the necessary electric auxiliary drives and devices. The good practical results recorded with sanforising machines thus driven are yet another proof that it is well worth while to introduce variable-speed electric drives in textile finishing plants, as well. Machines such as calanders, stentering frames, mercerizing machines and the like which operate at different speeds can only be utilized to the fullest extent if the drives with which they are equipped are both reliable and very adaptable.

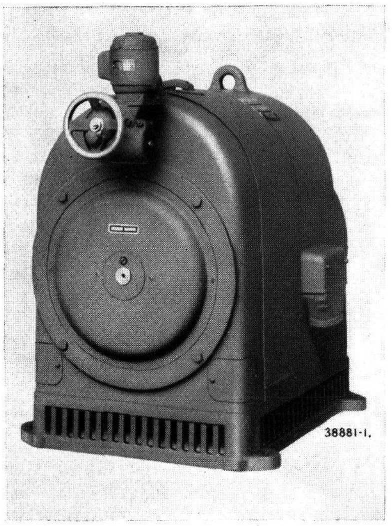


Fig. 1. — Three-phase shunt commutator motor, Type PNR with electric remote control of the brushes.
Range of speed variation 262—1570 r. p. m.

(MS 958) *H. Wildhaber. (Mo.)*

Some recent orders for automatic regulators.

Decimal index 621. 316. 722.

THE Brown Boveri automatic quick-acting regulator is being used, more and more extensively, in the most varied kinds of plants, not only in conjunction with Brown Boveri machinery but along with machinery by many other makers. This broadening of the field of utilization is due to the well-known qualities of the Brown Boveri regulator, namely:— great precision, absolute reliability, no parts which wear down, no supervision required, easy adaptability, etc. During recent years, only 25 to 30 % of regulators delivered have been for plants with Brown Boveri machinery, 70 to 75 % being for fitting to machinery by other makers.

It might have been expected that the present economic crisis would have brought about a fall in the number of regulators ordered, in conjunction with the reduced number of new generators being built. This has not been the case; the number of regulators ordered has, certainly, fallen off, but to a far lesser degree than that of the generators. This is due to the gradual but general recognition of two facts:— firstly, that it is necessary to put automatic regulation into older plants which worked to hand regulation up till now and, secondly, that no great capital is required for fitting automatic regulating gear. To this must be added the growing recognition of the undeniable qualities of the Brown Boveri automatic regulators of the new design.

Quite recently, Brown Boveri got some orders for their automatic regulators which are interesting from the point of view of the special operating conditions called for as well as from that of the extent of the order itself.

Mention should be made of the following orders among those given for A. C. automatic regulators.

The *Italian State Railways* gave Brown Boveri's Italian concessionaries the Tecnomasio Italiano Brown Boveri, Milan, an order for six complete regulating equipments intended for three synchronous condensers each of 10,000 kVA, 630—750 r. p. m., 42, 45 or 50 cycles, to be put in three substations for supplying newly electrified line sections. Tecnomasio Italiano Brown Boveri is only supplying one of the three condensers but the railways insisted on a uniform regulating and protective system and a uniform automatic paralleling system on all the machines. A comparison between different designs and the practical experience gained in plants running proved that the Brown Boveri system had the greatest number of advantages and this dictated its choice.

The synchronous condensers are specially intended for voltage regulation and are built to be over- and under-excited so as to allow of using them over a wide range, they have pilot exciters in order to impart to the excitation that stability which is required under low excitation. The voltage regulator, inserted between the pilot exciter and the main exciter, is designed to allow completely automatic regulation between zero excitation and maximum excitation corresponding to full load under over-excitation and this without it being necessary to make any commutations or hand regulation. Further, the synchronous compensators can carry very considerable overloads, such, for example, as 100 % for 1 min; 50 % for 3 min and 20 % for 10 min. To protect the machines against dangerous temperature rises under excessive overloading, there is a thermal relay which acts on the current-limiting regulator to regulate this apparatus to act under different values according to the temperature of the windings. The synchronous condensers are, also, equipped with the usual protective devices against excessive voltages and against earthings in the stator or rotor circuits; a differential protection produces cutting out and rapid suppression of excitation if an internal fault occurs in the machine.

British Brown-Boveri Ltd., London got an order for eight quick-acting regulators from the *Victoria Falls & Transvaal Power Co.* Six of these are of type AB 4/1 and two of Type AB 2/1, all being for the *Klip power station.* These regulators are for six main turbo-alternators each of 40,000 kVA, 10,500 V, 3090 r. p. m., 51·1 cycles and for two auxiliary sets each of 8750 kVA, 2100 V, 3090 r. p. m., all British built machines.

Simple and rugged automatic regulators, giving the highest degree of reliability and requiring neither supervision nor overhauling are an absolute necessity in overseas plants of this size, in the remoter districts, where skilled labour is not easy to get and where it takes time to replace damaged parts.

The *Steyrische Wasser- und Elektrizitäts-A.-G.* in *Graz* ordered from Brown Boveri, Vienna, four quick-acting regulators Type AB 4/1 for three alternators each of 13,000 kVA, 750 r.p.m. and for an alternator 1900 kVA, 250 r.p.m., all built by another maker, which are in the *Arnstein* and *Teigitschmühle* power stations. These plants were, formerly, equipped with regulators of the vibrating-contact type, while the *Pernegg* and *Mixnitz* power stations, belonging to the same Company and having alternators of 8000 kVA, 5250 V, 150 r. p. m. and of 11,000 kVA, 5250 V, 214 r. p. m., also built by other makers, were equipped with Brown Boveri regulators. The deciding factor in the replacement of the regulators with vibrating contacts by Brown Boveri regulators was the very satisfactory results obtained with the latter.

The *Société Edison, Milan,* ordered from Tecnomasio Italiano Brown Boveri the necessary equipment for automatic regulation and protection of two alternators each of 20,000 kVA, 504—600 r. p. m., 42/50 cycles built by the T. I. B. B. These regulators are of the new high-power type described in the Brown Boveri Review, August number, 1934, while the current limiting regulators are of Type A 4/3.

The *Ateliers de Jeumont* give our French concessionaries, the Cie Electro-Mécanique, Paris, an order for the equipment for automatic regulation of a synchronous condenser, 20,000 kVA, in the *Creney station* located at the end of the 220-kV transmission line from Kembs on the Rhine. In accordance with the system proposed for this network, the automatic regulator is designed for extra-rapid excitation by a separate quick-response winding. Although they never promoted this extra-rapid excitation, the advantages of which are very problematic, Brown Boveri were able to produce regulating devices to meet the conditions imposed by this kind of excitation.

Finally, mention should be made of an order given by the *Azienda Elettrica del Governatorato di Roma* to Tecnomasio Italiano Brown Boveri, Milan, for 10 regulating equipments, each of one voltage regulator, one current-limiting regulator and protective relays all for different alternators built by T. I. B. B. and others and running in power stations near Rome. This order means that all the steam and hydraulic power stations near Rome are now equipped with Brown Boveri quick-acting voltage regulators and Brown Boveri current-limiting regulators. The total numbers of Brown Boveri regulators in the said region amounting to about 60.

Among the *D. C. regulating equipments* mention can be made of an order given by l'*Usine de Produits Chimiques et Electrométallurgiques d'Alais, Froges et Camargue* to the Cie Electro-Mécanique, Paris, for the equipment of the *Saint-Jean de Maurienne* works with:—

four automatic current-limiting regulators Type AB 2/0;

two complementary regulators Type AB 2/0;

two automatic voltage-limiting regulators Type A 4/0.

These regulators will be used for four D. C. generators by other makers each built for 250 V, 5000 A, 375 r.p.m. and working under the following conditions (Fig. 1):—

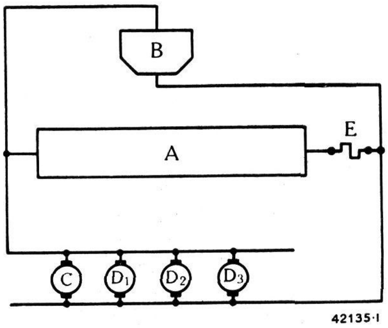


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Fig. 1. — Diagrammatic layout of the mixed supply of a series of aluminium furnaces by means of mutators and dynamos.

A. Series of furnaces.
B. Set of mutators.
C. Dynamo driven by hydraulic turbine.
D_1, D_2, D_3. Dynamos driven by induction motors.
E. Shunt.

The series of furnaces A is supplied, on the one hand, by one or by several mutator sets B and, on the other, by a certain number of generators C and D which are driven by hydraulic turbines or induction motors. The hydraulic sets have no speed governors and, thus, work to constant output, that is to variable current strength, according to the terminal voltage; they, also, have no electric regulators.

Since the total current must be kept constant and the resistance of the circuits being fed is always changing, voltage regulation of the machines becomes necessary and automatic regulation desirable.

The mutator sets B are provided with a device to make them deliver constant current and, therefore, they need not be taken into account in the regulation of the rotating machines. On the other hand, the generators of the rotary sets without speed governors cause variations in the current which must be balanced by the generators of the converter sets. The latter can, thus, be called on to work in two different ways.

(a) To constant current regulated between 2000 and 5000 A, as desired.

(b) To variable current, but limited to 5000 A, to make up the current delivered by the other generators and maintain the current through the shunt E at a constant value.

(c) Lastly, as is the case for all the other generators supplying the series of furnaces, the voltage must not exceed a certain value, which can be regulated as desired between 250 and 300 V.

To meet the conditions just set out the following device has been provided.

(a) Each generator has a current regulator allowing the current to be maintained at a constant value between 2000 and 5000 A.

(b) The shunt E supplies a complementary regulator which, in turn, acts on the current regulators of the sets which should operate at variable current so that the current through the series of furnaces is maintained at a constant value between 30,000 and 45,000 A.

In this case, the current regulator also plays the part of a current limiter, that is to say it prevents the current delivered by the machines exceeding the allowable maximum of 5000 A.

(c) Finally, a voltage limiter acts simultaneously on all the current regulators working, so as to limit the voltage to any value desired, between 250 and 300 V.

As the generators can work, alternatively, on two series of furnaces, there are two sets of complementary regulators and of voltage limiters.

Lastly, mention should be made of an order placed with Brown Boveri by the *S. A. pour l'Industrie de l'Aluminium of Neuhausen* for four current regulators Type AB 4/0 for regulating four D. C. generators by other makers, each built for 3000 kW, 350 V and working in the *Chippis* works (Canton Valais). The object of these regulators is to maintain constant current delivered by the machines, in spite of fluctuations in the resistance of the circuit they work on, which is composed of a series of aluminium furnaces. All these generators are driven by synchronous motors, which simplifies the regulating apparatus. These regulators were ordered thanks to the excellent results attained with six similar ones delivered some time ago to the Sava Company, an allied concern of the S. A. pour l'Industrie de l'Aluminium, Neuhausen, and used for regulating similar generators in the Porto-Marghera works near Venice.

(MS 960) *W. Marolf. (Mo.)*

Velox steam generators for New Zealand.

Decimal index 621.181.39 (931).

THE Wellington City Corporation has recently placed an order for two Brown Boveri Velox steam generators intended for its steam power plant at Evans Bay.

The power requirements of the city are ordinarily supplied by three distant government hydro-electric stations over a 110-kV transmission system. At certain times of the year severe storms are experienced, and although failures of the transmission system due to this and other causes are not frequent, they are a source of great anxiety when they do occur. These considerations together with the still fresh experience of the last earthquake have caused the Corporation to decide on the installation of quick-starting, stand-by generating plant in the existing thermal station, to supply the power requirements of the essential services in an emergency.

The choice of the type of equipment was made the subject of an exhaustive study by the client and his consultants, Mssrs. Preece, Cardew & Rider of London. The result of this investigation was a decision in favour of a quick-starting steam plant of 15,000 kW output with two Velox steam generators, each for a normal full-load evaporation of 41 t/h and a maximum evaporation of 45 t/h. This arrangement provides for meeting up to about 60 % of the full-load steam requirements by means of one Velox boiler only.

The purchaser's specification called for a starting period of not more than ten minutes: the guaranteed starting time at which the Velox steam generators can in an emergency be brought from the cold state to producing the full-load steam quantity at normal pressure, however, is only five minutes. This exceedingly short starting time was by far the shortest compared with those offered by any of the competing firms. This feature is one of the many advantages typical of the Velox steam generator and was largely responsible for the Corporation's decision in favour of the Velox boiler.

The normal steam conditions are 17 kg/cm^2 abs and a temperature of 345° C. The guaranteed efficiency with a feed-water temperature at the economiser inlet of 65° C is 92·5 % at full load and 91·5 % at half load. As mentioned, they will have a normal-rated evaporative capacity of 41 t/h and a maximum capacity of 45 t/h.

Some idea of their compactness is obtainable from the fact that each Velox generator complete with auxiliaries occupies only about $^2/_3$ of the floor space of the existing 13 t/h water tube boilers, i. e. of boilers having only one third of their output. They are designed for oil firing with any commercially obtainable grade of fuel oil.

The Velox steam generator, whether for peak load, or for stand-by service, or for both as for example the installation now under construction for the City of Oslo,[1] represents the ideal solution for such duty. Not only is it instantly available for service, but it is also very economical due to its high efficiency and to the avoidance of all banking losses.

(MS 974) *H. S. Hvistendahl.*

Service reliability of Brown Boveri material.

Decimal index 6 (009.2) : 621.313.322.

THE electricity works of the town of Aarau (Switzerland) were supplied with two two-phase generators, in the year 1905 and these machines are still running to-day. They are of type B 5000/96, output 500 kVA, 2000 V, 125 A, 38·5 cycles at 48 r. p. m. They are of the vertical-shaft type with rotating pole wheels and separate excitation. One of the two machines was rewound, in the meantime, for three-phase A. C. current, 8000 V, 50 cycles.

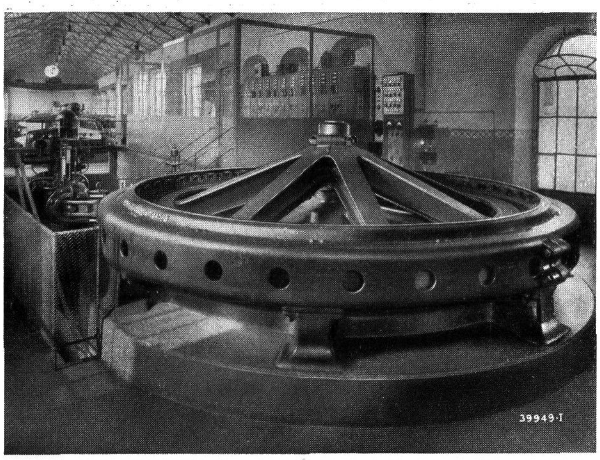

Fig. 1. — Aarau Electricity Works. Two-phase generator Type B 5000/96, 500 kVA, 2000 V, 38·5 cycles, 48 r. p. m., delivered in 1905.

The illustration shows both generators.

(MS 947) *Prop.*

[1] Brown Boveri Review 1935, No. 8, page 164.

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