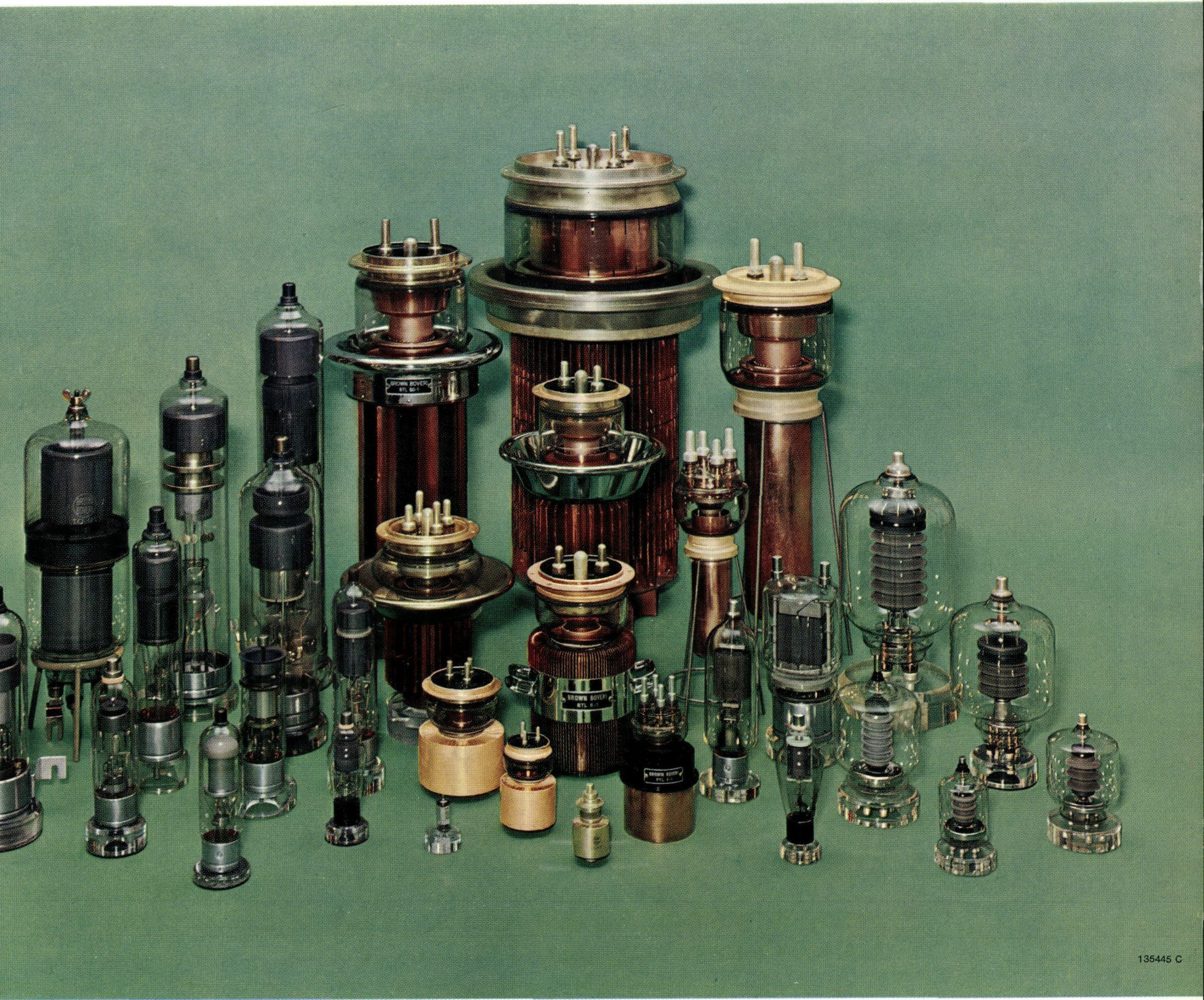
BROWN BOVERI REVIEW

Electron Tubes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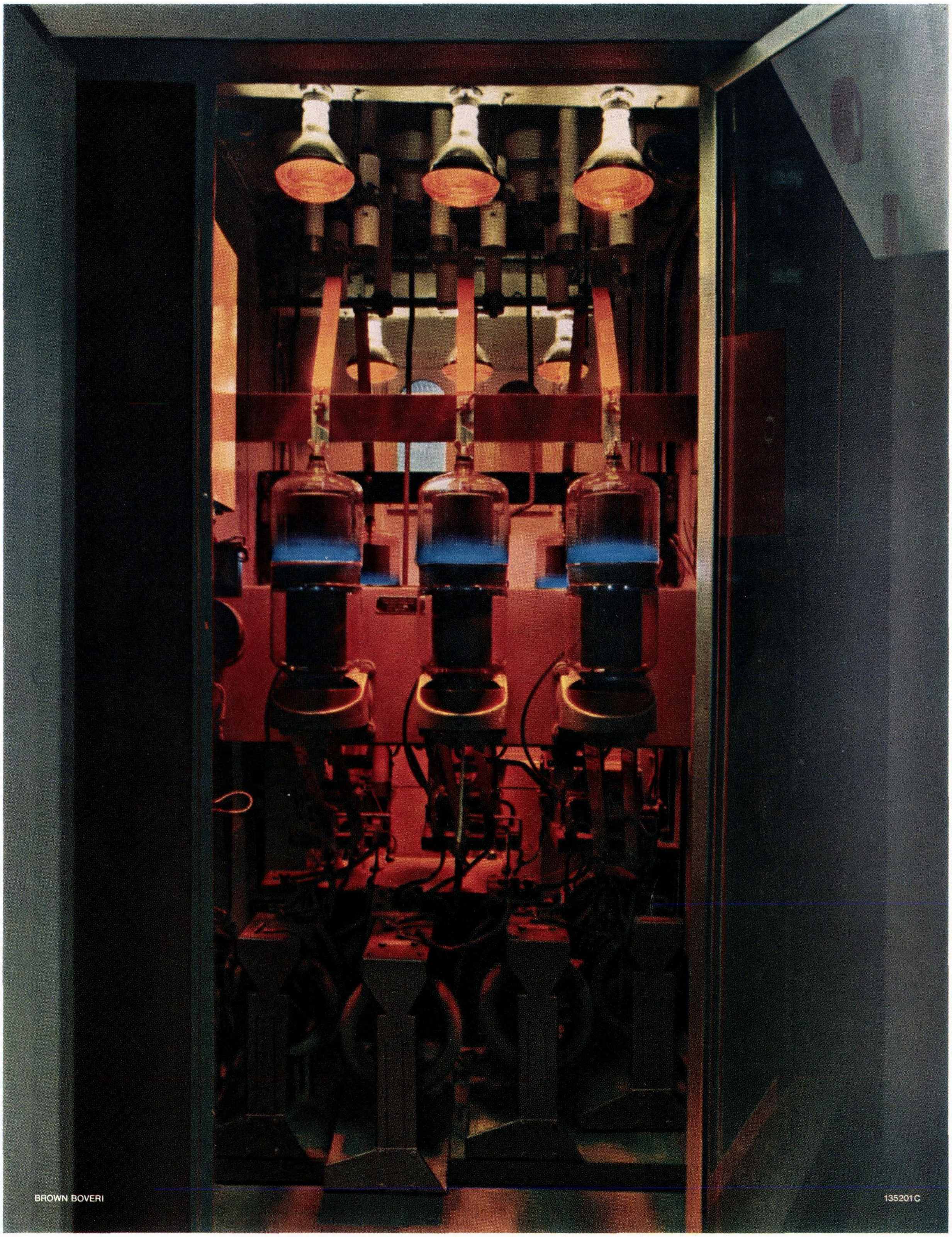

High-voltage rectifier containing six Brown Boveri thyratrons type TQ 91

used in conjunction with a 500-kW transmitter of another manufacturer, installed in Spain.
The rectifier is designed to produce an output voltage of 12·5–15 kV and can supply up to a maximum of 1 MW.

Front cover: A selection from the Brown Boveri range of electron tubes

Left: High-voltage rectifier tubes and thyratrons
Centre: Transmitting and industrial power tubes with forced air cooling and for effective outputs up to 600 kW
Right: Naturally cooled transmitting and industrial power tubes

THE BROWN BOVERI REVIEW

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FOREWORD

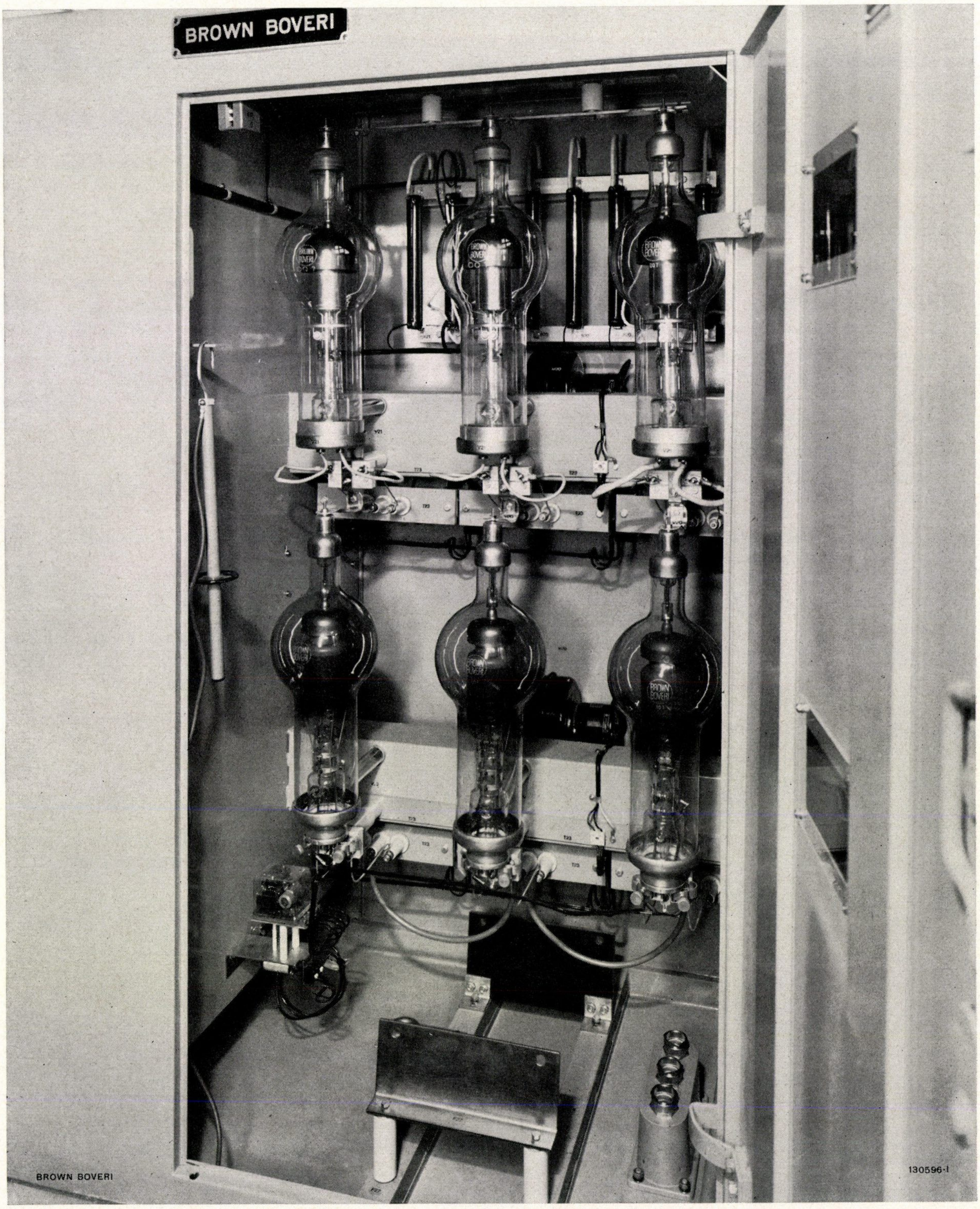
THE FIRST SPECIAL ISSUE of the Brown Boveri Review devoted exclusively to electron tubes appeared in 1949, when the subject was still young. Since then, new developments and advances in this field have been reported in individual articles as occasion arose.

Since Brown Boveri have now had more than 25 years' experience of manufacturing tubes, the time seemed ripe to show what has been achieved, particularly as this year the Company is celebrating 75 years of its existence, which itself is good reason for putting tubes on show, along with the other products of the Company.

The present issue will demonstrate to our readers that, despite semiconductors, Brown Boveri tubes have a significant part to play in radio communications and the spheres of electroheat and control, especially where high or very high outputs are involved. It will also become apparent that Brown Boveri are very much concerned with getting to the heart of problems which themselves are only details in the technological gamut of tube manufacture, but which nevertheless are of great significance in achieving outstanding quality.

Furthermore, all those customers who are interested primarily in using electron tubes will be able to see that great emphasis is laid on operating conditions and the testing of tube data.

(DJS) W. Lüdy



Rectifier tubes in a high-frequency industrial generator for induction heating

Top: Three diodes type DQ 71 Bottom: Three triodes type TQ 71

25 YEARS BROWN BOVERI TUBES

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Brown Boveri started development work on electron tubes in 1937 and batch production followed four years later. Due to the firm's traditional association with heavy-current engineering, particular attention was devoted to the development of transmitting and rectifier tubes of medium and large capacity. Receiving and other special tubes were, with certain exceptions, deliberately not developed. Today there are altogether eighty different types available which have applications in television, broadcasting, commercial communication systems, industrial and scientific research apparatus and medical equipment throughout the world.

Development History

DEVELOPMENT WORK by Brown Boveri in the field of electron tubes started in 1937. This was instigated by the realization of the importance of wireless communication. Particular attention was directed at the generation of high power based on the many years of experience already gained by the firm, especially in the field of heavy-current engineering. It was realized even then that larger tubes manufactured at a lower production rate were better suited to the existing production equipment than smaller (receiving) tubes for which specialized equipment is essential for large-scale production.

These considerations led to the development of the first 150-kW transmitting tube (Fig. 1) which could be disassembled and which had its own vacuum pump. This type of tube was used in the 100-kW medium-wave transmitter built by Brown Boveri in 1941 for the Swiss national broadcasting station at Beromünster. The success achieved with this tube and also the necessity of producing tubes in Switzerland due to the war led to a great deal of further development. The first sealed 10-kW transmitting triode, i.e. operating without a vacuum pump, was produced in 1942. There followed a period of rapid expansion in the special departments essential for the production of these tubes, such as materials testing, chemistry and physics laboratories, glass and ceramics processing, degassing and pumping, test rigs, etc., which permitted successive

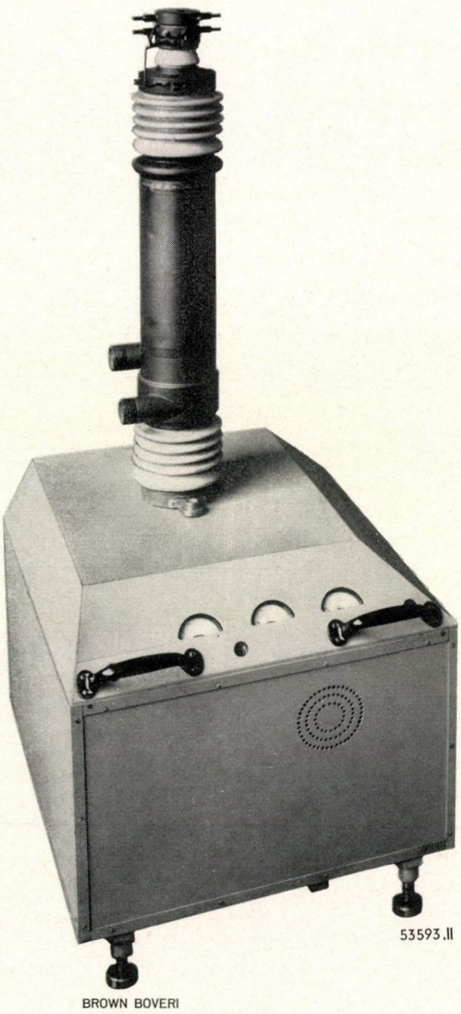

Fig. 1. – First dismantleable 150-kW transmitting tube made in 1939

The vacuum pump was housed in the box.

coordination and batch production. It is also noteworthy that several microwave and receiving tubes were developed in the early 1940s. Whereas the production of receiving tubes was discontinued after the war as they were no longer an economical proposition, the microwave tubes patented by Brown Boveri and marketed under the trade name "Turbator" remained an important production item for about 20 years.

Apart from the high-vacuum tubes already mentioned, mercury-vapour rectifier tubes and thyratrons were also developed and put into production in 1946. Shortly after the high-voltage rectifier tubes came the so-called medium-voltage thyratrons which completed the family of ionized-gas tubes.

The fact that Brown Boveri also developed and built the corresponding equipment (e.g. transmitters and generators) had a beneficial effect upon tube design.

In the past 30 years a range of 55 different types of standard tubes has been produced, along with 25 special models with various cooling systems and diverse base fittings. Approximately 800 000 tubes have been manufactured by Brown Boveri to date, representing a total output of more than three million kilowatts, the overwhelming majority of which have been installed in apparatus manufactured by other firms. For a full list see opposite.

The ancillary equipment essential for operating the tubes must also be catered for. This includes assembly and connecting parts, protective gear, equipment for cooling circuits, and so on. These points require special attention from the design point of view in order to ensure reliable operation of the tubes. Our comprehensive ancillary equipment encompasses all contingencies and leaves the designer a relatively free hand in the disposition of the tubes in the apparatus.

Observations on Fig. 2 to 12

Selections from our present manufacturing programme can be seen in Fig. 2 to 12.

Fig. 2 and 3 depict various tubes from the series with natural anode cooling. The solid graphite anodes are of special interest as they permit short periods of overload and therefore may be used for intermittent industrial operation. One of the largest tubes with natural cooling is the type T 2000–1 with an average anode dissipation capacity of 2 kW and up to 11 kW output. Fig. 4 to 10 show typical examples of transmitting and industrial tubes with air, water and vapour cooling. Fig. 9 shows the type BT 15–1 transmitting and industrial tube in its three forms, BTL 15–1 with air cooling, BTW 15–1 with water cooling and the vapour-cooled BTS 15–1. The availability of transmitting tubes with three different cooling systems permits not only a selection of tube size but also a choice of the most suitable cooling medium for each individual application. Practically all external-anode tubes with anode dissipation capacities of over 5 kW are available with three forms of cooling. At the present time the largest tube manufactured by us is the type BTS 150–2 shown in Fig. 10, which has an anode dissipation capacity of 200 kW and an output of 600 kW. Fig. 11 shows some of the high-voltage diodes and Fig. 12 shows several examples of high-voltage thyratrons, of which the largest available today is the type TQ 91 with a peak inverse anode voltage of 20 kV and a mean anode current of 45 A. A larger thyratron for 115 A anode current is being developed.

Development Trends

When studying the development trends in the tube field it must be borne in mind that the tube is an electronic component which is required to fulfil a definite task as economically and reliably as possible. Whether it succeeds or not depends not only on the tube itself but also on the design and operation of the other equipment which goes to make up the complete apparatus. In other words the apparatus should be considered as a complete unit. Further tube developments must be coordinated with developments in apparatus and equipment.

To illustrate development principles, the development trends in apparatus and installations in which Brown Boveri tubes play an important part will now be briefly described:

– *RF transmitters for broadcasting and communication systems*

The output capacity limit for radio transmitters in the long, medium and short-wave bands is being

Present Manufacturing Programme and Applications

The main groups of the manufacturing programme are as follows:

Group	Main function	Capacity	Frequency
High-vacuum tubes:			
Natural-cooled transmitting and industrial tubes (glass-bulb tubes)	Amplifiers, oscillators	100 W–10 kW	0–150 Mc/s
Transmitting and industrial tubes with forced cooling (external-anode tubes)	Amplifiers, oscillators	300 W–600 kW	0–600 Mc/s
Rectifier tubes:			
High-voltage diodes and thyratrons filled with mercury vapour	Rectifiers	10 kV/0·25 A–20 kV/45 A	0–500 c/s
Medium-voltage thyratrons filled with mixed gases	Power stages	1·3 kV/0·1 A–5 kV/25 A	0–400 c/s

Each of the above mentioned groups consists of a complete range within the given capacity and frequency limits. Table I contains a complete list of types with brief data and Table II gives the various application ranges.

Brown Boveri tubes are distinguished by the following significant characteristics

Group	Characteristics
Natural-cooled transmitting and industrial tubes (glass-bulb tubes)	• Robust, thermally stabilized, thoriated-tungsten cathode • Grossly overloadable graphite anode with large thermal capacity (specially suitable for intermittent industrial operation) • No special cooling equipment required
Transmitting and industrial tubes with forced cooling	• Robust, thermally stabilized, thoriated-tungsten cathode • Special grid capable of withstanding high overloads at low thermionic emission (patented by Brown Boveri) • Tubes with anode dissipation capacity of over 5 kW which can be supplied with one of three types of cooling:[1] a. forced-air cooling b. water cooling c. water evaporation cooling (vapour cooling) • Special tubes of robust construction for rough industrial operation
Rectifier tubes	• High inverse voltage (up to 26 kV peak anode voltage) • High resistance to back-fire • High capacity for momentary overloads • Special pellet technique for mercury-vapour tubes (patented by Brown Boveri)

[1] See also Table entitled "Comparing Methods of Cooling" from the article entitled "Selection of tubes for use in power generators and radio-frequency amplifiers" in this issue.

TABLE I

Brief Tube Data

Transmitting and industrial tubes

Model	Type	Cooling[1]	Main application[2]	Max. power output kW	Max. frequency Mc/s
Naturally cooled tubes					
T 50-1	Triode	N	B D	0·18	100
T 50-2	Triode	N	B D	0·22	100
T 110-1	Triode	N	A	0·12	0·02
T 150-1	Triode	N	B D	0·71	100
T 300-1	Triode	N	B	1·55	75
T 130-1	Triode	N	B	0·41	200
T 380-1	Triode	N	B	1·85	150
T 500-1	Triode	N	B	1·63	120
T 1000-1	Triode	N	B	4·4	60
T 2000-1	Triode	N	B	11·0	60
Q 160-1	Tetrode	N	A B C	0·43	120
Q 450-1	Tetrode	N	A B C	1·16	120
P 120-1	Pentode	N	A C	0·35	30
P 300-1	Pentode	N	A C	1·2	50
Forced-cooled tubes[3]					
AT 5-1	Triode	L, W	A B	11·0	100
AT 10-3	Triode	L, W	A B	21·5	55
BTL 1-1	Triode	L	A B C	1·9	220
BTL 3-1	Triode	L	A B C	6	220
BT 6-1	Triode	L, W, S	A B C	35	100
BT 15-1	Triode	L, W, S	A B C	66	100
BT 25-1	Triode	L, W, S	A B C	73	50
BT 50-1	Triode	L, W, S	A B C	173	35
BT 150-2	Triode	W, S	A B C	600	30
CTL 1-2	Triode	L	A B C	0·875	600
CQL 0·3-1	Tetrode	L	A	0·4	500
CQL 5-1	Tetrode	L	A	16	110
FT 3-1	Triode	L, W	B A	6·6	60
FTL 3-2	Triode	L	B A	6·6	60
FT 8-1	Triode	L, W, S	B A	26	60
FT 12-1	Triode	L, W, S	B A	40	30
FQ 15-1	Tetrode	L, W, S	A C	50	100

[1] N = Natural cooling W = Water-cooling
L = Forced-air cooling S = Vapour cooling (water-vapour)

[2] See Table II

[3] AT, BT, FT and FQ tubes have their type of cooling designated by the third letter (L, W or S). For example BT 25-1 with air cooling becomes BTL 25-1 or with vapour cooling it becomes BTS 25-1, etc.

steadily increased (the megawatt output limit per transmitter unit has almost been reached) with a simultaneous gradual reduction in the number of preamplifier stages. Another consideration of growing importance is a high overall efficiency and ease of control of such transmitters. There is a growing demand for tubes of high amplification and good linearity between output and input voltage for commercial communication systems.

Rectifier tubes

Model	Type	Filled with[1]	Main application[2]	Max. anode current (mean value) A	Max. inverse anode voltage (peak value) kV
High-voltage diodes and thyratrons					
DQ 2	Diode	Hg	A B C D	0·5	10
DX 2	Diode	Xe	A B C D	0·5	10
DQ 4	Diode	Hg	A B C	1·75	13·5
DQ 45	Diode	Hg	A B C	1·75	15
DQ 51	Diode	Hg	A B C	2·5	22
DQ 61	Diode	Hg	A B C	5	24
DQ 71	Diode	Hg	A B C	10	26
TQ 2	Thyratron	Hg	A B C	1	7·5
TQ 41[3]	Thyratron	Hg	A B C	1·75	15
TQ 51[3]	Thyratron	Hg	A B C	1·75	15
TQ 55	Thyratron	Hg	A B C	3	22
TQ 61	Thyratron	Hg	A B C	5	24
TQ 71	Thyratron	Hg	A B C	10	24
TQ 81	Thyratron	Hg	A B C	25	20
TQ 91	Thyratron	Hg	A B C	45	20
TQ 101[4]	Thyratron	Hg	A B C	115	20
Medium-voltage thyratrons					
QX 21	Tetrode	Xe	B	0·1	1·3
TQ 1/2	Thyratron	Hg+A	B	1·6	2
TQ 2/3	Thyratron	Hg+A	B	3·6	2
TQ 5/3	Thyratron	Hg	B	3·6	5
TQ 2/6	Thyratron	Hg+A	B	6·4	2
TQ 5/6	Thyratron	Hg	B	6·4	5
TX 2/61	Thyratron	Xe	B	6·4	1·5
TQ 2/12	Thyratron	Hg+A	B	12·5	2
TQ 2/25	Thyratron	Hg+A	B	25	2

[1] Mercury compound pellets in solid form are used in place of liquid mercury in all tubes filled with Hg and Hg+A. Various operational advantages are achieved by this (Brown Boveri patent).

[2] See Table II.

[3] Tubes differ by their various base fittings.

[4] In preparation.

– *High-frequency industrial generators for dielectric and induction heating*

Ever-increasing demands are also being made for higher outputs in this field. The output achieved per generator these days amounts to around 300 kW in the workpiece. Further requirements of growing importance for tubes of all classes are: Robust construction, high thermal overload capacity, high efficiency even at relatively low anode voltage, greatest possible economy, i.e. long operating life and low initial cost.

– *Amplifiers for industry and research*

There is a growing demand for high-power tubes for frequencies of several hundred Mc/s (e.g. in nuclear research).

– *High-voltage rectifiers*

As the output capacity of the transmitting and industrial tubes is increased, the capacity of the feeding rectifiers must also be increased correspondingly. There are other applications of d.c. energy at voltages from 20 to 60 kV and powers of several

TABLE II

Tube Applications[1]

Application range	Apparatus containing tubes	Use or function
Communications A[2]	Broadcast transmitters in the range from LW to VHF, television transmitters	RF amplifier
		Modulation amplifier
		High-voltage rectifier for tube feed
	Commercial communication transmitters in the range from LW to SW	RF amplifier
		Modulation amplifier
		High-voltage rectifier for tube feed
Industry B[2]	RF generators	Induction heating of metals for soldering, hardening, melting, etc.
		Dielectric heating of insulating materials for welding, glueing, drying, etc.
	AF amplifiers	Consumer load control
	Ultrasonic generators	Cleaning and metal-working
	Corona discharge generators	Plastic surface treatment
	Regulators and electronic controls in general	Motor controls and ignitron ignition, etc.
	High-voltage rectifiers > 10 kV d.c.	Power supply for electron beam furnaces and other users of high-voltage direct current
Research C[2]	Nuclear science, particle accelerators	Diverse amplifiers for beam control
	Laboratory amplifiers	Diverse research
Medicine D[2]	SW and VHF generators	Therapy

[1] Some less important uses are not listed here.

[2] These symbols are already listed in Table I in the main application column.

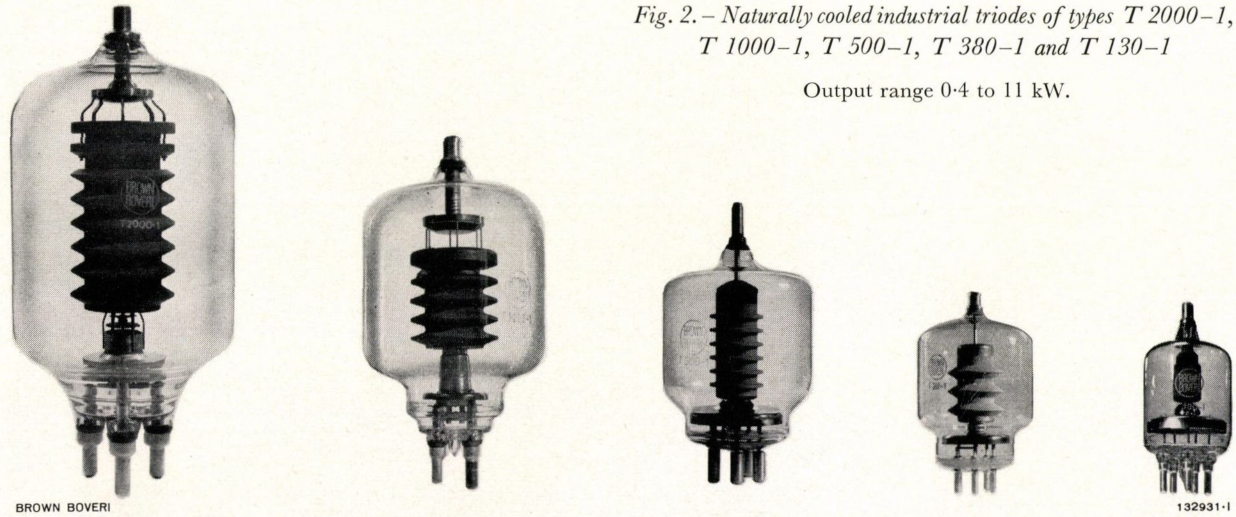

Fig. 2. – Naturally cooled industrial triodes of types T 2000–1, T 1000–1, T 500–1, T 380–1 and T 130–1

Output range 0·4 to 11 kW.

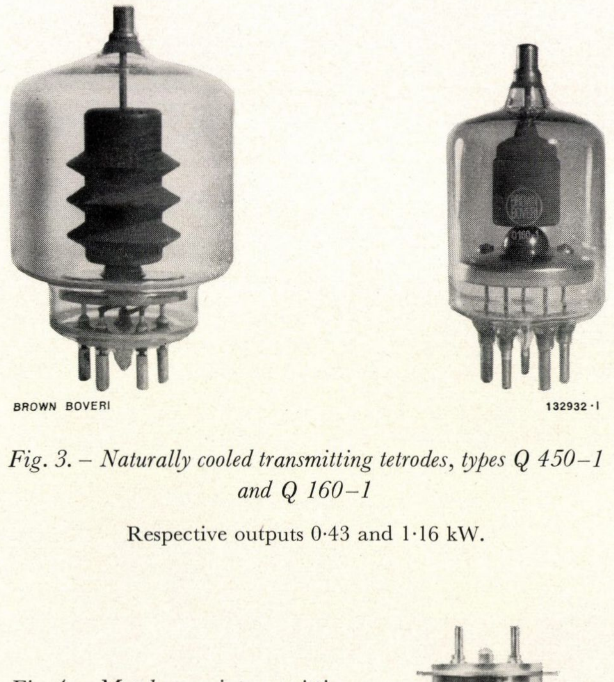

Fig. 3. – Naturally cooled transmitting tetrodes, types Q 450–1 and Q 160–1

Respective outputs 0·43 and 1·16 kW.

hundred kilowatts which are of growing importance (e.g. in nuclear research and metallurgy). These require the availability of suitable rectifier tubes and thyratrons.

It can be seen from the foregoing that the development is mainly taking place in the direction of higher outputs and higher frequencies. A series of experiments is being carried out with the object of investigating the feasibility of employing the latest materials in the most up-to-date tube designs.

Fig. 4. – Metal-ceramic transmitting and industrial triode with coaxial connections, type CTL 1–2

Output 875 W, max. frequency 600 Mc/s.

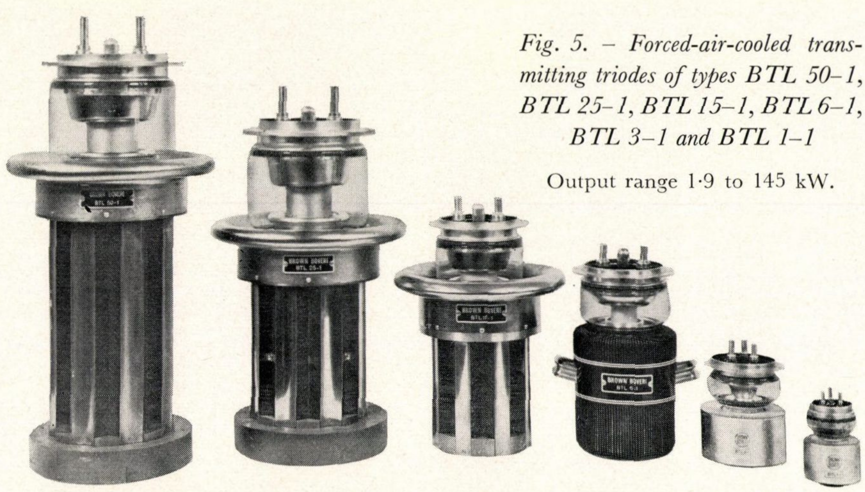

Fig. 5. – Forced-air-cooled transmitting triodes of types BTL 50–1, BTL 25–1, BTL 15–1, BTL 6–1, BTL 3–1 and BTL 1–1

Output range 1·9 to 145 kW.

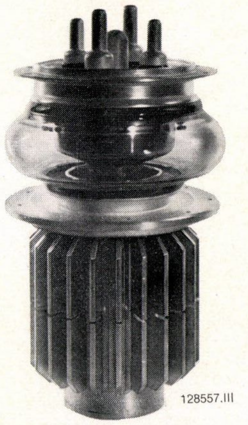

Fig. 6. – Vapour-cooled transmitting tetrode type FQS 15–1

Output 50 kW.
This tube has excellent power amplification and good linearity.

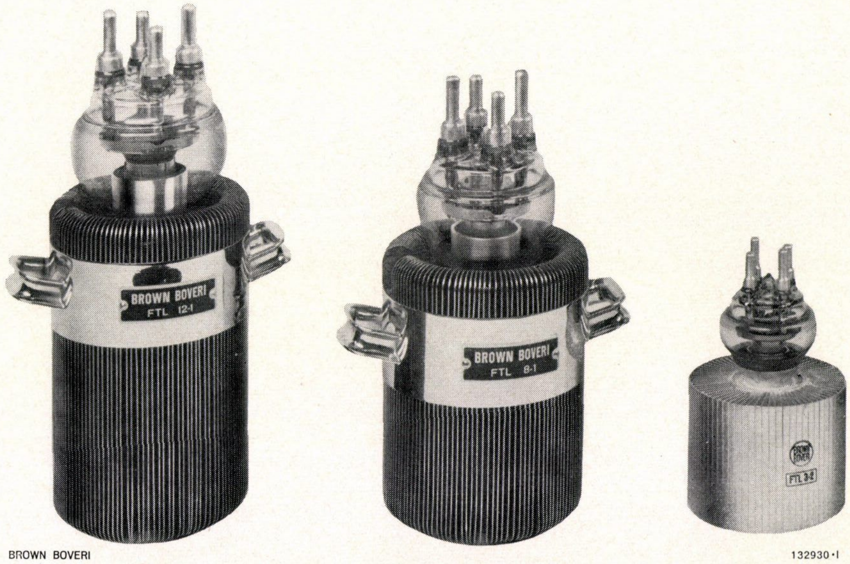

Fig. 7. – Forced-air-cooled industrial triodes, types FTL 12–1, FTL 8–1 and FTL 3–2

Output range 6·6 to 40 kW.

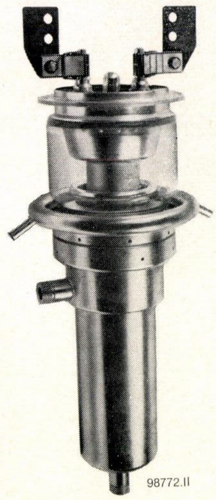

Fig. 8. – Water-cooled transmitting triode type BTW 50–1

Output 173 kW.

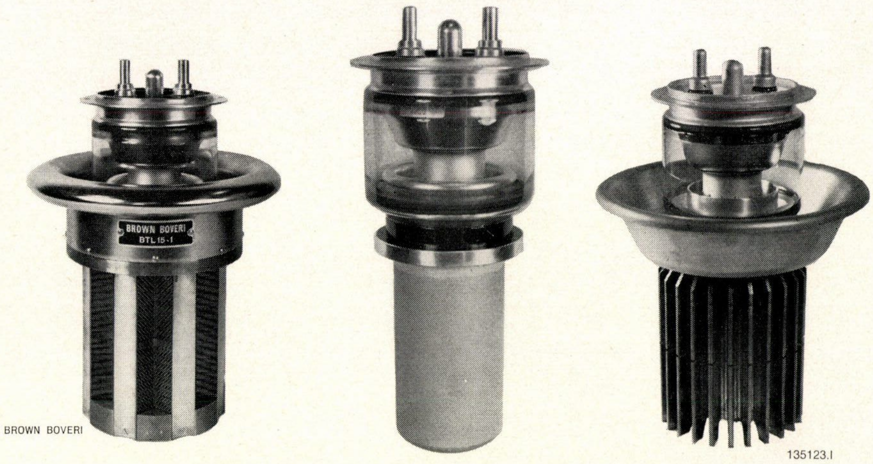

Fig. 9. – Transmitting triodes type BT 15–1 with three systems of cooling

Left = air cooling Centre = water cooling
Right = vapour cooling

Sales, Customer Advisory Service and After-Sales Service

Clientele

This includes all of the customers who either develop, manufacture or utilize any of the apparatus or installations listed in Table II. The customers can be divided into two main groups:

a. Apparatus and equipment manufacturers (customers for new equipment), and

b. Users (customers for replacement tubes).

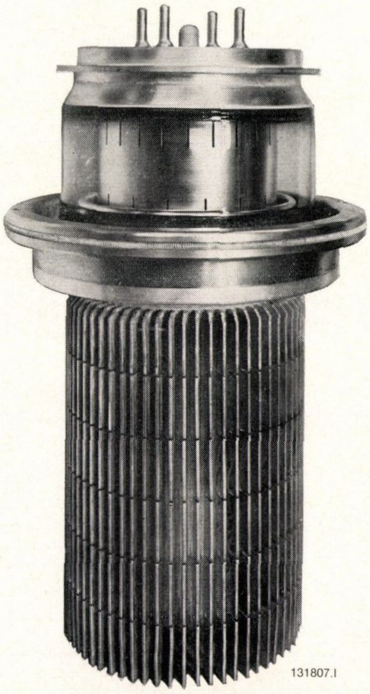

Fig. 10. – Super-power transmitting triode with vapour cooling, type BTS 150–2

Up to 600 kW output.

This is the largest tube made by us at present and weighs around 100 kg.

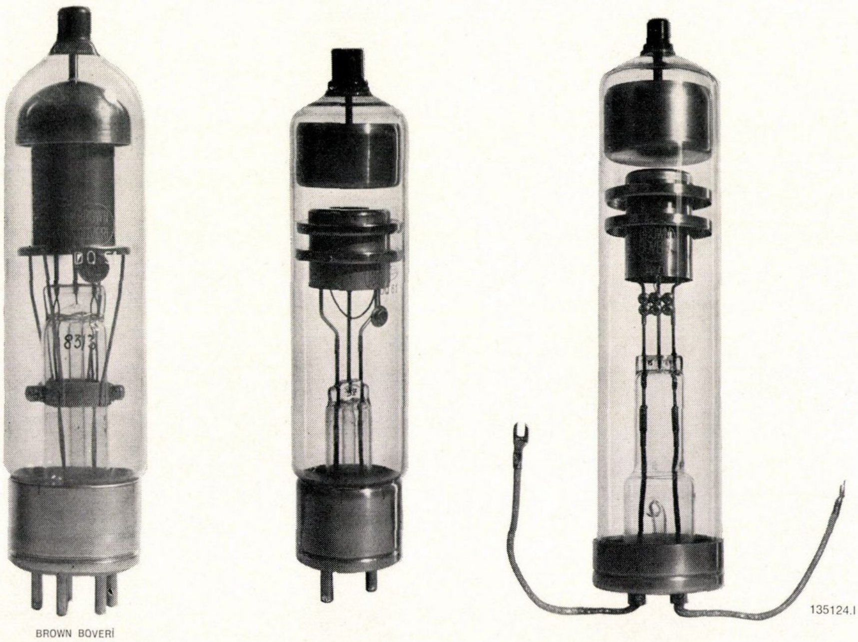

Fig. 11. – High-voltage diodes filled with mercury vapour, types DQ 51, DQ 61 and DQ 71.

Output range 2·5 A/22 kV to 10 A/26 kV.

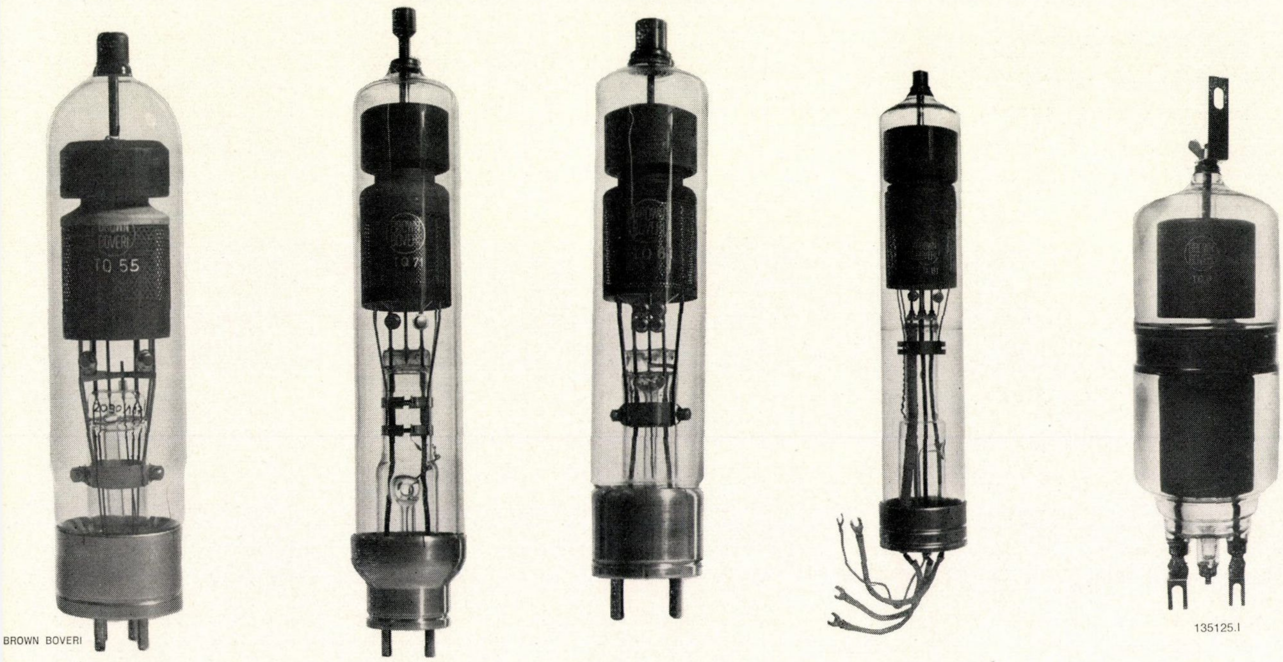

Fig. 12. – High-voltage thyratrons filled with mercury vapour, types TQ 55, TQ 71, TQ 61, TQ 81 and TQ 91

Output range 3 A/22 kV to 45 A/20 kV

A further group should also be mentioned here, being those customers who have converted equipment which was supplied by other manufacturers, to use our tubes in service.

Depending upon the customer's specific requirements it is the job of the sales department advisory section to establish a well-organized customer service system. This entails solving problems of application by instigating preliminary investigations in the applications laboratory, carrying out tube installation projects, preparation of individual data sheets up to descriptions and instructions for complete apparatus assembly and finally organizing after-sales service. These various tasks will be elucidated in the following chapters.

Customer Advisory Service

As equipment designers and other users of tubes are not always conversant with the actual tube data and their practical application, a comprehensive advisory service is essential. Brown Boveri have for a long time had a tube applications laboratory which was specifically designed and equipped for this purpose and is able to carry out experiments over a wide range of tube applications and supply complete sets of the requisite figures. The most suitable and practical solution to any special application problem can be found with the aid of these facilities. As a direct result of this the customer obtains optimum coordination between tubes and apparatus. This becomes self-evident with the passage of time as it results in long tube life. We consider it very important that our many years' experience in the use and application of tubes should be readily available to all interested parties. We have recently prepared special application reports especially for this purpose.

Publications

The following publications are available as a design basis for the client and also to illustrate the extent of our tube production programme:

- Individual data sheets for each type of tube (printed in German, French and English).
- An abridged data catalogue (Quick reference data) re-issued annually giving a comprehensive list of available equipment (printed in German, French, English and Spanish).
- Application reports on specific practices with dimensioning data for the corresponding circuitry (printed in German, French and English).
- Brochures and special publications covering many aspects of specific interest to the designer.

After-Sales Service

As electron tubes are subject to deterioration it is essential for replacements to be available at short notice. In order to guarantee this as far as possible throughout the world many Brown Boveri agencies carry a comprehensive stock of tubes from which it is possible to deliver spares in the shortest possible time. Every Brown Boveri agency is in a position to deal promptly with any customer's warranty claims (failure of tubes within the guarantee period) regardless of whether they supplied the tube or not. Finally, it is also noteworthy that certain general service operations on equipment containing electron tubes —such as rectification of a technical breakdown— can be carried out at the same time.

Future Prospects

A comparison of the latest developments in the fields of semiconductors and electron tubes shows clearly that the electron tube will retain its importance in the forseeable future. Interesting solutions have come to light, especially in the field of power electron tubes, which lead to the assumption that they will remain in use for some years to come.

(AH) A. LIENHARD

SELECTION OF TUBES FOR USE IN POWER GENERATORS AND RADIO-FREQUENCY AMPLIFIERS

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Anybody who has been given the task of equipping a h.f. generator or amplifier with the most suitable tubes, for the first time, is faced with a wide range offered by the various tube manufacturers. The object of this article is to point out some of the main aspects which have to be considered, some examples being given of how the original equipment requirements can best be met.

IN THE DESIGN of an r.f. appliance (industrial generator or transmitter) the working frequency or frequency band and the desired output are specified. Before determining the types of tube required, it is essential to answer those questions that are not directly connected with the tubes themselves, but which nevertheless directly affect the choice of tubes. These are questions relating to the technical requirements, e.g. power supply, method of cooling, space available (i.e. whether a compact construction is necessary or not), and of course the questions of an economic nature, such as initial cost, replacement costs, operating costs, maintenance costs and so on.

In many cases a tube is selected which only just produces the desired output and therefore only leaves a small safety margin. Obviously the initial cost of such a tube will be less than that of a larger one, though this will prove to be false economy in the long run. The tube's life is considerably shortened when it is run at or near the limit of its output. The technical ability of the operators also seriously affects the life of tubes. Only in rare instances are qualified personnel available to operate industrial generators, so that the safety margin has to be made correspondingly large.

The life expectancy of the tube should be taken into account when calculating the operating costs. The guaranteed life is of far less importance, as the effective life under normal conditions is many times greater. The guarantee covers the client against premature failure in the rare cases where defects escape detection during the final inspection (minute leaks which result in a slow deterioration of the vacuum, and also material flaws).

Method of Cooling

The d.c. input to the tube is completely converted into r.f. power (output) at an efficiency that is always less than 100 % (ratio of output to input). The difference is due to the heat generated, which has to be dissipated to prevent the anode from being destroyed. The method of cooling depends on whether the anode is located in the vacuum inside the envelope or whether it is part of the surface of the discharge vessel, in which case the anode is in direct contact with the cooling medium. Tubes of the first type are referred to as naturally cooled, those of the second type as external-anode tubes.

In operation the anode temperature of naturally cooled tubes rises so much that the heat has to be dissipated at the anode, the greater part passing through the glass envelope to the surrounding atmosphere, while some is absorbed by the glass. At relatively low anode dissipations the rise in temperature of the wall is so small that it can be adequately cooled by the surrounding air, which is warmed as it passes over the outside surfaces of the tube. At higher dissipations it is necessary to maintain the envelope temperature within tolerable limits by providing supplementary cooling by a fan (forced-air cooling). In modern high-power equipment (naturally cooled tubes with an anode dissipation of 5 kW are not uncommon nowadays) the glass envelopes are quite large and therefore the temperature rise inside the transmitter enclosure is also considerable, necessitating the provision of an adequate cooling system. For these reasons it is impossible to achieve very compact designs.

There are three possible cooling systems that can be used with external-anode tubes. Firstly forced-air cooling, where the anode is fitted with a large number of lamellar cooling fins cooled by a stream of air flowing rapidly over them. Secondly water cooling, where the smooth walls dissipate heat to a fast current of water in which the anode is submerged. Thirdly vapour cooling, where the anode is fitted with specially shaped cooling fins and immersed in water. The dissipated heat boils the water in contact with the anode, the steam thereby produced rising through tubes into a heat exchanger which absorbs the latent heat of evaporation. The steam condenses again, this water being returned to that surrounding the tube. The speed of this cycle adapts itself to the quantity of heat to be dissipated. The Table below compares the characteristics of the various cooling systems.

In many cases it is necessary to cool not only the anode, but also the other electrode connections (cathode bushings and grid connections) with air as these parts, especially at higher frequencies, are affected to a marked degree by the capacitive currents. These can become quite heavy at high frequencies due to the magnitude of the alternating voltage between the electrodes and due to their mutual capacitances.

Power Supply

Polyphase rectifiers are used exclusively in high-output generators and transmitters. In the latter case they are equipped with anti-hum filters. Single-phase rectifiers with or without filters are sufficient for lower outputs.

For cheap industrial generators the rectifier can be omitted and the tube operated with single-phase current. However, it should also be noted that, in

Comparing methods of cooling

Method of cooling	Range of application (approximate values)	Special features
Natural cooling	Low outputs, up to 10 kW	Inexpensive; cheap tubes and equipment; silent operation; small cooling fan required; slight air circulation desired (to remove dust).
Forced-air cooling	Outputs from 5 to 100 kW. Also at very high frequencies	Constant supply of coolant always available, advantageous in dry climates, relatively low installation costs. If air is dusty, filter needs periodical cleaning. Hot air has to be exhausted outside the building, needing fans and ducting: relatively high temperatures, therefore more susceptible to overloading than following methods; relatively noisy.
Water cooling	From 5 kW upwards	Efficient method, hence ample overload reserve; silent operation, low temperatures in equipment. Inexpensive, easily replaced tubes. Nearly all the heat generated can be dissipated in the water. Pumps and reserve tank needed if closed circuit employed. Mains water can often be used, but may involve descaling. The complex piping and insulating coils make the installation rather costly. The rate of flow may have to be adapted to suit overload conditions.
Vapour cooling	From 20 kW upwards	Very efficient method, automatically adjusts itself to the prevailing load, good overload reserve. Silent operation. No or only small pumps, etc., needed, hence low consumption in auxiliaries and high overall efficiency. Heat can be used to heat building, for drying, etc. Little water required. Condenser with stand-pipe required. Installation relatively expensive.

this case, the tube can only deliver a fraction of the power that it would produce in a filtered circuit, this also applying to a lesser extent in single-phase operation. The reason for this is that during each cycle of the mains-frequency current the anode current is low or even negative for part of the time, so that the average output drops by 10 % in unfiltered single-phase operation and by 30 % when the tube is fed with pure alternating voltage. In certain cases it is necessary to employ a tube of higher output rating, in which case one must decide whether dispensing with the rectifier is economically advisable or not.

Selection of Tubes According to the Electrical Operating Requirements

Output

Under normal circumstances one tube should be selected which will fulfil all the essential requirements. Only under very special conditions or for extremely high outputs is the use of several tubes in parallel necessary. Push-pull connection should only be used when it is absolutely essential (e.g. a.f. modulator or amplifier). Under certain circumstances it is more practical to use more tubes than are actually needed and to connect them in parallel, so that individual tubes are less heavily loaded, which means that the grid driving power and also the size of the preliminary stage can be reduced.

Tube manufacturers stipulate certain data for every type of tube and recommend that these figures should not be exceeded under any condition. Among these are the maximum permissible grid dissipation and anode dissipation, the maximum peak anode current, also the maximum frequency and the maximum anode voltage. The operational settings should be such that these maximum values are not exceeded. Above all, the grid dissipation is very critical, so that even if the permitted values are only slightly exceeded, without any apparent detrimental effects at first, the grid surface will gradually deteriorate in time due to the sharp increase in the thermal emissivity of the grid, leading to premature failure. Tubes should also be designed to suit the frequencies. The use of coaxial tubes with bushings of large diameter is recommended when high frequencies (from 100 Mc/s upwards) are involved. Such expensive equipment is not necessary at lower frequencies. In certain circumstances it may be advisable to lower the direct anode voltage to avoid overloading the bushings with capacitive current.

Efficiency

A high efficiency is always desirable, not only to keep the anode dissipation as low as possible, but also to reduce operating costs (power supply). In the transmitter field, where one endeavours to use the highest possible anode voltage with a high modulation index, this is particularly important as the alternating anode voltage should only be slightly less than the direct anode voltage. An increase in the efficiency can be obtained by suitably adapting the amplitudes of the alternating and direct grid voltages so that the duration of current flow is shortened and, at the same time, the height of the current pulse is increased. However, both these measures add to the grid load and therefore cannot be applied arbitrarily, as the driving power is also increased. Therefore the operational setting has to be a compromise between the demand for higher output and high efficiency, without exceeding the permitted grid dissipation.

No-Load Operation of Industrial Generators

When generators have to be operated at varying loads and for varying periods, the conditions at no-load must also be taken into consideration. On switching over from full-load to no-load the input to the tube and the anode dissipation are reduced, but the grid dissipation increases. This must be allowed for when establishing the full-load setting, so as to ensure that the grid is not overloaded.

Intermittent Operation of Industrial Generators

In many industrial applications high-frequency power is needed for short periods, sometimes only for a few seconds, e.g. for welding plastics, induction hardening, wood glueing, etc. In most cases the operation is followed by a period of rest. This permits a higher anode dissipation to be used during the working period than would be normally permitted for continuous operation, since cooling takes place during the rest period and, furthermore, the temperature of the anode does not rise unduly during the working period, especially if the anode has a high heat capacity (e.g. graphite anodes as in types T 150–1, 380–1, 1000–1 and 2000–1). In most of these cases a smaller tube can be used than would be required for continuous operation under similar conditions.

Stability, Grounded Grid or Grounded Cathode Connection in Amplifiers

Triodes can be operated either in grounded grid or grounded cathode connection. At high frequencies (short-wave transmitters) it is perferable to use the grounded grid connection. Of course it is possible to employ grounded cathode in amplifiers, provided the grid-anode capacitance is neutralized to achieve stable operation, but then the neutralization usually has to be changed every time the frequency is altered.

Triodes in grounded grid connection operate far more stably and do not require neutralization, but this arrangement requires a far higher driving power, which reduces the power gain and necessitates the provision of a preamplifier stage.

Tetrodes are operated in grounded cathode connection as they are inherently more stable; only a small, non-critical amount of neutralization is needed and it does not have to be changed when the frequency is altered. However, tetrode amplifiers are generally more difficult to handle when tuning. The screen-grid voltage should also be modulated in anode-modulated amplifiers. Driving powers are small. The power limit is determined by the screen-grid dissipation capacity. When transmission is disturbed or interrupted, e.g. on standby, the screen-grid of the tetrode is more heavily loaded than the control grid.

Examples of the Tubes Selected for Certain Applications

10-kW Generator for Induction Heating

A generator used for induction heating of metals is required to produce 10 kW by creating eddy currents in the workpiece. For this task inductors are provided which are closely coupled to the workpiece and, due to their small size, they are water-cooled. It is therefore convenient to use water-cooled tubes. At frequencies around 450 kc/s industrial tubes are very practical because of their simple but robust construction, which will guarantee a long life even under the most adverse conditions and with rough handling.

As the current in the inductor is heavy and since heavy reactive currents are produced in the output circuit, the correspondingly high reactive and dissipation powers in the output circuit must be taken into consideration. If we allow for 20 % losses in the output circuit, a tube must have an effective output of 13 kW if it is to produce 10 kW in the workpiece. In the absence of the workpiece from the inductor, no typical no-load requirements arise, owing to the ever-present losses, so that the grid dissipation can be nearer the maximum permissible value at full load. In this way the tube attains a higher efficiency. Operation at the highest possible efficiency with the maximum permissible anode voltage is often not practicable, for constructional reasons, because the close coupling between the workpiece and the inductor and also between the anode circuit and the output circuit, which are so essential, can only be achieved by having a small gap between the windings, which adds to the risk of breakdown. However, the capacitances of the resonant circuit also necessitate the selection of a lower anode voltage in some cases. In the instance referred to here an anode voltage of 8 to 9 kV was deemed to be suitable. Therefore a water-cooled tube is required which can produce about 13 kW at an anode voltage of 8–9 kV. We would therefore put forward our industrial tube type FTW 8–1.

5-kW Generator for Welding Plastics

Small and medium-capacity h.f. generators are used for welding plastic sheets, so that naturally cooled or forced-air cooled tubes can be utilized. If large quantities have to be produced with automatic feed, one must allow for the data applying to continuous operation. With manual charging and when rest periods are sufficiently long, the data applying to intermittent operation may be employed.

Our experience is that approximately 15–20 % of the output is consumed in the output and secondary circuits, so that the tube must have a rating of 6 kW in order to produce 5 kW in the workpiece. This can be produced equally well by the type T 2000–1 naturally cooled tube, or by the FTL 3–2 tube with forced air cooling. The former requires only a simple fan for cooling but occupies more space in the high-frequency part; the latter requires less space, but needs a larger fan for cooling. The triode T 2000–1 delivers about 6 kW in continuous operation and about 11 kW in intermittent operation. The corresponding figures for the FTL 3–2 are 6·3 and 7·8 kW. Therefore, provided sufficient space is available in the h.f. section, preference should be given to the T 2000–1.

R.F. Final Stage of a 50-kW Short-Wave Transmitter

At this output full advantage can be taken of vapour cooling. Allowing about 10 % losses in the tuning elements, the tube must be able to produce a carrier power of about 55 kW. The high efficiency that is so important in transmitters can be achieved by accurate voltage control and by using a narrow current flow angle, without incurring any risk of overloading the grid in operation, as there is no load surge. Medium and short-wave transmitters are normally anode-modulated and when the carrier setting is established the high peak anode currents occurring at maximum modulation must be taken into account. At elevated frequencies the grounded grid connection is preferred for stability reasons, as already mentioned. For the above carrier power the tube type BTS 25–1 operating at an anode voltage of 12·5 kV is adequate. The driving power is then 6·5 kW and the driver stage must also be modulated.

Tetrodes may also be used, with the advantage that operation in grounded cathode connection is completely stable and the driving power is low. Two transmitting triodes in parallel, type FQS 15–1, would also produce the same carrier power of 55 kW at an anode voltage of only 9 kV, for instance, while for the driving power of 500 to 600 W a small naturally cooled tube, e.g. the tetrode Q 450–1, will suffice.

All these aspects are of course purely summary in nature but should nevertheless enable the right tube to be selected from a catalogue.

For the definite selection particular attention should be paid to the calculation of the operating conditions, especially the dissipation. The data given in the catalogues as normal figures are naturally average values. In certain cases other settings may be preferable. Therefore in such cases close cooperation between the designer of the equipment and the tube manufacturer is obviously advantageous. After all, the tube manufacturer is naturally interested in seeing that his tubes are employed under the most favourable conditions.

(AH) O. ZEHNDER

THE BROWN BOVERI BT 150-2 HIGH-POWER TRANSMITTING TRIODE

621.385.3

The largest transmitting triode produced by Brown Boveri, the BT 150–2, is described, and some of the operating data are given. The water-cooled model is denoted BTW 150–2, and the vapour-cooled variant BTS 150–2. The tube is suitable for use in very high-power long, medium and short-wave transmitters, and also high-frequency industrial generators. It can also be employed in the nuclear physics field for the high-frequency generators of accelerators.

THE RISING DEMAND for medium and short-wave transmitters and for very powerful high-frequency industrial generators (outputs of 500–1000 kW are no longer a rarity) can be satisfied only by providing transmitting tubes designed for outputs considerably higher than was the case a few years ago. The technique of connecting several units in parallel can be used only to a small extent, and with short waves leads to serious difficulties, so that connecting more than two tubes in parallel is not to be recommended. For this reason Brown Boveri decided some years ago to extend their BT range of transmitting tubes to higher outputs by developing a new type, the BT 150–2. The largest type up till then was the BT 50–1. The new tube is now in service in Switzerland and abroad.

In the present article we shall first consider certain details of the tube's design. This will be followed by discussion of the principal features of the tubes and some examples of the operational settings for r.f. and a.f. amplifiers. As a result of the favourable experience gained it has been possible to exceed the original design values substantially.

Determination of the direct anode voltages was based on the stipulation that the tubes must be capable of use both in industrial generators and in transmitters. Whereas with transmitters there is a well-defined trend towards higher anode voltages, lower values are preferred in the case of industrial generators. This, however, means handling heavier currents (for the same power output) which in turn implies a cathode with greater emission and higher filament power and a grid capable of dealing with heavier loads. The anode voltage has been made higher than that of the other tubes in the BT series, amounting to 18 kV in the case of unmodulated class C r.f. amplifiers for frequencies up to 30 Mc/s, and 15 kV for carrier operation with anode modulation; a lower anode voltage must be selected for higher frequencies. At the same time a cathode with higher emissivity was incorporated.

The dimensions of the tube are shown in Fig. 1. The left-hand half of the diagram shows the water-cooled version, while on the right is the vapour-cooled type. The construction of the tube is as follows: a copper anode (6) is connected to the glass envelope (4) via a Kovar cone (9); at the other end of the envelope is the grid flange (3). The base (8), which fits exactly in the grid ring (3) and carries the grid, the cathode structure and the filament terminals (1), is arc-welded in the flange to provide an air-tight seal.

It was decided not to replace the glass envelope by a ceramic one, as in the intended frequency range there is no need for the considerably more expensive ceramic material which would thus only increase the cost of the tube unnecessarily. For the same reason the filament terminals were not arranged concentrically.

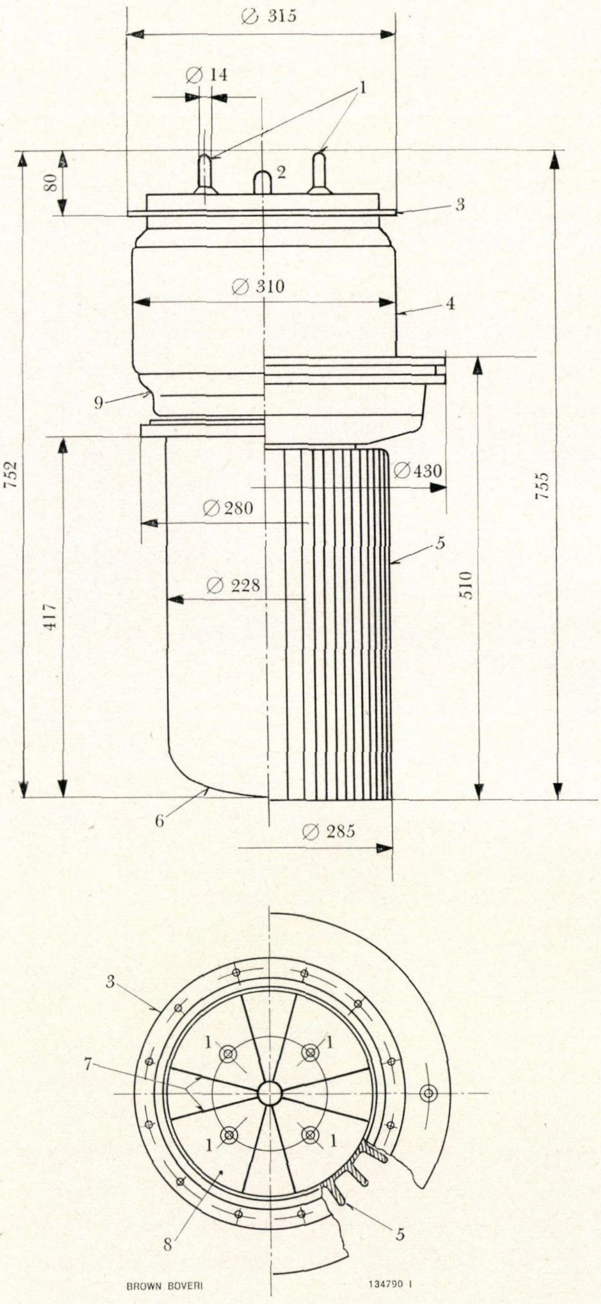

Fig. 1. – Dimensioned outline

1 = Filament terminals
2 = Protective cap over exhaust stem
3 = Grid flange
4 = Glass envelope
5 = Cooling fins
6 = Anode
7 = Stiffening ribs
8 = Metal base
9 = Kovar cone

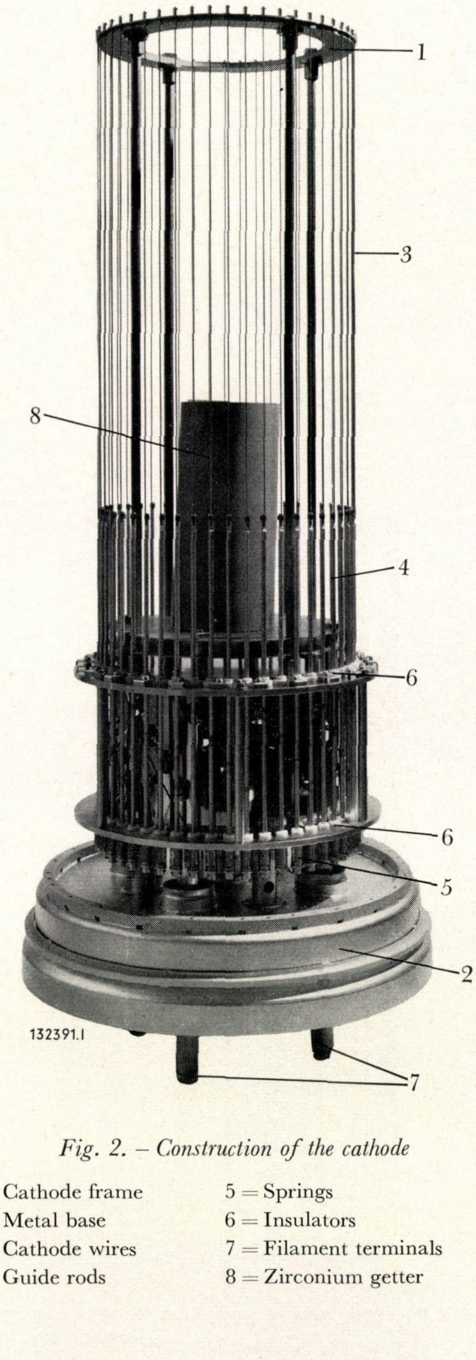

Fig. 2. – Construction of the cathode

1 = Cathode frame
2 = Metal base
3 = Cathode wires
4 = Guide rods
5 = Springs
6 = Insulators
7 = Filament terminals
8 = Zirconium getter

The cathode (Fig. 2) of thoriated tungsten is in the form of 48 straight wires (3) fixed at one end to a rigid frame (1). The other ends of the wires are connected to separate guide rods (4) held by two insulators (6) and attached to the frame in such a way that they are free to move longitudinally. The free end of each guide rod carries a tensioning spring (5) so that each wire and its guide rod is held taut separately. This method of springing ensures that despite any irregularities in the length or temperature of the wires, they are always under tension and stay straight without any need for intermediate supports. Wires mounted in this manner are subject only to tensile stress, bending stresses can never occur. This is an advantage as carburized tungsten wires have little resistance to bending, and a bending load can easily lead to failure. Fitting the wires into the frame is very simple.

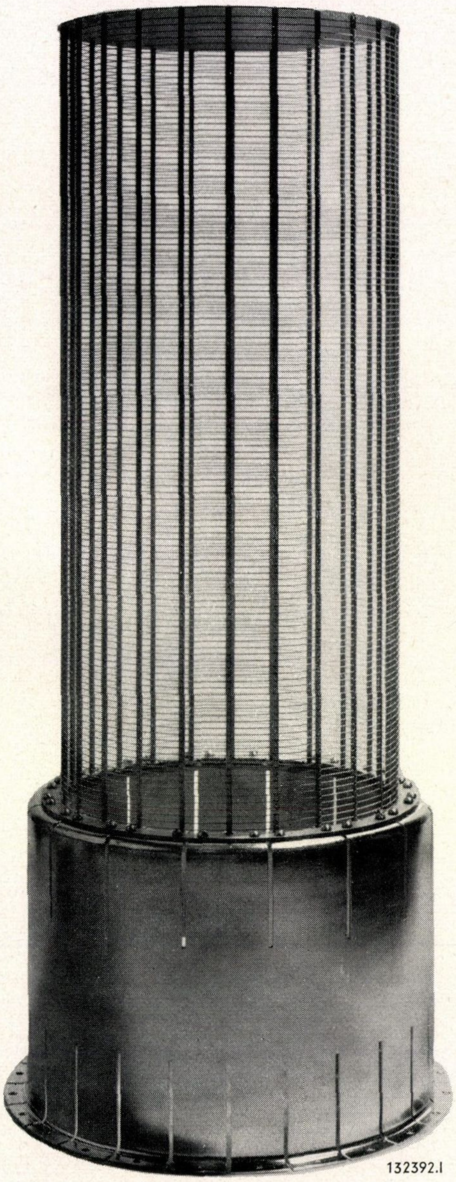

Fig. 3. – Grid

The frame itself is screwed to the grid base (2 in Fig. 2) through insulators. The grid base also carries the four filament bushings (7). These are only used to carry current and do not have to support the entire cathode structure, as is usually the case. The 48 guide rods are flexibly connected in groups of 12 to the cathode bushings. In this way each bushing has to carry only half the filament current. When in service the four terminals (7) are joined together in pairs so that the magnetic forces exerted on each wire by the adjacent wires cancel each other out. This is important in view of the length of the wires.

With a filament heating power of 11·5 kW the cathode provides an emission current of 1200 A, which means that peak cathode currents of up to 450 A are permissible under normal operating conditions.

The grid (Fig. 3), which is also screwed to the grid base, is in the form of a cage of tungsten wire coated with a thin layer of rhenium followed by a layer of platinum [1]. The purpose of this double coating is to prevent the grid from becoming activated by thorium atoms evaporating from the filament. True, simply plating the grid with platinum also prevents activation—for a time, but when the grid operating temperatures are high, diffusion eventually gives rise to an alloy of platinum and tungsten which then no longer possesses the essential attribute of being resistant to activation. The result is thermal grid emission which increases with time and finally makes the tube unusable. The purpose of the layer of rhenium between the tungsten core and the platinum coating is to prevent the tungsten and platinum from diffusing. (For further details see [2].) In recent years this technique, developed by Brown Boveri, has yielded excellent results regarding the grid load capacity and, hence, the tube life. The maximum permissible grid dissipation of the BT 150–2 is 7 kW.

In order to protect the metal base of a tube from deformation by the atmospheric pressure it is stiffened by means of radial fins. Normally the fins are soldered to the inside of the base. In the case of the BT 150–2, however, they are on the outside and thus help to improve cooling. Otherwise, if cooling were inadequate the base would become too hot, owing to the high filament heating power of the cathode. A

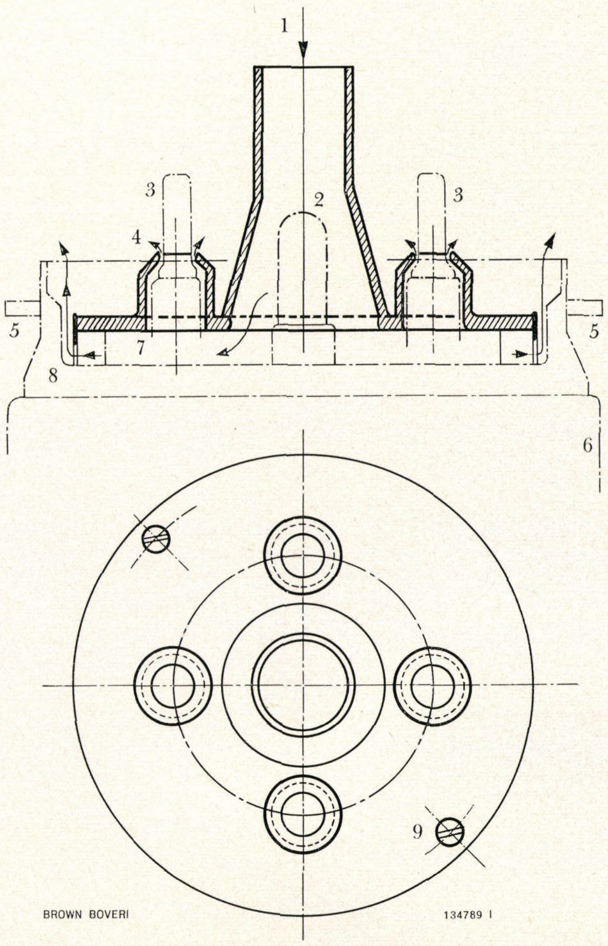

Fig. 4. – Cooling-air supply to the base

1 = Air inlet
2 = Protective cap over exhaust stem
3 = Filament terminals
4 = Air outlet
5 = Grid flange
6 = Glass envelope
7 = Stiffening ribs
8 = Metal base
9 = Fixing screws

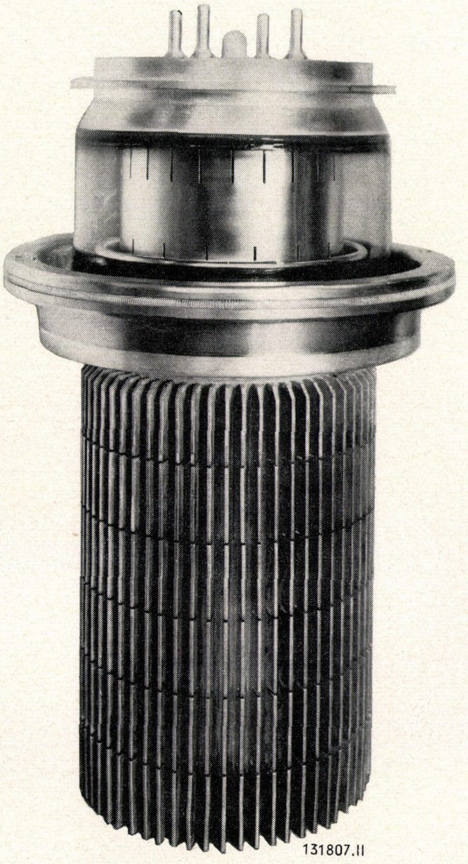

Fig. 5. – The BTS 150–2 with vapour-cooled anode

shaped attachment of plastic material (Fig. 4) ensures that all critical parts of the surface are swept by the air stream; at the same time its design enables a considerable reduction to be made in the volume of air required. The air leaving the supply pipe passes over the base and along the fins, and also pro-

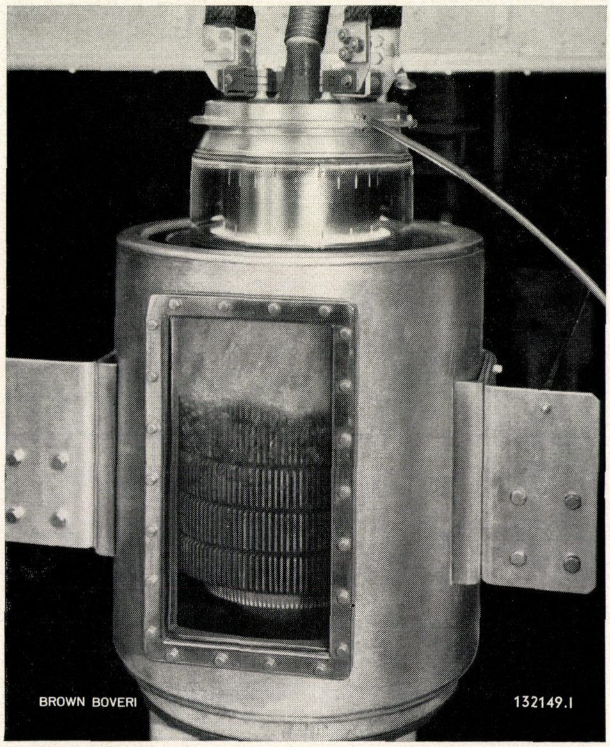

Fig. 6. – The BTS 150–2 in its boiler on the test stand

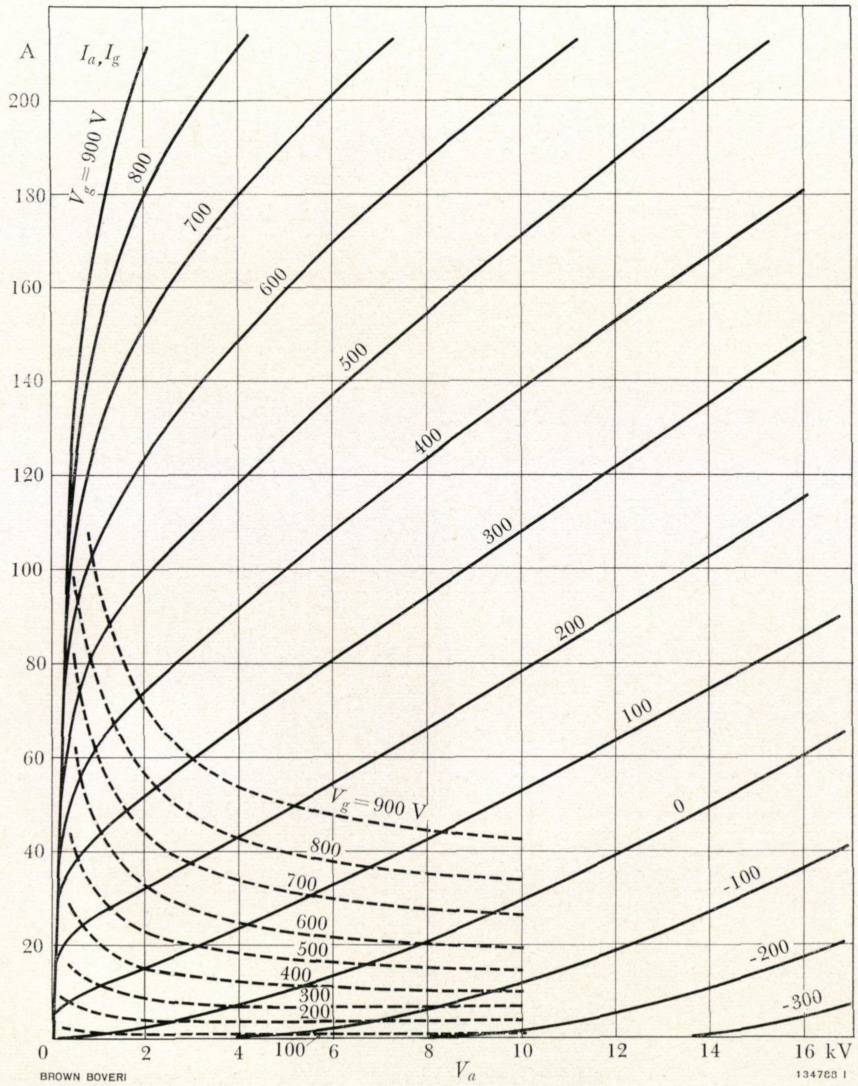

Fig. 7. – Characteristics

I_a = Anode current ——
I_g = Grid current - - - -
V_a = Anode voltage
V_g = Grid voltage

vides intensive cooling for the cathode connections. A flow rate of 5 m^3/min is sufficient. The cooling system is effective to the extent that the terminals (3) can easily be touched with the hand when at their hottest. Following the usual practice, the anti-corona rings are in the form of nozzle rings to cool the envelope and the glass-metal joints of the grid and cathode. With the BT 150–2 the amount of air required for this is about 0·2 m^3/min.

The BT 150–2 is available in either water-cooled (BTW 150–2) or vapour-cooled (BTS 150–2) versions; owing to the high anode dissipation, air cooling for the anode is no longer practical. At the maximum permissible anode dissipation of 220 kW the special cooler for the water-cooled version requires a water flow rate of 220 l/min, in which case the pressure drop across the cooler is 0·95 kg/cm^2. There is still a large safety margin, should overloading occur.

The anode of the vapour-cooled version (Fig. 5) has a large number of long, comparatively thin fins. These are either hard-soldered into longitudinal slots or consist of T-shaped sections which are arranged with the crosspiece against the smooth anode and then brazed to it. The advantage of both methods lies in the absence of soldered joints; both provide effective cooling and permit a maximum anode dissipation of 220 kW. This is far higher than the values reached in normal service.

Fig. 7 shows the I_a, V_a and I_g, V_g characteristics. General data and the permissible values for voltages, dissipation and peak cathode current are given in Table I, while Table II lists examples of operating data. All these examples correspond to average conditions. Obviously, other settings are possible in which individual parameters are somewhat higher.

Fig. 6 shows a BTS 150–2 in its boiler on the test stand.

(DJS) A. RUSTERHOLZ

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[1] Swiss Patent 370844

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TABLE I

General data		
Cathode: thoriated tungsten, directly heated		
Filament voltage		20 V ± 5%
Filament current	appr.	570 A
Cold filament resistance		0·004 Ω
Mutual conductance (V_a = 6 kV, I_a = 16 A)	appr.	175 mA/V
Amplification factor	appr.	45
Inter-electrode capacitance		
Grid-to-anode	appr.	200 pF
Grid-to-cathode	appr.	450 pF
Anode-to-cathode	appr.	5 pF
Length	appr.	750 mm
Greatest diameter		315 mm (BTW 150-2) or 430 mm (BTS 150-2) (see Fig.1)

Maximum operating data	
Direct anode voltage (in Class C r.f. amplifier unmodulated)	18 kV
D.C. grid voltage	—1500 V
Anode dissipation	220 kW
Grid dissipation	7 kW
Peak cathode current	450 A
Frequency (for full anode voltage)	30 Mc/s

TABLE II

Examples of Normal Operating Data

The examples below relate to average service conditions. Other settings are possible in which individual parameters are somewhat higher.

1. Class B a.f. power amplifier and modulator (2 tubes in push-pull)

D.C. anode voltage		15	12·5	kV
D.C. grid voltage		—295	—240	V
Peak d.c. grid-to-grid voltage		1890	1780	V
Max. signal d.c. anode current		82	82	V
Zero signal d.c. anode current		5	5	A
D.C. grid current	appr.	18	18·5	A
Driving power	appr.	15·3	14·6	kW
Power output		870	710	kW
Load resistance, anode-to-anode		420	340	Ω

2. Anode-modulated r.f. amplifier (class C telephony) (carrier values for max. modulation of 100%)

D.C. anode voltage		15	12·5	kV
D.C. grid voltage		—1055	—1120	V
Peak r.f. grid voltage		1745	1930	V
D.C. anode current		30·6	37·5	A
D.C. grid current	appr.	7·4	10·2	A
Frequency	max.	30	30	Mc/s
In grounded-cathode circuit:				
Driving power	appr.	12·2	18·5	kW
Power output		355	355	kW
In grounded-grid circuit (including power transferred from driver stage):				
Driving power	appr.	60	83·5	kW
Power output		403	420	kW

3. R.F. power amplifier (class C telegraphy):

D.C. anode voltage		18	15	kV
D.C. grid voltage		—775	—770	V
Peak r.f. grid voltage		1460	1580	V
D.C. anode current		35	43	A
D.C. grid current	appr.	8·0	11·5	A
Frequency	max.	30	30	Mc/s
In grounded-cathode circuit:				
Driving power	appr.	11	17	kW
Power output		500	500	kW
In grounded-grid circuit: (including power transferred from driver stage):				
Driving power	appr.	55	76	kW
Power output		545	560	kW

ACTIVATION OF TANTALUM AND PLATINUM BY THORIUM AND THORIA

621.385.032.213.13

The work function of tantalum and platinum coated by evaporation with thorium and thorium oxide is examined and fundamental differences are indicated. This article is an extract from a detailed study at present being undertaken in collaboration with the Department of Advanced Electrical Engineering of the Swiss Federal Institute of Technology in Zurich.

Introduction

ALTHOUGH grids with platinum surfaces have been widely used for many years in modern transmitting tubes with thoriated tungsten cathodes, the literature contains next to nothing on the work function of platinum which has been exposed to thorium or thorium oxide vapour. It has been generally assumed, in fact, that such deposition has no effect on the work function of platinum, and attempts have been made to explain this in terms of diffusion phenomena. Nevertheless, experience in the field of tube manufacture has proved again and again that, having been coated with cathode material, platinum electrodes no longer exhibit the relatively high work function of pure platinum ($\varphi = 5{\cdot}32$ V) but yield measured values of between 4·2 and 4·8 V. Furthermore, the original condition can no longer be restored, even by heating to 1600 °K for many hours.

Depending on the ambient conditions of the grid, however, the specific emission of platinum remains within tolerable limits and, with a constant grid temperature of 1500 °K, rises from the value for pure platinum (10^{-9} A/cm^2) to something of the order of 10^{-6} or 10^{-7} A/cm^2. Under unfavourable circumstances the thermal electron emission from the grid can rise so high that proper operation of the tube is endangered.

The aim of the present article, therefore, is to examine the reasons for the increase in emission of platinum when it has been coated by cathode material, in order to elucidate the diffusion mechanism of thorium in platinum on the one hand and, on the other, so as to be able to study further possibilities of reducing primary grid emission.

Activation of Tantalum

In order to be able to understand the processes of deposition on platinum, it was first necessary to ascertain the extent to which tantalum can be activated by the evaporation products of conventional thoriated tungsten cathodes.

The activation of tantalum by thorium has been studied before, it is true, but not under the same conditions as here. The observation that in the first hours of operation both thorium-tungsten cathodes and cathodes made of pure metallic thorium initially produce predominantly thorium oxide, and that pure thorium is not vaporized until later, provided grounds for repeating these measurements. This phenomenon gives rise in the course of a tube's life to all kinds of deposition processes and combined effects which are difficult to distinguish.

Since, unlike platinum, tantalum can be cleaned by heating after each coating process, exeperiments can be interrupted at the various stages, the original condition restored and the test repeated. The degree of activation of the tantalum was determined by recording and comparing its Richardson lines, the slope of which is known to be a measure of the work function. This was done before and after coating

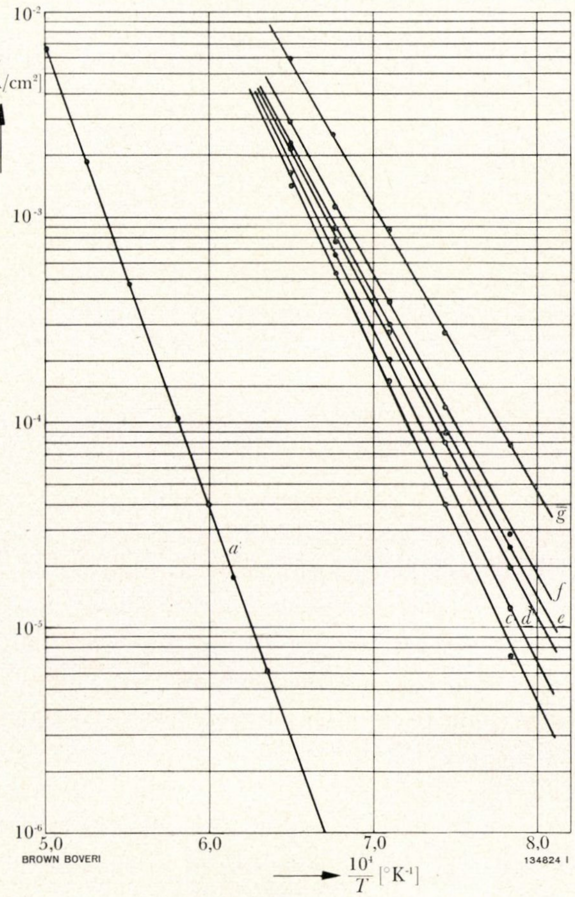


Fig. 1. – Richardson lines for tantalum coated with thorium or thorium oxide

Curve *a*: pure tantalum
Curves *b–g*: coated in stages

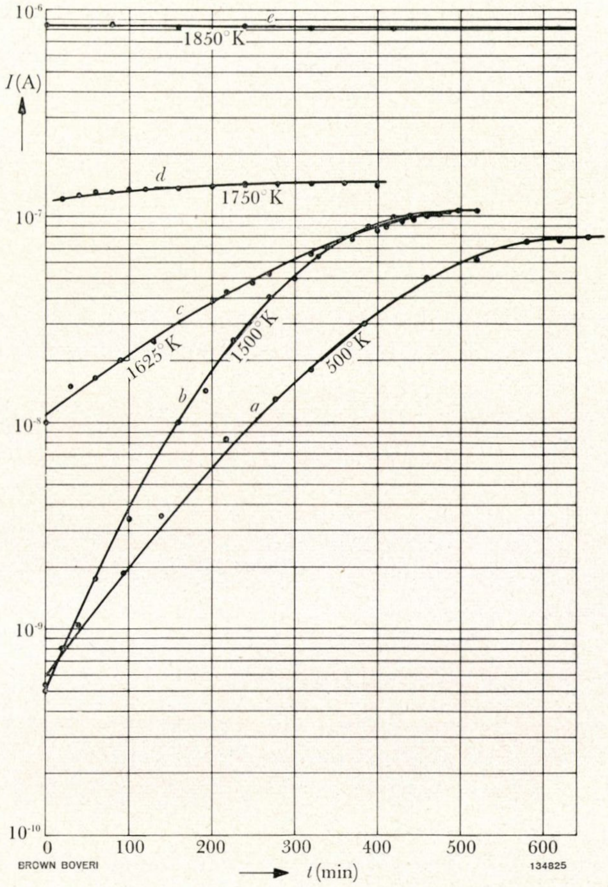


Fig. 2. – Activation of platinum coated at different temperatures with thorium

with the required quantity and quality of a chosen cathode material.

In each series of measurements the tantalum test wire, previously cleaned by heating, was exposed to the chosen vapour at a specified temperature (coating temperature) until the curve of emission as a function of time was approximately horizontal, thus indicating a monolayer of the deposited material.

At this point, deposition was interrupted and the work function was determined by Richardson plots.

The coating could be completely evaporated again by heating for a short time at 2400 °K, whereupon the wire was once more ready for deposition. The effectiveness of cleaning could be ascertained by checking the work function. A set of Richardson lines is illustrated in Fig. 1. Line *a* is the Richardson line of pure tantalum with a work function of $\varphi = 4{\cdot}15$ V and a value for the constant A of 32 A/cm² deg K². These values agree with those given in the literature for pure tantalum. Line *b* represents the condition found after the *first* deposition, which gives us values of $\varphi = 3{\cdot}15$ V and $A = 42$ A/cm² deg K². These figures correspond to the data for pure thorium oxide on tantalum. Subsequent study of the cathode (by X-ray diffraction or electron absorption diagrams obtained with the microprobe) verified these measurements in that it was found that the surface of the evaporating cathode consisted principally of thorium oxide. The work function after the *second* coating is shown by curve *c*, for which $\varphi = 2{\cdot}95$ V and $A = 4{\cdot}0$ A/cm² deg K². It can be inferred from the decrease in the work function that not only thorium oxide has been evaporated, but also thorium, though in small quantities.

The next coating process (curve *d*) yields $\varphi = 2{\cdot}80$ V and $A = 1{\cdot}5$ A/cm² deg K², i.e. more pure thorium is evaporated in addition to thorium oxide. By continuing this procedure we obtain curves *e* and *f* (which show that the proportion of thorium oxide decreases continuously), and after a certain number of coatings we finally attain values of $\varphi = 2{\cdot}54$ V and $A = 0{\cdot}74$–$1{\cdot}1$ A/cm² deg K² (curve *g*), i.e. only *pure* thorium is being evaporated.

Thus, by measuring the emission of coated tantalum it is possible to analyse the evaporation products of a cathode in stages, so that in later tests with platinum specimens one knows exactly what the platinum is being presented with at a given moment during the deposition process.

Further tests on tantalum specimens with thorium oxide sources have been carried out, but these will not be considered here. Briefly, it can be said that the work function of thorium-oxide coated tantalum wire depends on the temperature of the cathode; the higher the temperature of the thorium oxide cathode, the lower is the work function of the coated tantalum.

Activation of Platinum by Thorium

After it had been established that the evaporation products of thoriated-tungsten cathodes can be either thorium alone or thorium oxide, a study was made of the activation of platinum by metallic thorium, thorium oxide and combination of the two. In the present instance, however, we shall discuss only the activation of platinum by *pure* thorium.

Measurements show that, under certain circumstances, platinum can indeed be activated by thorium, to the extent that in the case of one monolayer the work function φ falls from 5·32 to 2·40 V. The work function of thorium on platinum depends largely on the temperature of the platinum during deposition and on the rate of deposition from the cathode.

The experimental procedure was basically the same as for tantalum. Fig. 2 shows a selection of activation curves for different temperatures of the platinum filament. In every case the rate of deposition on the cathode was constant at about 10^{-4} monolayers per second. Curve *a* illustrates the activation of unheated platinum ($T = 500$ °K, due entirely to radiation from the cathode). A monolayer was achieved after a period of 10 hours. The emission current of the platinum was measured periodically at a temperature of 1500 °K, the procedure lasting only a few seconds in order to avoid any possibility of diffusion. Measurement of the work function then yielded $\varphi = 2{\cdot}40$ V. Subsequent heating at 1600 °K for a few hours resulted in the value of the work function for pure platinum, i.e. $\varphi = 5{\cdot}32$ V. This was followed by deposition at a constant platinum temperature of 1500 °K (curve *b*). It is interesting that the form of this curve suggests saturation, even though the thorium layer is not monatomic, as was proved by subsequent measurement of the work function. This gave a value of $\varphi = 3{\cdot}90$ V, which is 1·50 V higher than the work function of platinum coated when cold. It follows from this that at 1500 °K and the given rate of deposition a monolayer was unable to form, as otherwise the work function would again be $\varphi = 2{\cdot}40$ V. Thus it can be concluded that the region suggesting saturation represents a state of equilibrium between deposition and diffusion, i.e. the rate of evaporation of the thorium is in equilibrium with the diffusion of the thorium in platinum. The other curves show the activation at even higher platinum temperatures: for curve *c*, $T = 1625$ °K, curve *d*, $T = 1750$ °K and curve *e*, $T = 1850$ °K. The respective values for φ of 4·30, 4·60 and 5·30 V show that as the temperature of the platinum rises, activation becomes increasingly difficult, and finally, at least as regards the considered test conditions, ceases at 1850 °K.

The number of thorium layers deposited on the platinum was determined by activation analysis and the result agreed with the quantity calculated from the rate of deposition.

Further tests on platinum in connection with thorium oxide intermediate layers are still in progress. It will be clear from this article how important such research is if tubes are to be of the very best quality.

In conclusion, we would like to thank Professor M.J.O. Strutt, Head of the Department of Advanced Electrical Engineering at the Swiss Federal Institute of Technology, for his consistently lively interest and stimulating discussions.

(DJS) M. DEÁK

MODERN GAS-FILLED TUBES FOR HIGH VOLTAGES AND CURRENTS

621.387

The uses of gas-filled tubes for industry and radio communications are summarized, together with reasons justifying their existence in the "semiconductor age". The operation and construction of modern rectifier and thyratron tubes for high voltages and currents are described and the influence of bulb shape on the inverse voltage strength is considered. Various quantities such as heating time, mercury temperature, short-circuit current, etc., are discussed, together with directions for practical use. Development trends in this field in general, and the technical feasibility of very-high-voltage tubes in particular, are also discussed.

Introduction

FOR some years now, gas-filled tubes with oxide cathodes, particularly as pure rectifier tubes for industrial and radio-communication purposes, have had to face competition from semiconductors.

The question therefore arises as to whether the development of new tubes is still reasonable, and under what circumstances can their use still be of advantage to the equipment designer.

When comparing the characteristics of semiconductors and tubes it is immediately evident that a far higher electric strength can be attained with tubes, while at the same time the sensitivity to overcurrents and overvoltages is less. This advantage on the part of the gas-filled tube is of particular benefit in controlled installations, where it is possible to rectify voltages of 20 kV and more with only one tube per current path, and have electronic control by means of high-voltage thyratrons. To achieve a similar result with thyristors they would have to be connected in series, which would make the cost appreciably higher, and also technical difficulties would be incurred regarding, for example, control in the event of short circuits. In order to ease the task of all those who design electrical equipment, of whatever kind, when choosing between tubes and semiconductors, the operation and properties of modern gaseous-discharge tubes are described below. It can be deduced from this that the present place of the gas-filled tube is undoubtedly also assured for the future.

Principle of the Gaseous-Discharge Tube

Since it can be assumed that the processes taking place in a gas-filled tube are already known, this aspect need be touched on only briefly.

An electric current can flow between anode and cathode despite insulation, in which case the conducting medium existing between these electrodes is formed by the electrons and positive ions liberated by ionization of the gas filling in the tube. The motion of these electrons and ions in an operating gas-filled tube is shown diagrammatically in Fig. 1. Owing to the presence of ions in the anode-cathode space, the negative space-charge created by the electrons is compensated so that the electron stream (*b*) can pass unhindered from the cathode to the anode, and as a result a current is produced in the outer circuit. At the same time, the ions (*c*) flowing to the cathode recombine with the negative electrons to form neutral gas atoms.

In order that the cathode may provide sufficient quantities of electrons to maintain gaseous discharge, it has to be heated. The oxide-coated cathode has shown itself to be particularly suitable for gaseous-discharge tubes, with its relatively low operating temperature, small filament power requirement, large load capacity and long life. The oxide-coated cathode usually consists of a carrier of nickel mesh, or sheet, with a coating of metal oxides.

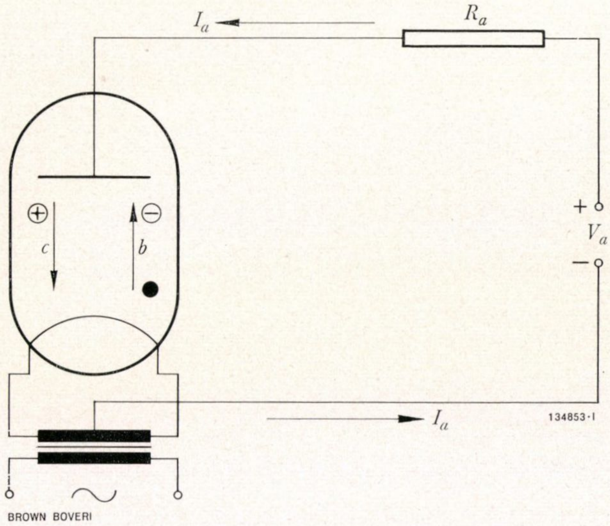


Fig. 1. – Directions taken by the electrons and ions in an ignited gaseous-discharge tube

I_a = Anode current (+)
b = Electrons (—)
c = Positive ions (+)

If a control grid is fitted between the anode and cathode of a rectifier tube, the result is a thyratron tube, which as a current regulator can perform a much wider variety of functions in electrical circuits. By applying a sufficiently high negative voltage between the grid and the cathode it is possible to prevent the tube from igniting. The value of the grid voltage at which a thyratron ignites depends on the anode voltage. This is obvious if one considers that the electrical field created at the anode passes through the grid to act on the cathode. The stronger the field between the anode and the cathode space, the more negative the control grid must be if ignition is to be prevented. This relationship follows from the control characteristic. Derivation of the ignition characteristic from the control characteristic is illustrated in Fig. 2, with allowance made for any variations in position and shape brought about, for example, by a change in the mercury vapour temperature or a drop in the cathode emission during the service life.

Construction of Modern Gas-Filled Tubes

The internal construction of the latest Brown Boveri high-voltage rectifiers and thyratron tubes, with hot cathodes and filled with mercury vapour, is shown in Fig. 3 and 4. Fig. 3 shows the electrode arrangement of the DQ 71 high-voltage rectifier tube and the corresponding thyratron TQ 71, both of which are provided with direct cathode heating.

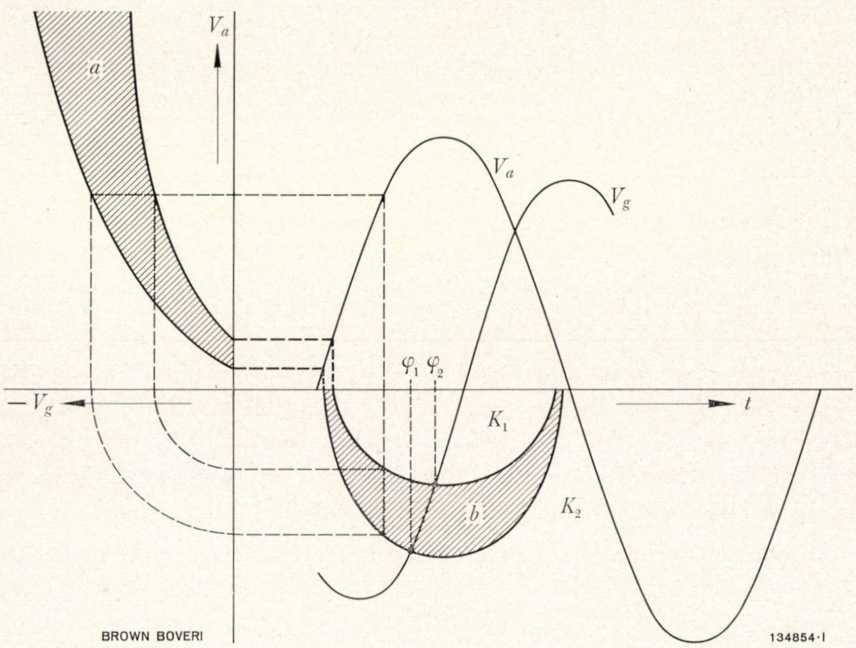


Fig. 2. – Derivation of the ignition characteristic from the control characteristic, with account taken of deviations

It is assumed that the breakdown characteristic, like the control characteristic, lies within two limiting values, curves K_1 and K_2.

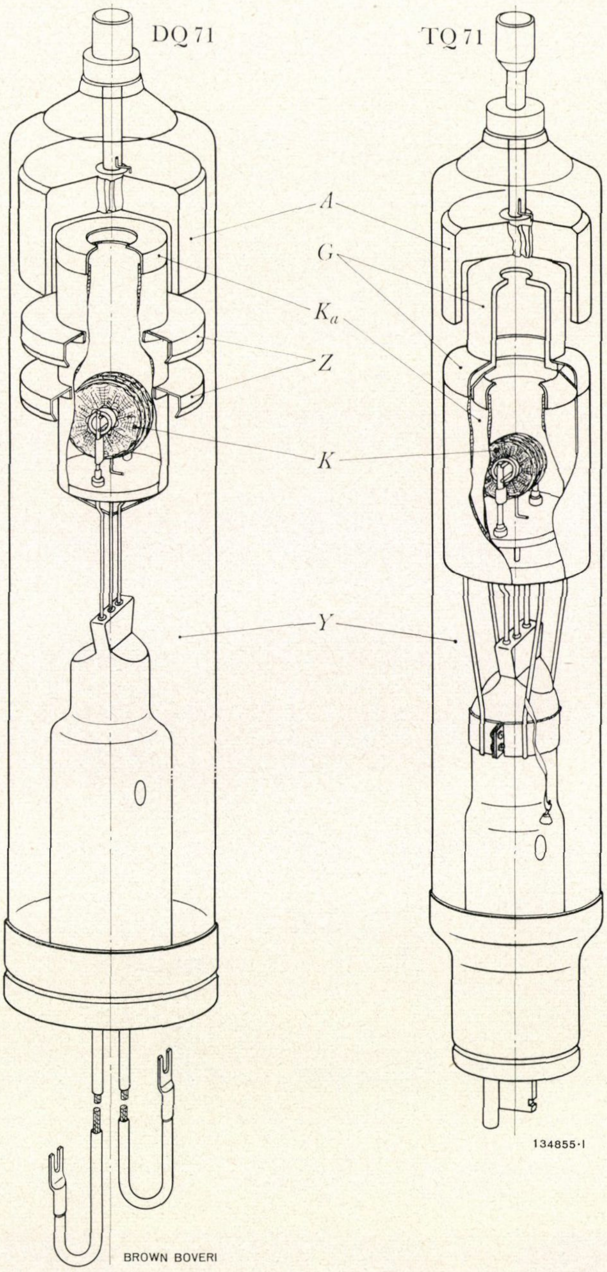
V_a = Anode voltage
V_g = Grid voltage
a = Control characteristic
b = Ignition characteristic
φ_1, φ_2 = Phase angles

Fig. 3. – DQ 71 and TQ 71 high-voltage tubes with mercury-vapour filling

Left, a DQ 71 rectifier tube for an inverse voltage of 26 kV and a mean anode current of 10 A.

Right, a TQ 71 thyratron tube for an inverse voltage of 24 kV and a mean anode current of 10 A.

A = Anode
G = Control grid
K_a = Heat shield
Z = Protective rings
K = Cathode
Y = Glass envelope



The cathode (K) consists of a carrier of high-grade nickel-wire mesh wound spirally on to a ceramic holder to form a mechanically stable unit. The surface of the mesh is coated with a mixture of metallic oxides. To bring the rectifier or thyratron tube to the working condition the oxide-coated cathode must be heated to its operating temperature of 800–850 °C. To achieve a uniform temperature distribution and good thermal conditions during service the cathode is enclosed by a heat shield (K_a). The purpose of the rings (Z) on the heat shield in the DQ 71 tube is to prevent arcing in the bottom of the tube, to the bushings in the stem for instance, under conditions of high inverse voltages. The control grid (G) between the cathode and anode in the TQ 71 tube has as large an area as possible so as to achieve a low operating temperature and, hence, reduce the risk of grid emission. The upper grid cap (with hole), which projects into the anode and is the most heavily loaded part, and also the anodes (A) of both types of tube, are made of electrographite for maximum performance. The whole tube system is enclosed in a close-fitting bulb (Y).

Fig. 4 shows a high-output thyratron TQ 91 intended for use at high voltages and currents. It differs from the TQ 71 described above by having an indirectly heated oxide-coated cathode and a control grid which is brought out concentrically. The cathode (K) is heated from inside by a heating coil (H). This enclosed arrangement gives a cathode with extremely good heat economy, so that the heating power required per square centimetre of cathode surface is appreciably less than for the directly heated type. This cathode has a drawback, however, in that the heating time is comparatively long owing to the very large thermal capacity compared with the filament power. The control grid (G) is made concentric with the grid ring (G_r), which results in very good mechanical stability for the whole grid structure. Furthermore, additional cooling of the control grid is obtained by normal convection of air over the outside of the grid ring. Here again, very pure electrical graphite is used for the grid and the anode.

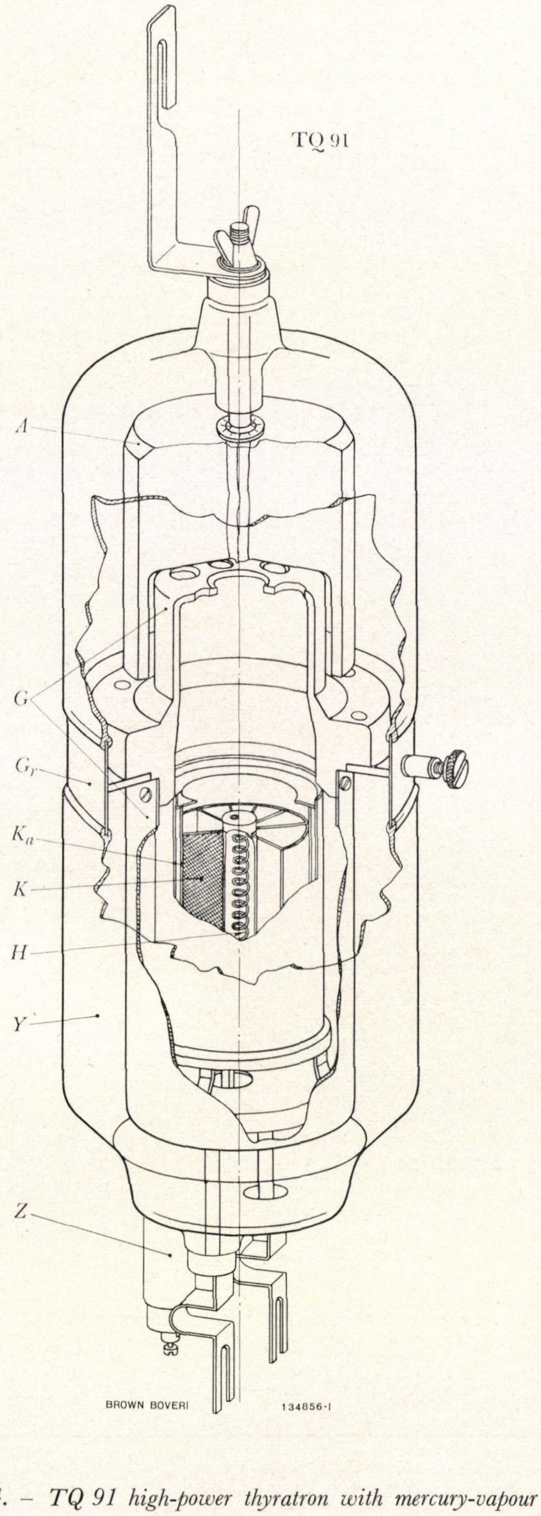


Fig. 4. – TQ 91 high-power thyratron with mercury-vapour filling

Inverse voltage 20 kV, mean anode current 45 A.

A = Anode
G = Control grid
G_r = Grid ring
K_a = Cylinder screening cathode
K = Cathode
H = Heater
Y = Glass envelope
Z = Mercury condenser

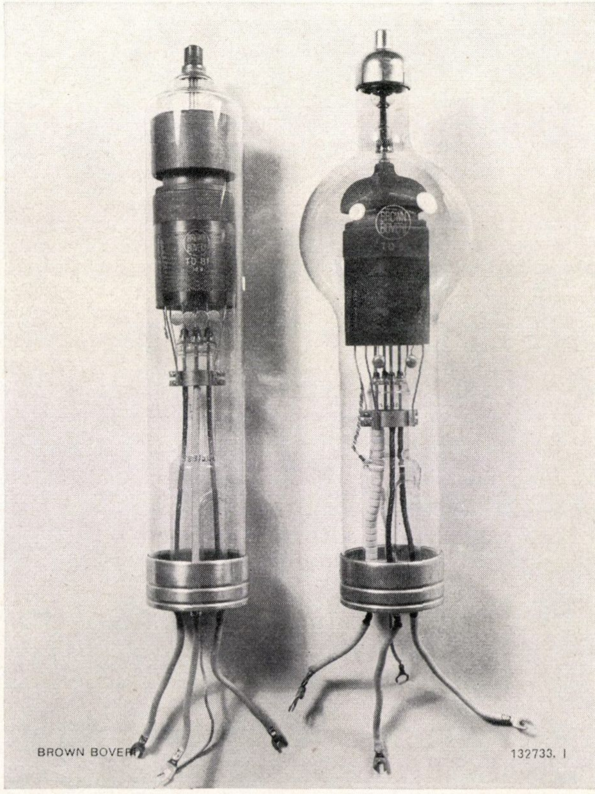


Fig. 5. – Shapes of envelope used for thyratron tubes: right, TQ 8 (superseded) and left, TQ 81 (new)

With all Brown Boveri rectifier tubes and thyratrons it has been possible to achieve a radical improvement in the inverse-voltage characteristic by altering the conventional balloon-shaped envelope. The changed shape is illustrated in Fig. 5 by the TQ 8 thyratron (superseded) and TQ 81 (new). This further improvement in the inverse-voltage characteristic can be mainly attributed to the fact that the glass envelope fits closely round the system of anode, grid and cathode, which has the effect of shortening the breakdown distance in the anode-cathode space considerably and, in accordance with the Paschen law, results in an increase in the inverse voltage. This has been confirmed by practical investigation and comparison of numerous types of tube. The necessary measurements were carried out on a "cheater circuit" [1], which allows the test specimen to be loaded with the maximum permis-

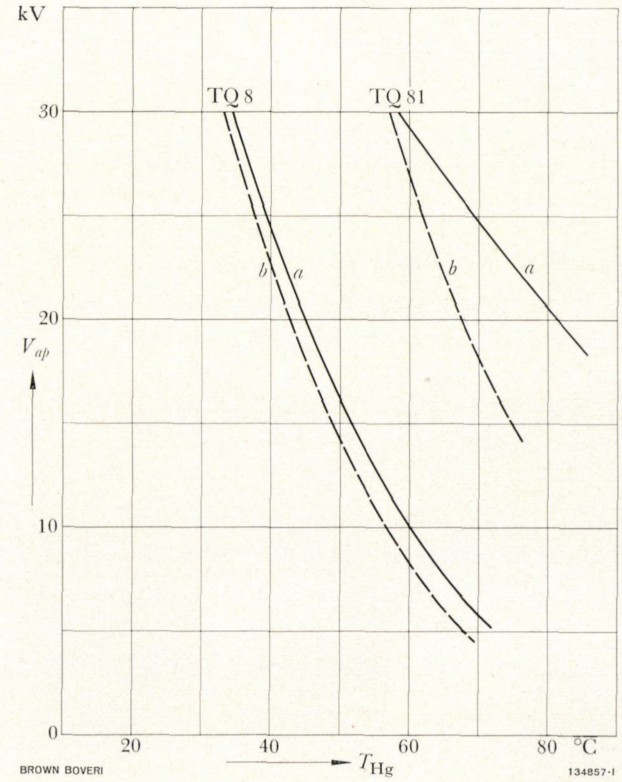


Fig. 6. – Inverse voltage characteristics of tubes TQ 8 (superseded) and TQ 81 (new)

T_{Hg} = Mercury temperature
V_{ap} = Peak anode voltage
a = Anode negative
b = Anode positive

sible mean anode current in the forward phase. The results of such tests, which were obtained for a large number of tubes, are illustrated for the high-voltage thyratrons TQ 8 and TQ 81 in Fig. 6. The improvement in the inverse voltage obtained with the TQ 81, both with negative and with positive anode voltages, is quite evident.

Data and Directions for Practical Use

The following points are summarized here in the interests of both user and manufacturer, as they have a strong influence on reliability and service life.

a. Filament Voltage

The limit values given for each type of tube must not under any circumstances be exceeded. Underheating can lead to cathode sputtering and rapid loss of cathode emission. Overheating causes excessive evaporation of the metallic oxides from the cathode, which shortens the life of the tube.

In the case of tubes with directly heated cathodes a heating transformer with a middle tapping and a phase shift between V_f and V_a of $90° \pm 30°$ is recommended. This will make for optimum conditions as regards life expectancy. The filament voltage must always be measured directly at the filament terminals of the tube.

b. Heating Time and Operating Temperature

The total heating time of a rectifier or thyratron tube filled with mercury vapour alone is composed of the heating times of the cathode and the mercury.

The thermal inertia of directly heated cathodes is generally considerably smaller than that of the indirectly heated type, and this affects the heating time accordingly. As the mercury in the tube is heated by thermal radiation from the cathode, the total heating time is dependent on the ambient temperature. The minimum temperature for the condensed mercury ($T_{Hg\ min}$) as given in the data sheets must be reached before the anode voltage is applied to the tube. To ensure a long service life, however, the minimum temperature of the condensed mercury should be considered only as an initial condition; care should be taken to ensure that the temperature of the condensed mercury reaches the optimum value given in the data sheets ($T_{Hg\ opt}$) by the time the tube has been in operation for at most a few hours. Too low a temperature results in too low a vapour pressure in the tube, which reduces the conductance, raises the arc voltage and so causes the metallic oxides on the cathode to disintegrate too quickly, thus shortening the tube life. An excessively high temperature results in too high a vapour pressure, which reduces the inverse voltage strength in both reverse and forward directions. It is recommended that the mercury temperature should be measured with a thin thermocouple at the point of condensation, which as a rule is immediately above the base of the tube.

c. Grid Resistance

The optimum and maximum permissible grid resistance will be given in the data sheets. The minimum value is found from the maximum permissible grid current for the particular tube, with allowance being made for the applied grid voltage. An upper limit is set on the grid resistance in the interests of exact and reliable controllability. Using resistances which are too high can cause displacement of the ignition characteristic and thus give rise to inaccurate control. A further consequence is lengthening of the recovery time [2].

d. Anode Voltage

Exceeding the maximum permissible value stipulated by the tube manufacturer for the anode voltage in both forward and reverse directions can lead, on the one hand, to backfiring and loss of rectification and, on the other, to failure of the controlling function of the grid.

In addition to the inverse voltage strength being influenced by the temperature of the condensed mercury, as already mentioned, the presence of electrical or magnetic fields near the tube can cause undesirable ionization of the gas filling, and this can result in breakdown and backfiring within the tube. Care must therefore be taken to see that leads to or from the anode or cathode do not run in the immediate vicinity of the tube, but are led directly away from their terminals in the direction of the tube axis.

e. Maximum Short-Circuit Surge Current

This value only serves as an indication for the equipment designer when planning the anode circuit. The short-circuit surge current given in the data sheets should not be used as a normal operating value. It merely represents the maximum value of a brief current caused by unexpected overloading or a short circuit. The length of time for which this current may flow through a tube is limited to a maximum of 0·1 s, which provides the tube with a relatively high chance of survival. Repeated overloads of this kind, however, shorten the life of the tube substantially, and at the same time endanger the reliability of the installation.

The picture on the right of Fig. 7 shows an oxide-coated cathode damaged by repeated short-circuits. Signs of sputtering resulting from improper use can be clearly seen on the cathode surface. An undamaged cathode is shown on the left. By including appropriate resistances in series with the anode circuits and providing quick-acting overcurrent

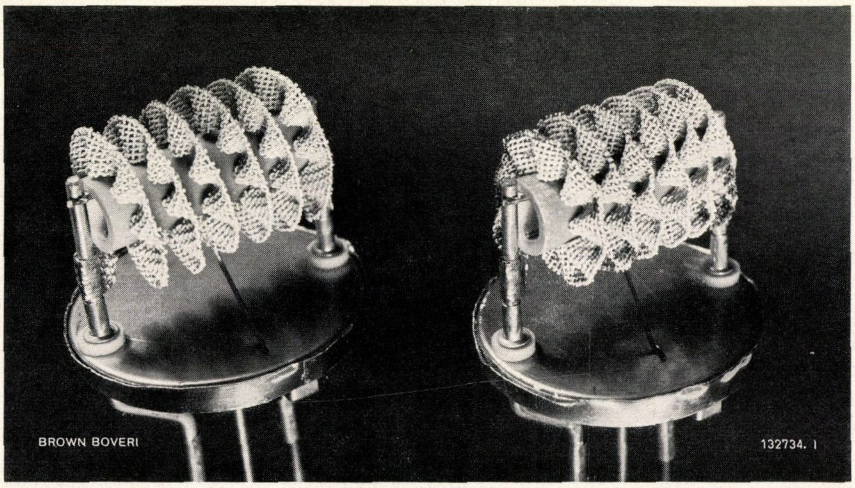


Fig. 7. – Right, an oxide-coated cathode damaged by repeated short circuits, left, an undamaged cathode

relays on the primary side of the anode transformer, unpredicted short-circuit currents can be easily restricted and, just as important, they can be interrupted quickly.

f. Installation and Commissioning of Gas-Filled Tubes

In general, gas-filled tubes should be mounted with the filament terminals or the base downwards. Special attention should be paid to the tube holder and the construction of the rectifier installation, particularly to ensure that air can circulate freely round the tube. If forced cooling is necessary, care must taken to ensure that the cooling-air stream reinforces the natural circulation. This prevents the highly undesirable formation of mercury droplets in the upper part of the tube. In high-power polyphase installations a great deal of heat is developed by losses from the tubes and other components, and therefore the temperature of the condensed mercury (T_{Hg}) in the lower part of the tube must be kept within the prescribed limits by means of a gentle stream of air. The mercury-condensation zone is cooled effectively by means of ring-shaped plastic tubes provided with air-injection holes on the side facing the area to be cooled. It is recommended that this cooling air should be regulated thermostatically so that variations in the mercury temperature (T_{Hg}) can be largely evened out. Ventilation for the whole cabinet is provided in those cases where the ambient temperature, measured near the upper part of the tube, exceeds 50°C. Here again, thermostatic control is very useful. Instructions for the correct sizing and arrangement of cooling systems are available.

Where several tubes are installed together, care must be taken to ensure that the distance separating them is between a half and one maximum diameter of the tubes.

An operational polyphase rectifier installation equipped with Brown Boveri TQ 91 high-voltage thyratrons is shown in the picture inside the front cover. It is designed for a d.c. output of 900 kW at a voltage of 15 kV.

It goes without saying that the characteristics and practical hints discussed here by no means exhaust the subject. The intention here has been to mention those features to which particular attention has to be paid in practice when mercury-vapour-filled rectifier and thyratron tubes are employed.

Development Trends

In recent years, the development of controlled high-voltage rectifier installations for radio transmitters has shown a trend towards higher outputs at practically the same operating voltage. This has led to the very recent development in the Brown Boveri tube laboratories of another high-voltage mercury-vapour thyratron tube for a peak anode voltage of 20 kV and a mean anode current of 115 A. One of these tubes, the TQ 101, is shown in Fig. 8. In the fields of industry and nuclear research, on the other hand, there is considerable demand for even higher voltages than have been used hitherto.

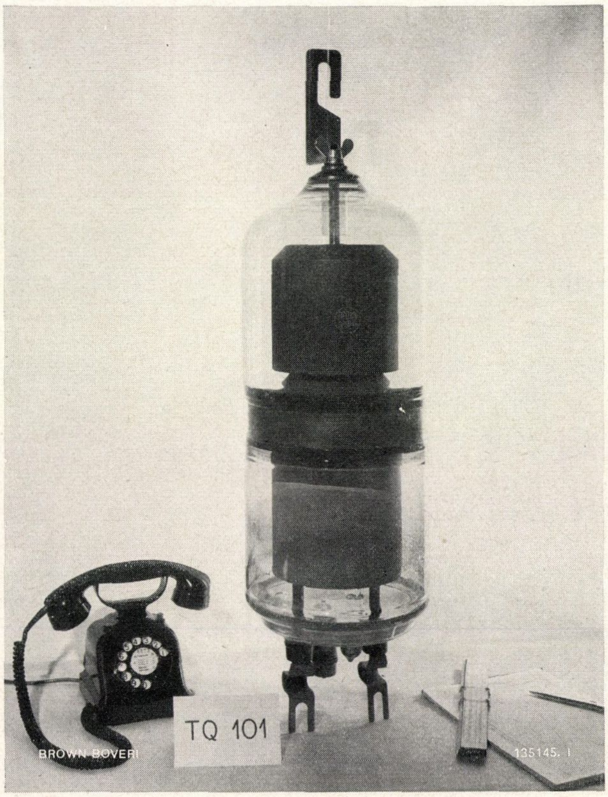


Fig. 8. – TQ 101 high-power thyratron tube with mercury-vapour filling

Inverse voltage 20 kV, mean anode current 115 A.

An example is electron beam melting, which is becoming more and more widely used in industry. The equipment for this requires d.c. voltages which at times are as high as the maximum permissible inverse voltages of ordinary thyratron tubes. Furthermore, the short circuits which occur quite normally during operation as the result of gas escaping from the melt can give rise to voltage peaks in the inductances of the equipment which are far greater than the maximum permissible peak anode voltage of the thyratron. As regards peak current, too, the loading in electron beam melting installations is generally substantially higher than the tubes would be able to tolerate. In short, service conditions are created, on the one hand by the high voltages and on the other by high current loadings, which can only be withstood by extremely robust rectifier tubes.

The tube manufacturer is thus faced with the technical problem of making thyratron tubes for very high voltages, in the region of 40 kV or more, as well as for higher peak current loads than have been customary in the past.

He must also decide whether a tube of this kind should be made using techniques involving metal and glass or metal and ceramics. Because it can be more heavily loaded thermally than glass, a ceramic envelope would enable the system to be more compact, which is a desirable feature in the case of gas-filled tubes for high voltages.

The requirements considered in this article are already a reality, and will become even more demanding in the future. Basically they govern the trends in the development of mercury-vapour-filled thyratrons, though it is not yet possible to forecast with certainty that the problems involved can be overcome.

(DJS) A. PATRIARCA

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THERMAL GRID EMISSION IN GAS-FILLED TUBES

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The nature and cause of thermal grid emission in gas-filled tubes are described, together with measures for preventing it. The effects of thermal grid emission on the ignition characteristic and inverse voltage strength are considered, and their influence on the design of the grid circuit is examined. Experimental investigations have been carried out using various grid and cathode materials, e.g. Ni, carbonized Ni, gold-plated Ni, platinum-plated Ni, Ni coated with tantalum carbide, and passive Ni for the cathode heat shield. The results are discussed.

The Principle of Thermal Grid Emission

THYRATRONS employed in industry and radio communications are frequently exposed to operating conditions which impose very heavy demands as regards control and reliability.

The problems considered below were studied only in connection with thyratrons having oxide-coated cathodes.

In a thyratron the oxide-coated cathode is the only electrode with the task of generating the electron stream migrating towards the anode. This is achieved by coating the cathode with a material having a low work function and heating it to a temperature of about 1050°K.

Thermal emission from the other electrodes causes the tube to acquire properties which adversely affect its performance to a greater or lesser extent, and can even result in failure.

The thermal grid emission current I_{gp} is particularly troublesome, and this will be considered in greater detail below. Various stages of operation are shown diagrammatically in Fig. 1.

Fig. 1a shows a thyratron tube in the ignited condition. Since the control grid in this case is negative, a stream of positive charge carriers (I_{gi}) flows towards it, the magnitude of the current created by the stream depending only on the outer grid-circuit impedance. Should emission of thermal electrons (I_{gp}) occur at the grid, flow is to either the anode or the cathode, but as it is of no practical significance in this condition, we need not consider it further here.

Fig. 1b illustrates the stage of operation with the tube blocked, a strongly positive anode voltage and again a negatively biassed control grid. When thermal grid emission occurs, positive charge carriers are produced by vigorous acceleration of the electrons in the grid-anode space and in the grid-cathode space and in both cases they move towards the negative grid.

The situations in Fig. 1c correspond to those of b, with the only difference that, owing to the strongly negative anode voltage, no ions are produced as primary emission in the grid-anode space by the thermally emitted electrons.

Effects of Grid Emission in Practice

Grid emission can have undesirable consequences both for the tube itself and for the associated equipment. Its occurrence in the critical stages of operation is discussed briefly below. Let us first consider the ignition process in a thyratron tube. Because a grid current flows from the grid to the cathode before the desired moment of ignition is reached, a voltage drop occurs which corresponds to the magnitude of the grid current at the grid resistance. As a result, the negative voltage acting at the control grid is reduced and the tube ignites earlier than intended, so that the current flow angle is increased accordingly. As the anode current rises, the grid is heated

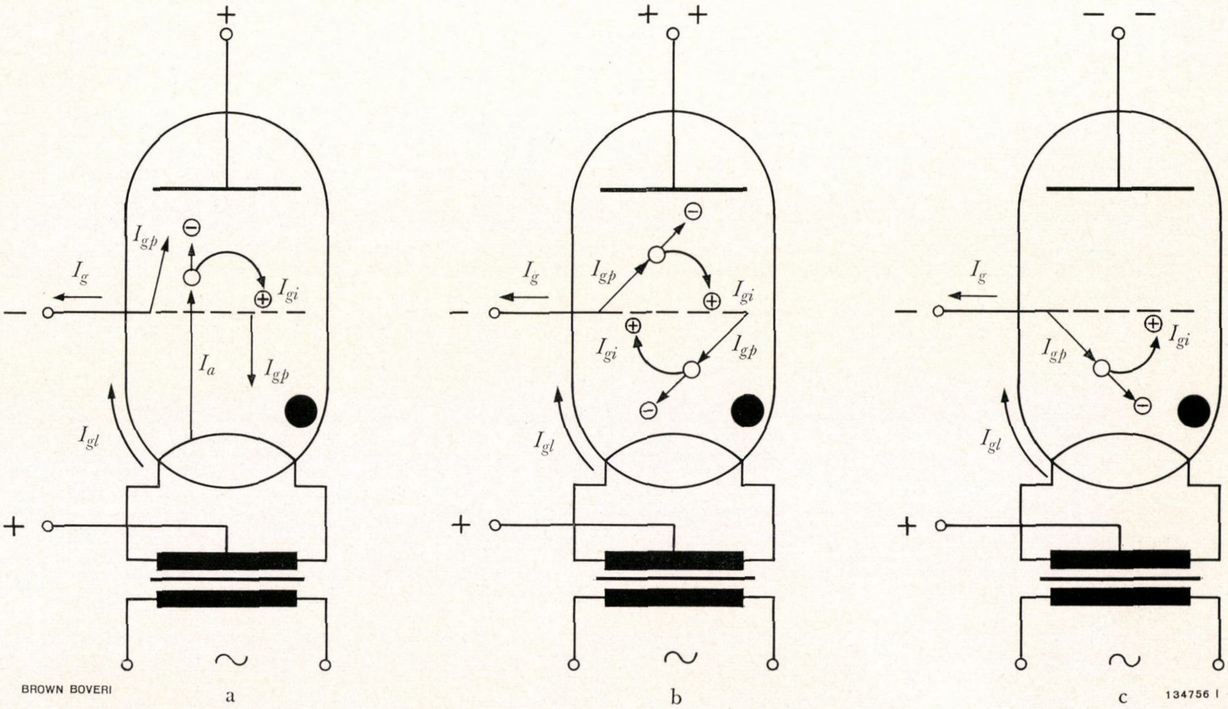


Fig. 1. – Diagrams showing the components of grid current at different stages of operation

I_{gp} = Thermal grid current
I_{gi} = Ion current
I_{gl} = Insulation current

I_g = Total grid current
I_a = Anode current

a: Tube ignited, grid negative
b: Tube not ignited, grid negative, anode positive
c: Tube not ignited, grid negative, anode negative

more intensely and the negative grid voltage collapses more and more as the grid current increases. The tube can lose its controlling ability completely in consequence.

In the positive blocking phase, ignition can occur even with slight grid emission. This is caused by the electrons moving from the grid to the anode and the resulting discharge in the grid-anode space.

During the negative blocking phase there is a risk that backfiring will occur owing to the charge carriers generated in the grid-cathode space as a result of grid emission. These in turn emerge from the grid voids through the negative field on the anode side, are accelerated towards the anode and can give rise to backfiring.

To counteract disturbances of this kind when grid emission is present, the user should observe the following points regarding the layout of the grid circuit.

a: Pulsed control systems should be used, so that deviations in firing angle can be largely eliminated solely by the steepness of the grid voltage as it passes through the ignition zone.

b: Under no circumstances should the total impedance of the grid circuit be made too high. The values given by the tube manufacturer for each type of tube should not therefore be exceeded.

Causes of Thermal Grid Emission

The main reasons for thermal grid emission which may occur as a result of the design are:

a: Heat radiation on to the control grid from the neighbouring electrodes;

b: A coating of evaporated or sputtered cathode material on the grid, which lowers the work function;

c: Use of easily activated grid material.

As far as the user is concerned, incorrect operation, such as frequent and excessively large short circuits, backfiring, underheating of the oxide-coated cathode and so on, can give rise to sputtering[1] at the cathode, whereupon the neighbouring electrodes, the grid for example, can become activated by the evaporating cathode material.

Sputtering, and hence thermal grid emission, can be largely reduced by correctly sizing installations equipped with thyratrons, in particular the filament and anode circuit, and by including protective devices for rapidly interrupting and limiting short circuits of all kinds.

Means of Preventing Thermal Grid Emission

Thermal grid emission in thyratrons can be reduced by adopting the following measures in the tube design:

a: By making the grid of a material having the highest possible work function, from which the emission current density j_s can be found with the aid of the Richardson equation as follows:

$$j_s = AT^2 = \exp\left(\frac{e\varphi}{kT}\right) \quad [\mathrm{A/cm^2}]$$

T = Temperature [°K]
e = Electron charge [As]
φ = Work function [V]
k = Boltzmann's constant [Ws/deg]
$A = 120$ [A/cm² deg²)]

b: By ensuring through proper design of the system that the control grid receives as little heat energy as possible by radiation or conduction from the other electrodes, and so has the lowest possible operating temperature.

The heat balance of a thyratron grid in operation is shown in Fig. 2. It can be seen that it receives radiation from both the cathode and the anode.

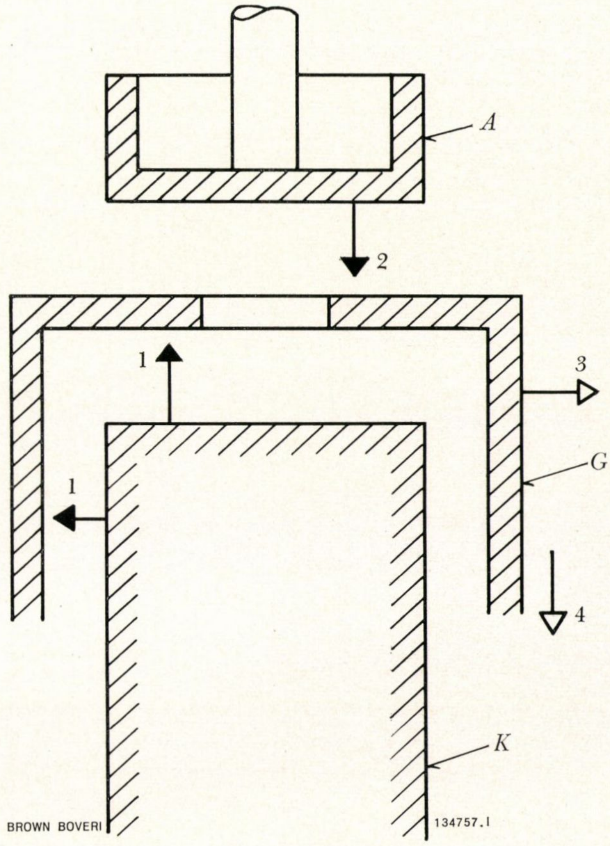


Fig. 2. – Heat balance of a thyratron grid

1 = Radiation from the cathode
2 = Radiation from the anode
3 = Radiation to outside
4 = Conduction to outside
A = Anode
G = Grid
K = Cathode
—▶ Heat gains
—▷ Heat losses

Heat is removed partly by radiation and partly by conduction through the mountings and leads. It is therefore advantageous to make the grid of a thyratron from a material having a high thermal conductivity and with external parts having good total emissivity.

c: By ensuring that as little cathode material (of small work function) as possible is evaporated on to the control grid. Apart from correct adjustment of the cathode temperature, this is achieved by making the core of the cathode and its shield, which are usually of nickel, so that they contain only very small amounts of reducing constituents such as silicon, magnesium, manganese and similar substances.

[1] Since the coating on the cathode has a certain electric conductivity, excessively high current densities in the coating can lead to local overheating as the result of Joulean heat. Emission increases at the overheated points. This results in a further temperature increase, finally causing spot failure of the coating. On such occasions, glowing particles can be seen flying from the cathode. This phenomenon is known as "sputtering".

If such reducing substances are present in excessive quantities, surplus barium will be liberated not only from the cathode but also from its shield, which when in operation is constantly receiving barium oxide by evaporation from the cathode, and in consequence the grid opposite the cathode becomes activated.

It is, of course, most important that the tube designer should know and master the techniques for preventing grid emission mentioned above, but equally important for him are economic considerations which, especially in the case of the smaller gaseous-discharge tubes, are of very great significance. This applies particularly to the choice of grid material, as in many cases it would be too expensive to use solid gold or graphite, for example. It is common practice, therefore, to use nickel as the base material, and to coat this electrolytically with a film only a few microns thick of a material which is hard to activate (gold or graphite). Another method consists in carbonizing the base material of the grid in a suitable atmosphere so that, as regards work function and total emissivity, values almost the same as for graphite are obtained, and with the same reluctance to become activated. Tests carried out in this context are considered in more detail below.

Experimental Studies and the Results

The basic circuit used for determining the thermal grid emission of experimental tubes is depicted in Fig. 3.

The anode side of the tube is loaded by means of a d.c. generator with the desired anode current, and for sufficient time to allow the tube to reach temperature equilibrium. The anode voltage is then switched off and after a short pause of 10–20 ms the negative grid bias of −150 V is applied, so that the maximum grid current I_{gp} can then be determined with the aid of a microammeter.

Previous tests showed that under no circumstances should the negative grid bias be applied to the tube under test during the loading time, as otherwise any (generally harmful) activating barium layer evaporated during earlier operation will be destroyed again by the stream of ions flowing towards the control grid. This, of course, introduces serious errors into the measured results. It should be mentioned that the grid voltage applied for measurement must be sufficiently large for the thermal electron current to reach its saturation value.

Our tests were carried out chiefly on existing medium-voltage thyratrons of the TQ 2/6 type. These have the following features:

Cathode, oxide-coated, directly heated;
Filling, mercury and inert gas;
Filament power, approx. 55 W;
Maximum mean anode current, 6·4 A;
Peak inverse voltage, 2000 V;
Arc drop, approx. 10 V.

A section through a tube of this kind is illustrated in Fig. 4.

Our investigation of thermal grid emission covered mainly the following grid materials: nickel, platinum-plated nickel, gold-plated nickel, carbonized nickel and nickel coated with tantalum carbide. Apart from these tests, in another variant the whole cathode cylinder was made from nickel of higher quality than usual. The grid used in this case was of carbonized nickel. Thus, in each case the base material of the grid was nickel.

The gold and nickel plating was done electrolytically, while the tantalum carbide was sprayed on in

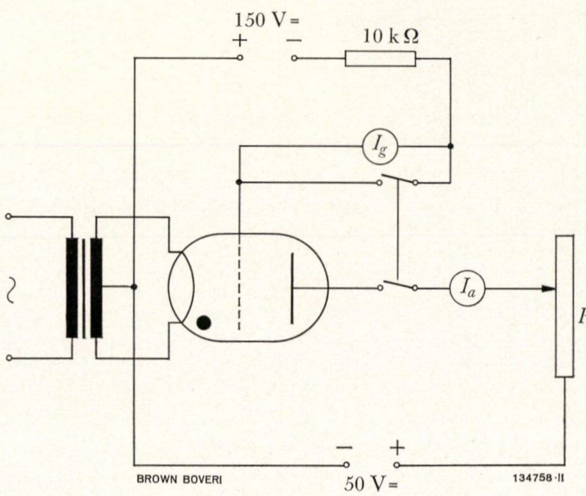
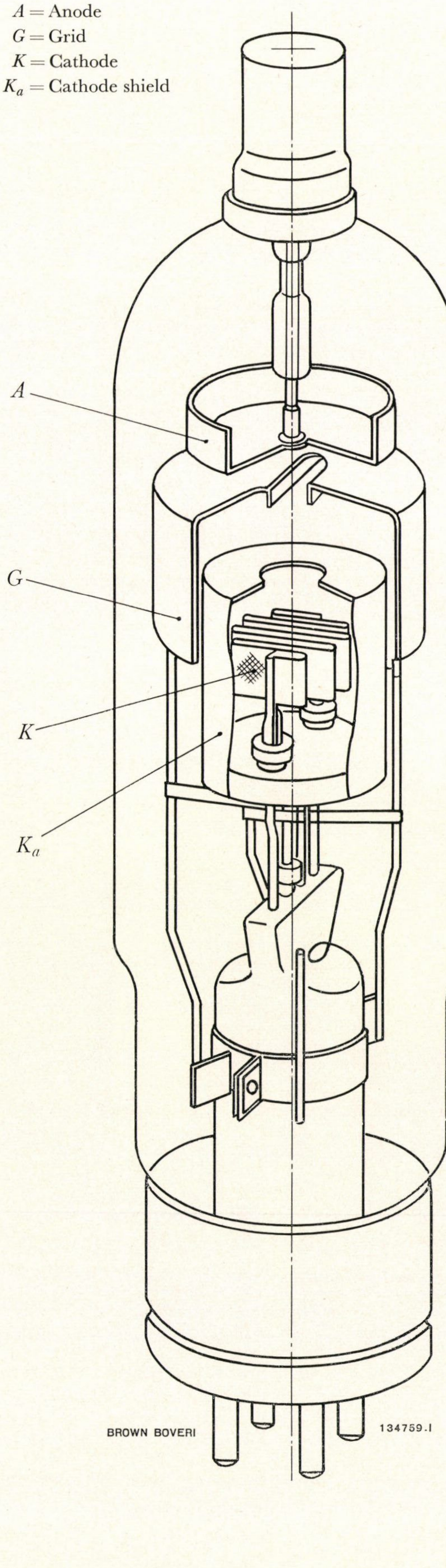


Fig. 3. – Basic circuit for measuring grid emission

Fig. 4. – Construction of a TQ 2/6 experimental tube

A = Anode
G = Grid
K = Cathode
K_a = Cathode shield



powder form together with a suitable binder and then sintered at 1350 °K in purified hydrogen. Carbonization was carried out in a methane-nitrogen atmosphere at approximately 1300 °K.

The distinguishing feature of the variant with the cathode shield made from high-grade nickel (H.P.A.[2]) instead of that normally used (O grade nickel[2]) is that the content of reducing substances such as magnesium, silicon and aluminium is much less.

The variation of grid emission with time is shown in Fig. 5 for the tests in question. During this time the experimental tubes were fully loaded to the normal operating conditions. The grid circuit impedance was set high for the reason already mentioned, namely at approximately 1 megohm, so that ion bombardment of the grid could be suppressed as much as possible. It is evident from Fig. 5 that, except in the case of the test with the very pure cathode shield, the emission from the grid reaches a maximum in the first phase of operation, after which it approaches a more or less stable end value. The emission maximum can probably be attributed to the comparatively high evaporation of free barium from the cathode and its shield during the conversion or subsequent activation of the oxide layer.

It is interesting that this effect is almost completely eliminated by using passive nickel for the cathode shield.

Thermal grid emission in relation to the anode loading was determined for the three tubes which yielded the most favourable test results after 1000 h operation. The tubes were overloaded by up to 40 % and the results are shown in Fig. 6.

Conclusion

With high-power thyratrons it is of great importance that thermal grid emission should be suppressed as effectively as possible. This can be achieved by introducing special methods of treating the grid, such as gold-plating or carbonization, or by using

[2] Quality code employed by Henry Wiggin & Co., Birmingham.

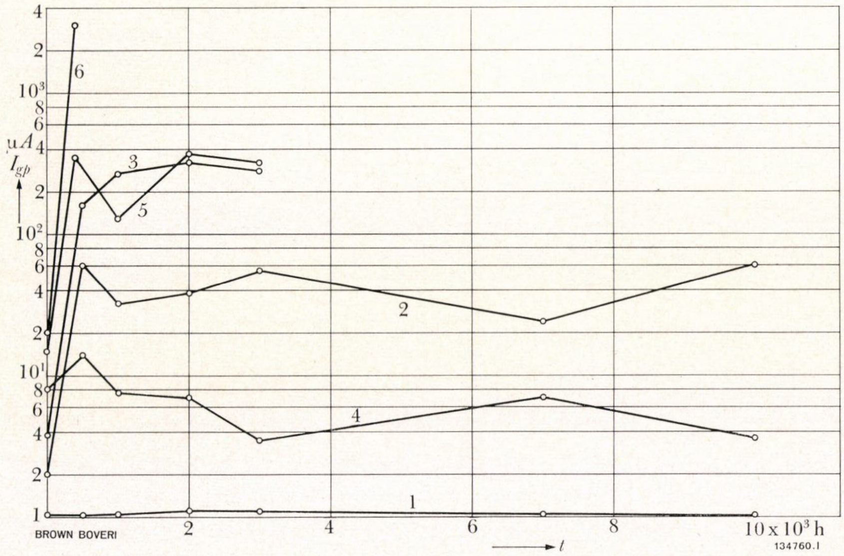


Fig. 5. – Thermal grid emission I_{gp} during life t for different grid coatings and cathode materials

1 = Carbonized nickel + cathode shield of HPA nickel
2 = Carbonized nickel
3 = Ni + Ta carbide
4 = Ni + Au
5 = Ni + Pt
6 = Ni

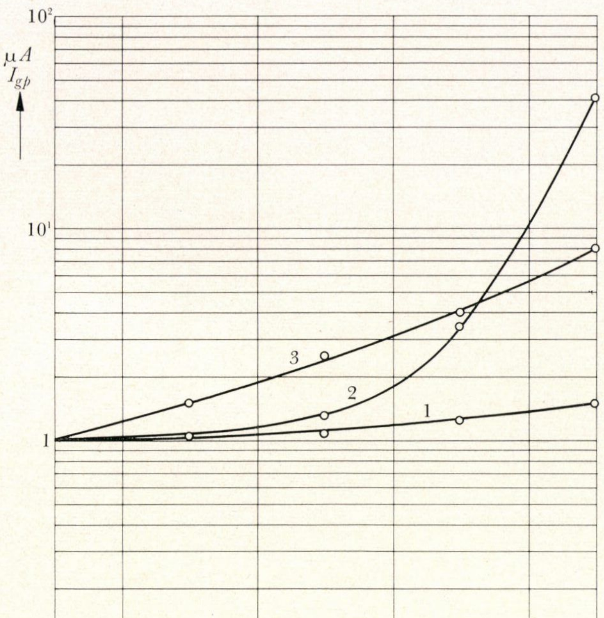


Fig. 6. – Thermal grid emission I_{gp} in relation to anode loading I_a

1 = Carbonized nickel + cathode shield of HPA nickel
2 = Carbonized nickel
3 = Ni + Au

high-grade nickel for the cathode shield, or alternatively by measures in the design intended to yield as little heat transfer as possible from the electrodes surrounding the control grid to the grid itself.

The results of the investigations carried out in recent years in our laboratories have to a large extent been incorporated in Brown Boveri thyratron tubes, the result being substantial improvements in both performance and reliability.

(DJS) A. PATRIARCA

SOLDERING PROBLEMS IN THE PRODUCTION OF ELECTRON TUBES

621.385:621.791.35

This article is concerned with the solution of soldering problems by experimentation. Several processes are described and the results of the contact angle tests, capillary rise tests and shear tests on various types of soldered joints are evaluated.

General Aspects

THE JOINING of materials by soldering or brazing plays an important part in modern electron tube production. This technique has become important as a result of the development of suitable filler materials for high-vacuum applications and above all it has considerably simplified the manufacturing processes involved.

The general conception of soldering and brazing is the joining of solid materials with a filler material which has a lower melting point. The adhesion is caused by the contact reaction occurring in the boundary layer between the solid phase of the base material and the fluid phase of the filler material.

It is of great value to have suitable experimental methods available for the examination of joints in cases where soldering and brazing constitute an important part of the manufacturing process. The results obtained from these experiments contribute specific evidence towards the solution of certain soldering problems.

Experimental Methods

The use of soft solder with flux in the manufacture of tubes is mainly confined to external parts. In connection with several of the problems mentioned here systematic experiments were carried out using various types of soft solder and different fluxes in conjunction with diverse base materials. The experiments were also intended to disclose suitable processes which, with due consideration to the time and personnel factors, i.e. with the minimum of equipment, give immediate information with regard to the particular problem at hand. This information was also intended to be adapted for tests on brazing processes which play an important part in electron tube engineering.

The wetting qualities of a liquid solder on a solid base, its spreading qualities in the gap and the adhesion of a soldered joint are essentially significant parameters which provide conclusions regarding materials, i.e. which materials may be suitably joined together, environment conditions and quality of the joint.

Several well-known processes are described in the following text which are used for determining the effects of these conditions and their corresponding experimental results are given.

Wetting

To ensure a perfect soldered joint it is essential to cover the whole joint area with liquid solder in such a manner that a completely intimate contact with the base material occurs. The wetting characteristic of a drop of liquid on a solid surface is determined by

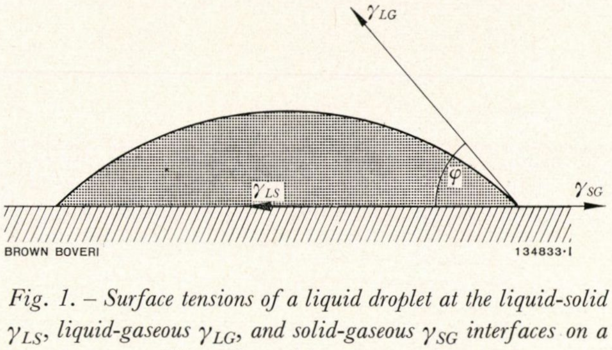


Fig. 1. – Surface tensions of a liquid droplet at the liquid-solid γ_{LS}, liquid-gaseous γ_{LG}, and solid-gaseous γ_{SG} interfaces on a solid surface with contact angle φ

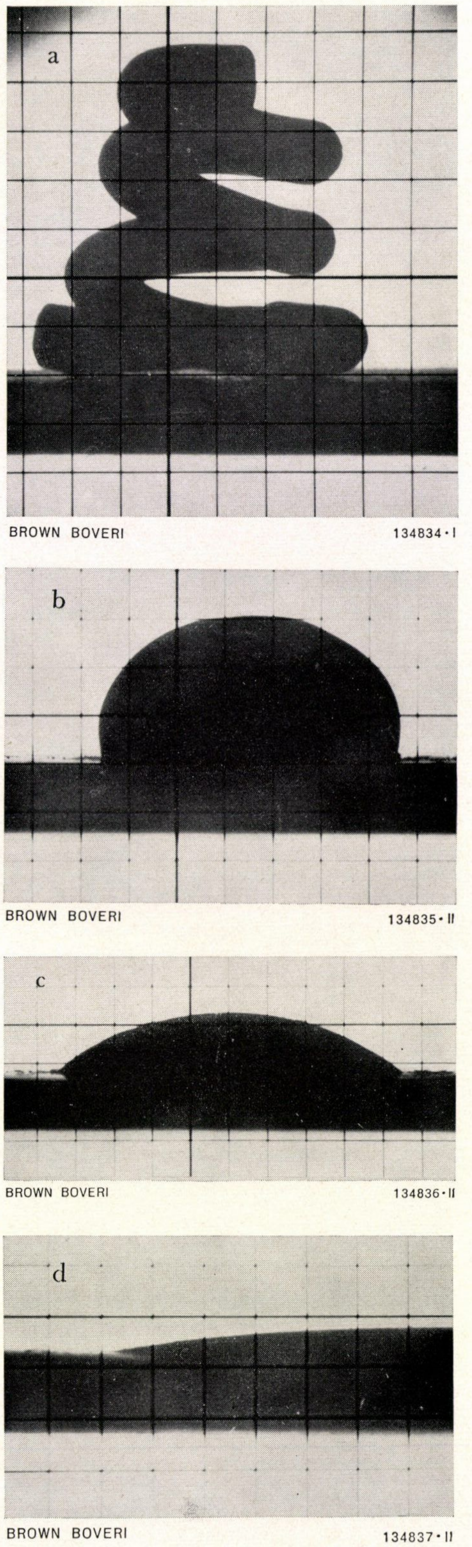


Fig. 2. – Wetting of a tin-silver solder

a: Spiral solder specimen in the original condition
b: Solder droplet on FeNiCo alloy (Kovar)
c: Solder droplet on copper
d: Solder droplet on silver-plated copper (showing left half of picture only)

the surface stresses at the boundaries of the three phases, solid, liquid and gaseous. If γ_{LG}, γ_{SG} and γ_{LS} represent the surface tensions at the interface between liquid and gaseous, solid and gaseous and liquid and solid, respectively, and φ represents the contact angle, then the equilibrium condition is given by:

$$\gamma_{SG} = \gamma_{LS} + \gamma_{LG} \cos \varphi$$

(See Fig. 1.)

The contact angle gives a value for determining the wetting capacity of a fluid. The case of total wetting is expressed by the inequality

$$\gamma_{SG} > \gamma_{LS} + \gamma_{LG}$$

and represents the complete dispersal of a drop of liquid on a solid surface.

The use of the contact angle for determining the wetting behaviour of molten metals for predetermined base materials and environment conditions is adequately discussed in [1] and [2].

The specimen, consisting of the basic material in the form of flat plate with a sample of solder placed on it, is heated in an oven to the melting temperature of the solder and the behaviour of the solder droplet is observed with the aid of a suitable optical instrument.

The contact angle is measured either directly from the screen or from a photographic image.

The results obtained with some of the test pieces can be seen in Fig. 2a to d. Fig. 2a shows a spiral shaped solder specimen in the original condition and b, c and d show the wetting behaviour on FeNiCo (Kovar) alloy, copper and silver-plated copper, respectively.

Tables I and II show the contact angles of various test specimens on copper and FeNiCo alloy with various pretreatments of the base material and variations of flux.

The experimental results give a definite indication of the effect of the composition of the flux. Specimens tested in the as-delivered condition showed clearly that the best wetting results were obtained with the more active flux FM 2.

Wetting results with FeNiCo specimens were poorer than with copper but were improved with surface treatment and this also reduced the differences between the contact angles obtained with both flux qualities.

TABLE I

Contact angles of various soft solders on copper with diverse surface treatments using an organic flux (FM 1) with low activator concentration and an inorganic zinc chloride based flux (FM 2)

Solder	T_L T_S	Contact angle							
		A		B		C		D	
		FM 1	FM 2	FM 1	FM 2	FM 1	FM 2	FM 1	FM 2
Sn/3·5 Ag	221	82	34	31	28	27	19	33	16
Sn/5 Sb	240–235	53	41	31	31	47	36	18	19
Sn/2 As	250–232	85	40	58	32	41	24	16	17
Sn/5 In	225–270	130	32	130	27	130	16	26	18
Pb/25 In	250–240	130	21	130	11	130	19	130	11

T_L = Liquid temperature °C
T_S = Solid temperature °C
A = As-delivered condition
B = Pickled copper
C = Gold-plated copper
D = Silver-plated copper

TABLE II

Contact angle of various soft solders on FeNiCo alloy with diverse surface treatments using two qualities of flux as described in Table I

Solder	Contact angle							
	A		B		C		D	
	FM 1	FM 2	FM 1	FM 2	FM 1	FM 2	FM 1	FM 2
Sn/3·5 Ag	102	32	77	30	38	26	29	18
Sn/5 Sb	101	33	46	34	47	30	10	10
Sn/2 As	93	36	60	32	26	28	14	20
Sn/5 In	90	45	69	25	48	23	10	16
Pb/25 In	94	31	65	20	31	12	21	10

A = As-delivered B = Pickled FeNiCo C = Copper-plated FeNiCo D = Copper-plated and silver-plated FeNiCo

Fig. 3 gives a comprehensive representation of the contact angle distribution for the solder specimens with five varieties of flux of gradually increasing activity on copper specimens, based on the same surface preparation as for Tables I and II. The contact angles are listed in the caption to Fig. 3 for the groups 0 to 5 respectively, groups 4 and 5 represent the degree of wetting required for a suitable joint. As can be seen from the images, the tin-silver solder gives the best results in both groups.

Spreading Qualities (Flow Behaviour)

As a direct result of its ability to wet solid surfaces, the capillary action of molten solder is largely similar to that of other fluids.

The effect of the gap geometry and the viscosity of the molten solder can be established after determining the spreading speed of the liquid solder in the capillary gap based on the formula connecting the gap width, solder viscosity and spreading speed.

There are established methods for assessing the flow behaviour which are based on determining the spreading speed of a solder droplet by measuring the area covered by it in a definite time.

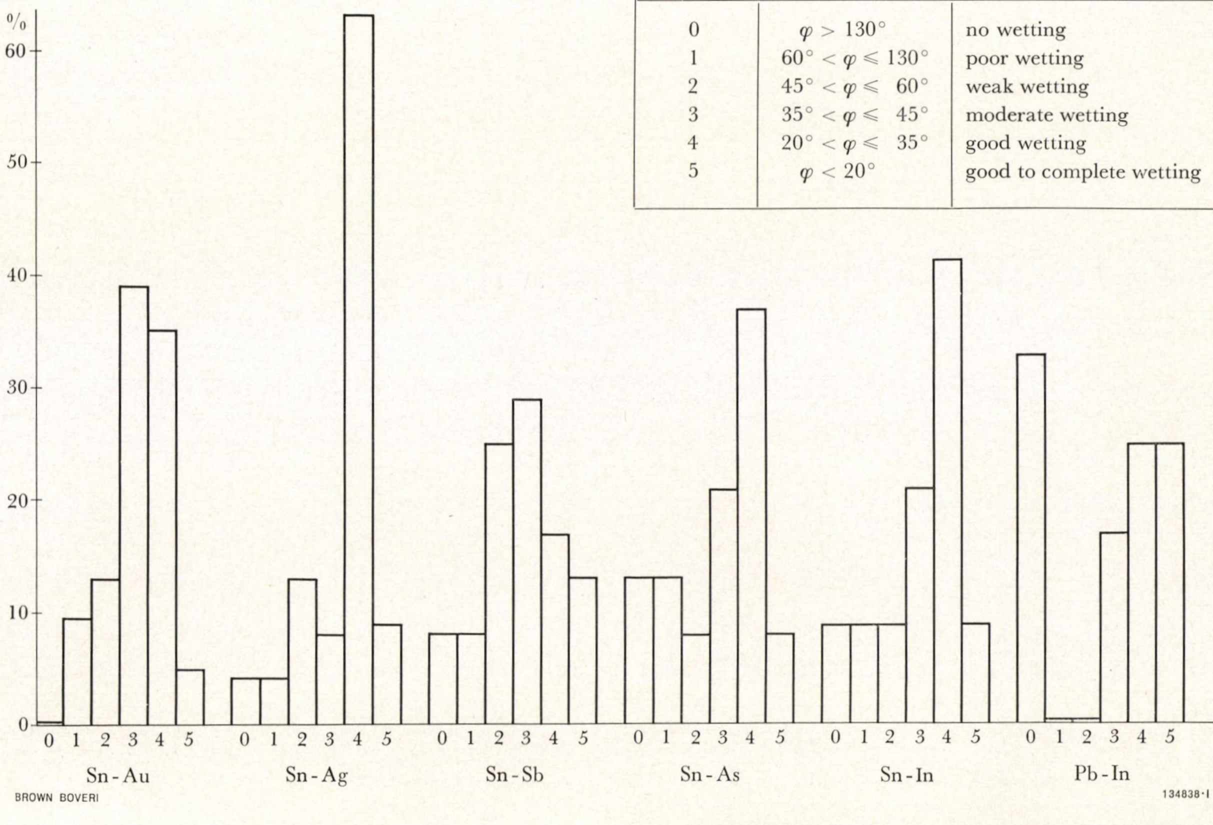
A simpler method than this is to measure the time taken for a solder droplet to flow over a wire which is dividing the droplet into two parts [3].

A further possibility for investigating the spread of solder consists of measuring the height of the rise of molten solder in a capillary system after equilibrium

Fig. 3. – Contact angle distribution of various types of soft solder on copper with diverse surface treatments

Numerical group order:

Wetting order	Contact angle	Characteristics
0	$\varphi > 130°$	no wetting
1	$60° < \varphi \leqslant 130°$	poor wetting
2	$45° < \varphi \leqslant 60°$	weak wetting
3	$35° < \varphi \leqslant 45°$	moderate wetting
4	$20° < \varphi \leqslant 35°$	good wetting
5	$\varphi < 20°$	good to complete wetting



is reached. Alternatively, the rise height can be established by using twisted wires [4] or two plane parallel plates.

These tests were carried out using a specimen consisting of two copper plates 1 mm thick, 5 mm wide and 60 mm long with a constant gap of 0·15 mm and using various solders, fluxes and material pretreatments.

Fig. 4 shows various rise heights obtained with a tin-silver solder using various qualities of flux of increasing activator concentration and Fig. 5 a group of specimens after removing one plate. The results obtained with three qualities of flux are listed in Table III.

The difference between the rise height of the pickled samples and the untreated ones when using the weaker fluxes FM 1 and FM 2 is self-evident. The effect of surface refinement for individual solders varies with the coating.

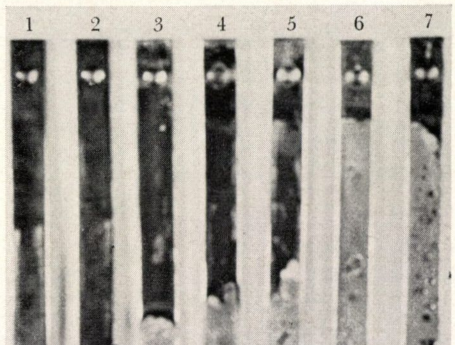


Fig. 4. – Rise heights of a tin-silver solder in a capillary gap between two copper plates using various fluxes

Specimens 1 to 5, organic flux of increasing activator concentration; specimens 6 and 7, zinc chloride based inorganic flux.

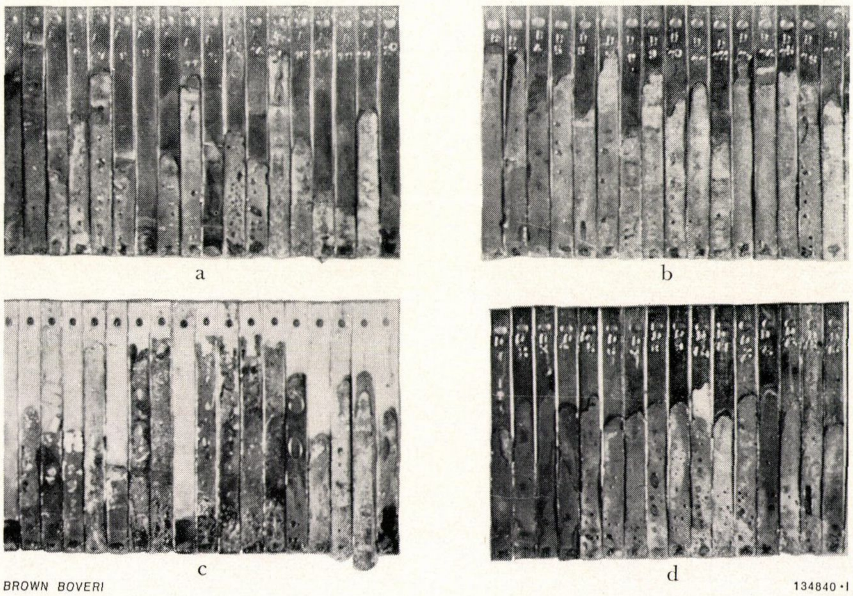


Fig. 5. – Rise heights of diverse types of soft solder on copper with various surface treatments

Group A: Copper as-delivered
Group B: Pickled copper
Group C: Silver-plated copper
Group D: Gold-plated copper

Adhesion

Apart from the wetting qualities and flow characteristics of solders with respect to the specified materials to be joined together and environment conditions, the mechanical strength and service life of a soldered joint is also very important. The reactions between base materials and solder, mainly precipitation processes, can lead to a reduction in strength of a soldered joint [5].

Apart from the effect on the strength, which is determined by the boundary layer reactions, the mechanical and thermal properties of the base material and solder are also very important. In connection with long-term behaviour consideration must be paid to corrosion resistance on the basis of the particular ambient conditions.

Tearing tests were carried out on suitable samples to determine the adhesive strength of the soldered joints.

In order to obtain specific information from these tests regarding the influences of the materials and ambient conditions on the adhesive strength of the soldered joints, the tests must be carried out under reproducible test conditions in each case using similar specimens. If it is necessary for the items to be soldered to have specific constructional qualities, the test specimens can be suitably adapted but the soldering operations must be carried out under the same conditions as before.

TABLE III

The rise of several soft solders in the parallel gap between copper plates with various surface treatments using two organic fluxes FM 1 and FM 2 with increasing activator concentration and inorganic zinc chloride based flux FM 3

Solder	Rise height (mm)											
	A			B			C			D		
	FM 1	FM 2	FM 3	FM 1	FM 2	FM 3	FM 1	FM 2	FM 3	FM 1	FM 2	FM 3
Sn/3·5 Ag	14·7	28·5	38·6	38·6	31·2	43·5	28·3	24·9	24·1	34·1	29·0	30·5
Sn/5 Sb	13·9	19·2	38·2	39·6	33·4	36·8	38·2	36·8	47·4	32·3	37·0	28·9
Sn/5 In	24·7	18·0	44·6	44·0	42·1	39·7	46·0	47·4	45·6	34·1	31·8	44·9
Pb/25 In	12·8	8·0	30·5	33·3	31·9	34·9	22·3	37·1	34·2	15·3	11·5	24·0

A = As-delivered condition B = Pickled copper C = Silver-plated copper D = Gold-plated copper

TABLE IV

Shear strength of copper and FeNiCo alloy soft-soldered joints of various surface treatments using an organic flux of medium activator concentration

Solder	Shear strength (kgf/mm^2)				
	A	B	C	D	E
Sn/3·5 Ag	5·05	4·15	4·30	2·94	3·40
Sn/2 As	4·32	4·60	3·36	2·92	2·20
Sn/5 In	4·80	4·56	4·32	4·13	0
Pb/25 In	0	0·80	0	0	0

A = Pickled copper
B = Silver-plated copper
C = Pickled FeNiCo alloy
D = Copper-plated FeNiCo alloy
E = Copper-plated and pickled FeNiCo alloy

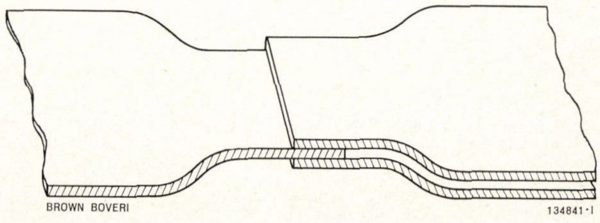


Fig. 6. – Test specimen for determining the shear strength of soldered joints

Depending upon the arrangement of the specimens used for the strength tests, the adhesion strength can be classified as a pure tensile strength, pure shear strength or a combination of the two. Although these values are valid for butt-jointed thin rods or strips or mitred joints, the bending moments superposed on the shear loads in overlapped joints must also be accorded due consideration.

Table IV lists the experimental results of several soft soldered joints which provide information regarding the shear strength. Tests were carried out on specimens as depicted in Fig. 6, with an overlap of 12·5 mm on each side, which were soldered in an air oven.

The effect of various flux qualities on the mechanical strength of the soldered joints can be seen from Table V by comparing the shear stress values. Comparison of the results obtained when using the slightly organic flux FM 1 with those using the inorganic $ZnCl_2$ based flux FM 3 shows clearly that considerably higher strength values are obtained with the more active flux.

The experimental processes employed for solving soft soldering problems associated with external tube parts are also eminently suitable for solving problems encountered in high melting point brazing processes for internal tube parts. As a result of the specific requirements derived from the experiments described here relating to vacuum techniques the experimental apparatus has to be appropriately modified to cope with the higher temperature requirements.

The experiments being carried out at present could lead to interesting possibilities for production control and provide answers to questions related to processes and materials.

(AH) H. J. STEIN

TABLE V

Shear strength of several soft-soldered joints using FeNiCo alloy in the as-delivered condition and two types of flux

Solder	Shear strength (kgf/mm^2)	
	FM 1	FM 2
Sn/Au	3·80	4·76
Sn/3·5 Ag	3·64	5·05
Sn/5 Sb	4·00	6·06
Sn/2 As	2·84	3·52
Sn/5 In	3·88	5·90

FM 1 = slightly organic flux
FM 2 = zinc chloride based inorganic flux

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TESTING HIGH-POWER TRANSMITTING TUBES

621.385:621.373.026.001.4

Examples of the test facilities developed by Brown Boveri are described, and a number of our methods of testing and measuring are discussed with a view to illustrating the great care which is taken to ensure consistently high quality.

Static Measurements

LET US first consider in some detail certain of the many static measurements from which one can obtain an initial approximate indication of the properties of a tube. These include measuring the cathode emission, plotting the tube characteristics and checking the grid emission. In each instance a direct voltage, or a train of voltage pulses, is applied to the electrodes of the tube, care being taken to ensure that the tube does not begin to oscillate in the circuit.

Measuring Cathode Emission

When measuring the emission it is convenient to plot the diode characteristic of the tube, i.e. cathode current I_k against anode voltage V_a, in which case all the grids must be connected with the anode. A family of these characteristics is shown for different cathode temperatures in Fig. 1. The curves were obtained with the aid of an instrument for measuring emission which we developed specially for our high-power tubes.

When the anode voltage is several kilovolts the emission of these large tubes in the saturation region amounts to 1000 A and more, and so it is absolutely essential, if the tube is not to be destroyed by such high power, that measurement should be carried out using short pulses (lasting approximately 100 μs) applied at set intervals. For this, a pulse generator (essentially a capacitor which can be charged with the aid of a thyratron up to several kilovolts) is discharged by means of a heavy-current thyratron via an instrument transformer and the item being measured. The charging voltage of the capacitor and the pulse frequency can thus be adjusted at will. The

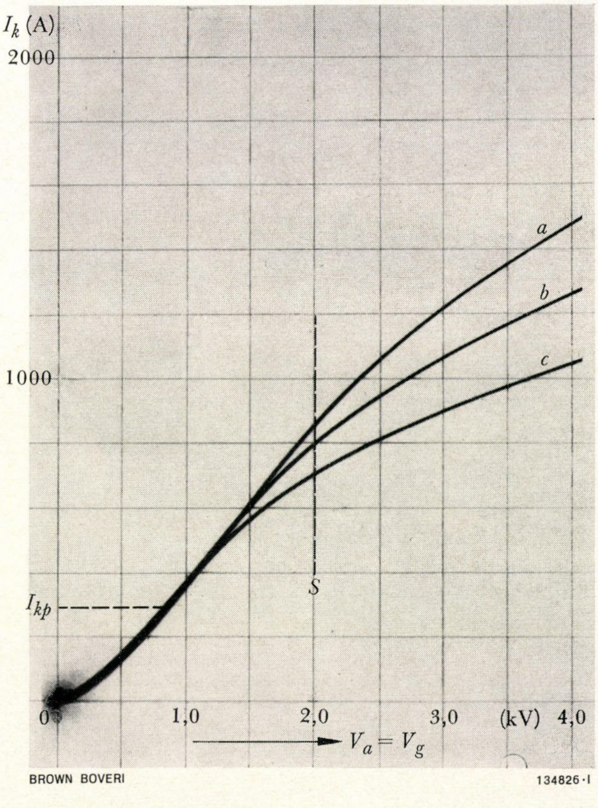


Fig. 1. – Oscillogram of the diode characteristic of a transmitting tube

$$I_k = f(V_a = V_g)$$

a = Cathode temperature too high
b = Correct cathode temperature
c = Cathode temperature too low

It is evident that the common practice of measuring the peak anode current—in this case $I_{kp} = 300$ A—does not yield sufficient information regarding the quality of the electrode, in contrast to measurement in the saturation zone to the right of S.

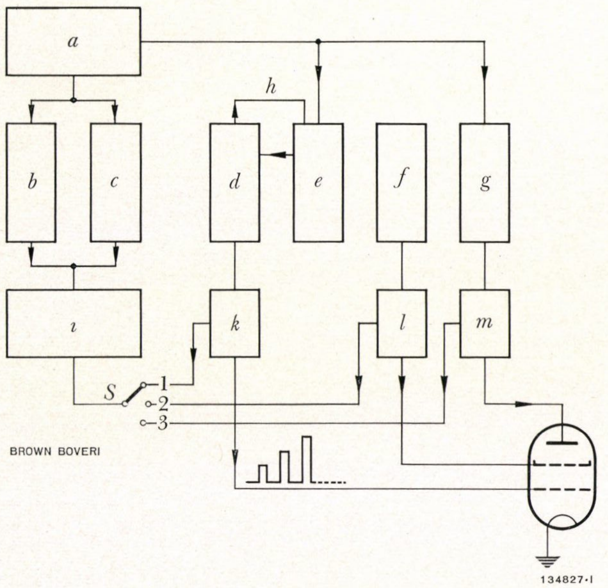


Fig. 2. – Block diagram of the characteristic recorder

a = Control-pulse generator
b = Calibration voltage vertical
c = Calibration voltage horizontal
d = Current-pulse amplifer
e = Voltage-pulse amplifier
f = Rectifier
g = Anode voltage pulse generator
h = Negative feedback
i = Cathode-ray oscilloscope
k = Potentiometer
l = Potentiometer
m = Potentiometer

values for anode voltage and cathode current obtained by the instrument transformer are indicated on a cathode-ray oscillograph, which yields a characteristic like that shown in Fig. 1.

In the saturation zone the shape of the characteristic varies with the chosen cathode temperature, which shows quite clearly that measuring emission in the region of the permissible peak cathode current which is permissible for continuous operation of the tube I_{kp}, as is commonly the practice, can tell us nothing about variations in the quality of the cathode. Therefore, measurements should be carried out with currents approximately three times as great as I_{kp}. Since these measurements, however, are made with the grid (or grids) connected to the anode and at least one third of the energy stored in the capacitor is converted into heat at the grid, care must be taken that the maximum grid dissipation is never excedeed.

The energy W_c stored in a capacitor is given by the formula

$$W_c = \frac{1}{2} C V^2$$

in watt-seconds, if the capacitance C is given in farads and the charge voltage V in volts. For example, if a capacitor of $C = 25$ μF is charged to 6 kV, it has stored 450 Ws of energy. If the emission instrument is then connected to a tube having a dissipation of 5 kW, only eleven pulses per second can be applied if the grid is not to be overloaded.

Plotting the Tube Characteristics

In order to specify the operating data of a high-power transmitter tube it is necessary to determine its characteristic in the region of positive grid voltages as well. To avoid the tube heating up excessively the measuring pulses must be either sufficiently short or applied in a sufficiently slow sequence. The ratio of the periods for which current flows to those where there is none must be made such that the permissible mean dissipation is not exceeded. Disregarding the filament power, dissipation in the tube is made up of the following components:

$$P = P_a + P_g = \frac{1}{T} \int_0^{t_1} v_a \cdot i_a \cdot \mathrm{d}t + \frac{1}{T} \int_0^{t_1} v_g \cdot i_g \cdot \mathrm{d}t$$

where t_1 is the length of a single pulse and $\frac{1}{T}$ is the pulse repetition frequency. The values of P_a and P_g must always be smaller than the maximum permissible values.

The characteristic recorder developed by Brown Boveri is suited to these requirements. The principle of operation can be seen from the block diagram shown in Fig. 2. The amplifiers of the oscillograph are calibrated with the units "calibration voltage horizontal" and "calibration voltage vertical". These are for setting the desired scales. The pulse amplifers receive their signals from the control pulse generator. The pulses are given at 10 ms intervals. The width of the pulses arriving at the grid of the tube being measured can be adjusted. A pulse width of approximately 1 ms was chosen. The capacitor of the V_a pulse generator is discharged across the anode of the test specimen with a time-lag of about 0·1 ms, reckoned from the rising slope of the grid pulse.

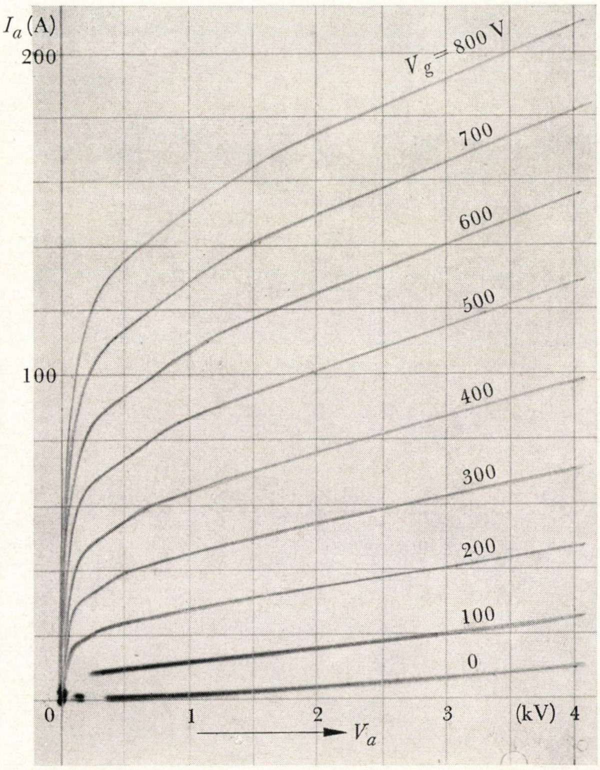


Fig. 3. – Oscillogram of characteristics $I_a = f(V_a, V_g)$ of a high-power transmitting tube, obtained with the characteristic recorder

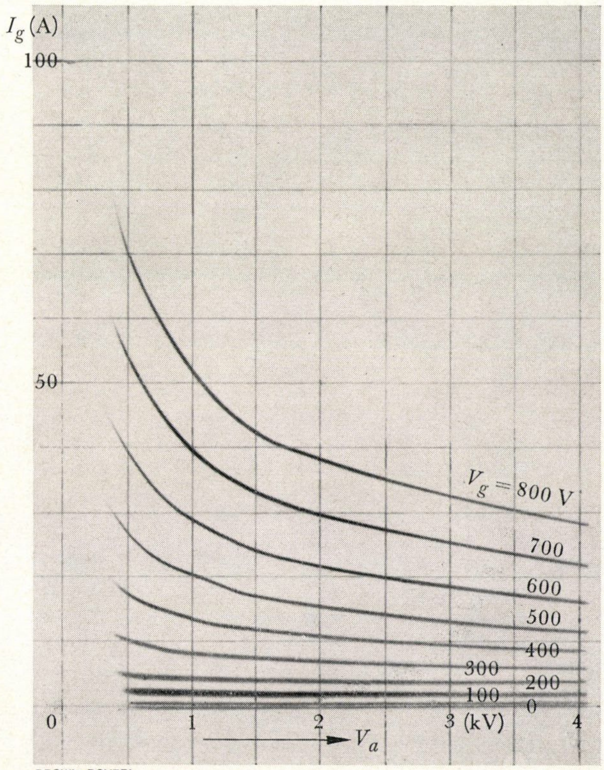


Fig. 4. – Oscillogram of characteristics $I_g = f(V_a, V_g)$ of a high-power transmitting tube, obtained with the characteristic recorder

During this process the height of the grid voltage pulse must remain as nearly constant as possible. With switch S on position 1 the oscillograph records one of the desired characteristics $I_{g1} = f(V_a)$. At position 3 the characteristic $I_a = f(V_a)$ is recorded. The entire family of characteristics can be plotted by altering the height of the grid voltage pulses:

$I_a = f(V_a, V_{g1})$, $I_{g1} = f(V_a, V_{g1})$ or $I_{g2} = f(V_a, V_{g1})$.

The characteristic recorder which we have developed allows nine different grid voltage pulses to be generated in quick succession. The voltages can be chosen arbitrarily, though usually equidistant values are selected, such as 0, 100, 200 V, etc. The pattern of the grid pulses with time is indicated in Fig. 2.

Fig. 3 and 4 show photographs of the characteristics of a high-power triode. It can be seen from the curves of $I_g = f(V_a, V_g)$ that with small anode voltages the grid current rises towards 100 A, hence the presence of pulse current amplifier d.

Measuring the Grid Currents

When the grid voltage is negative there is a small grid current, composed of:

a. Leakage current
b. Ionic current to the grid
c. Current caused by electrons thermally emitted from the grid.

This current flows in the opposite direction to the grid current arising when the grid voltage is positive. It is therefore known as "negative grid current".

Under certain circumstances this can be a nuisance in practice, and determines, among other things, the maximum permissible value for the grid resistance. Thus it is essential for the negative grid current to be kept as small as possible, and in order that appropriate steps can be taken to achieve this it is necessary to define the three components of the current. Furthermore, one must know how and why they occur.

a. The leakage current is the result of poor insulation between the grid and the other electrodes. A tube is usually constructed in such a way that the leakage resistance between grid and cathode is much smaller than that between the other electrodes. Therefore, the leakage current I_g depends chiefly on the leakage resistance R_{is} and the difference in potential ΔV_{gk} between grid and cathode. We have the equation

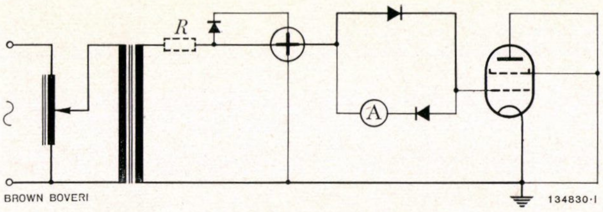


Fig. 5. – Basic circuit diagram of apparatus for measuring I_{gp}

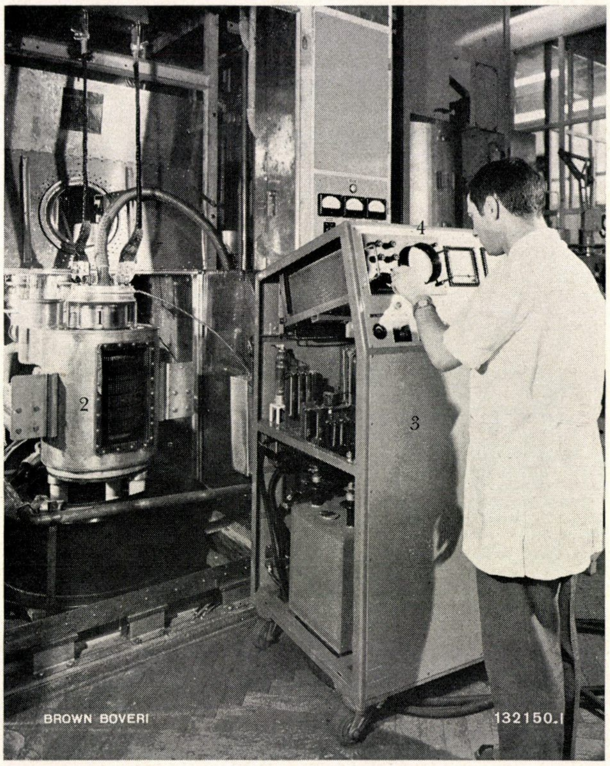


Fig. 6. – Measuring the emission of a BTS 150–2 high-power transmitting tube mounted on its test stand

1 = BTS 150–2 high-power transmitting tube
2 = Evaporation cooler
3 = Instrument trolley for measuring emission and I_{gp}
4 = Plug-in unit with oscilloscope for recording the emission curve $I_k = f(V_a = V_g)$

$$I_{g\,is} = \frac{\Delta V_{gk}}{R_{is}}$$

The leakage current thus bears a linear relationship to the grid voltage.

b. Vacuum current I_{gv} is caused through ionization of the residual gases by the electrons moving from the cathode to the anode. It is proportional to the anode current I_a as

$$I_{gv} = p \cdot I_a$$

where p is the so-called gas ratio. This is proportional to the pressure of the residual gases and depends on their nature.

c. Thermal grid emission depends on the emissivity of the grid, its temperature and, hence, on the grid loading.

Three measurements are required for separating the components of the negative grid current. These consist in measuring $I_g^{(1)}$ at high I_a, $I_g^{(2)}$ at $I_a = 0$ and $I_g^{(3)}$ at $V_f = 0$. This yields three equations with three unknowns. The unknowns are the desired values of $I_{g\,is}$ and I_{gv} and the thermal grid emission current I_{gp}. We have:

$$I_{gv} = I_g^{(1)} - I_g^{(2)}$$
$$I_{gp} = I_g^{(2)} - I_g^{(3)}$$
$$I_{g\,is} = I_g^{(3)}$$

When measuring the thermal grid emission as described above the grid is heated only by radiation from the cathode, because the grid dissipation is zero. Nevertheless, it is also necessary to test thermal grid emission at maximum grid dissipation, as only then does the grid attain its maximum operating temperature.

This can be done by means of the circuit shown in Fig. 5. Here, a positive half-wave current is applied to the grid and then regulated until the desired grid dissipation is reached. The other grids and the anode are connected to the cathode. During the negative half-wave, ammeter A is used to measure the current produced by thermal grid emission.

It can happen that the amplitude of the voltage in the negative direction is insufficient to remove all the thermally emitted electrons from the grid, particularly if the grid emission is very large. In a case like this the amplitude of the negative half-wave of the alternating voltage must be increased, while at the same time the voltage amplitude of the positive half-wave has to be reduced so that the desired value for the grid dissipation P_g can still be set. This is achieved by including a suitable resistor R in the power lead to the wattmeter.

On the right in Fig. 6 can be seen a mobile instrument trolley for measuring emission and I_{gp}, while to the left is one of our test stands for high-power triodes.

Dynamic Measurements

After the static data have been determined, the tube is put into dynamic operation in order to ascertain its behaviour under r.f. conditions. In this, particular attention must be paid to the following four points:

1. Determining and checking limiting values
2. Efficiency
3. Possibility of breakdown
4. Thermal behaviour.

In practice, high-power tubes have two fundamentally different applications, in oscillators or in power amplifiers (anode-modulated or unmodulated).

Therefore, in order to simulate actual operating conditions as closely as possible when testing, oscillators and anode-modulated transmitting amplifiers must be available in all sizes. This, however, involves a considerable quantity of instruments, power, time and facilities for cooling and interference protection, and the like.

Tubes in Oscillators

High-power oscillators are mainly used in industrial generators for capacitive or inductive heating of workpieces. The tubes almost always work as class C oscillators in order to achieve the highest possible efficiency. When testing the tubes, the different loadings of capacitive and inductive generators are simulated by dummy aerials.

In high-power, and hence large, tubes the electrodes have relatively high reactances, and so a grounded-grid circuit is the obvious choice.

One of our test oscillators is illustrated in Fig. 7. The apparatus is suitable for both static and dynamic operation. By fitting the appropriate cooling system it can be adapted to suit either water-cooled or vapour-cooled transmitting tubes. With these very large tubes the filament power alone may be as high as 12 kW. Outputs up to 1000 kW can be produced on the test stand. The 800 kW, approxi-

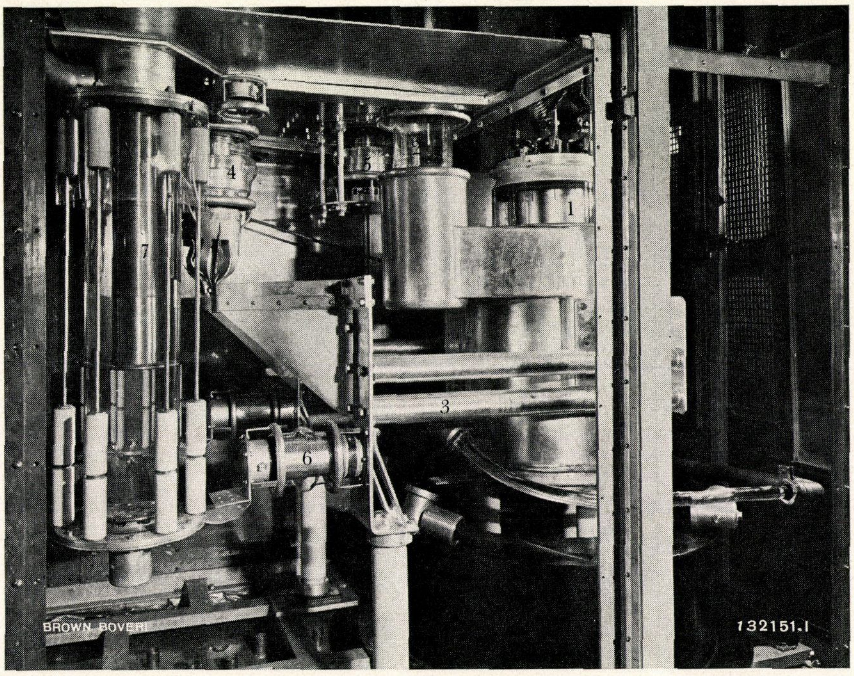


Fig. 7. – View inside a test stand for high-power transmitting tubes

1 = BTS 150-2 vapour-cooled transmitting tube
2 = Steam extraction pipe
3 = Resonant circuit inductance (L_1)
4 = Variable vacuum capacitor (C_1)
5 = Variable vacuum capacitor (C_2) for feedback
6 = Coupling capacitor (C_8)
7 = Water-cooled dummy aerial (R_a). The aerial resistance can be infinitely varied by moving the plunger visible in the upper portion.

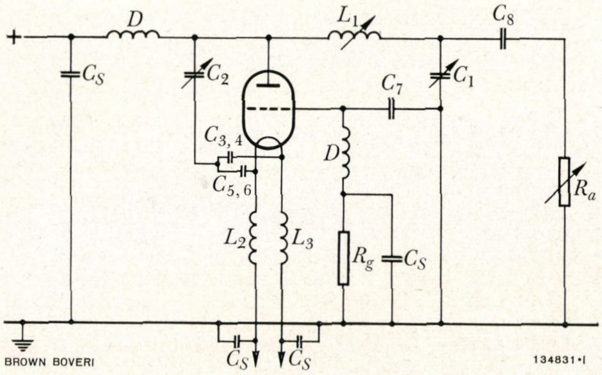


Fig. 8. – Basic circuit diagram of the test oscillator

L_1 = Inductance of the anode circuit
L_2, L_3 = Inductance of the cathode circuit
D = Choke
C_1 = Resonant circuit capacitor
C_2–C_6 = Feedback capacitors
C_7 = Grid capacitor
C_8 = Coupling capacitor
C_s = Smoothing capacitors
R_a = Dummy aerial
R_g = Grid resistance

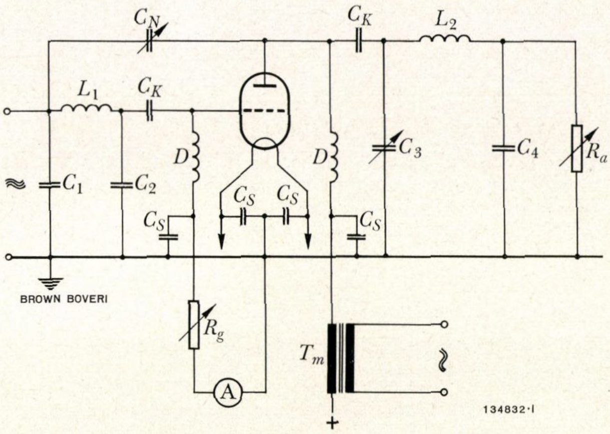


Fig. 9. – Basic circuit diagram of the anode-modulated transmitting amplifier

L_1 = Inductance of the grid circuit
L_2 = Inductance of the anode circuit
D = Choke
T_m = Modulation transformer
C_1, C_2 = Capacitances of the grid circuit
C_3, C_4 = Capacitances of the anode circuit
C_k = Coupling capacitors
C_n = Neutralizing capacitor
C_s = Smoothing capacitors
R_a = Dummy aerial
R_g = Grid resistance

mately, of r.f. power are converted into heat at a water-cooled dummy aerial which, together with the anode cooling system, requires up to 500 litres of water per minute.

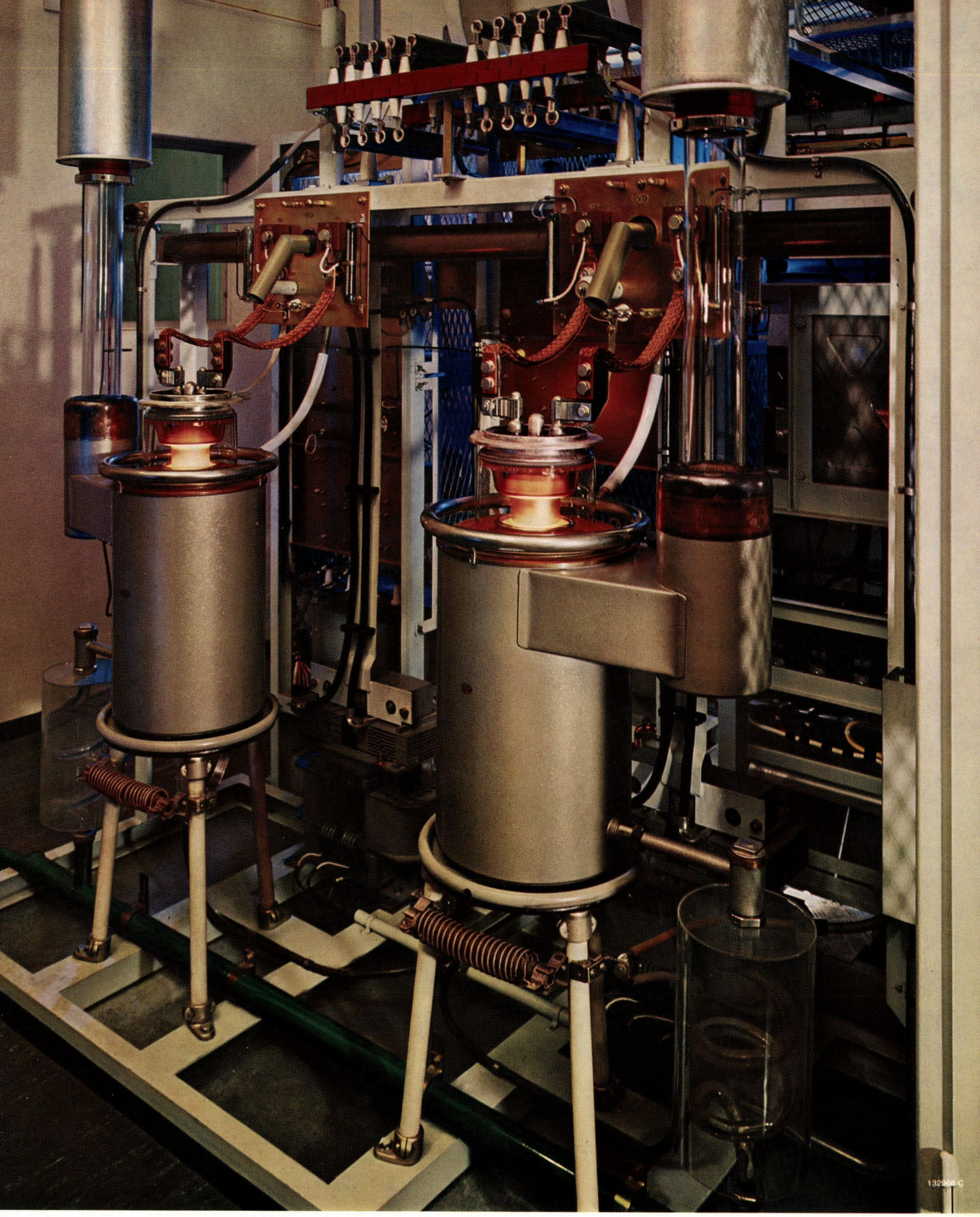
This test oscillator is so designed that all the parameters of interest can be varied in order to match most of the circumstances encountered in practice. The frequency-determining part of the oscillator is in the form of a π network, one parallel capacitance of which is given by the capacitances of the tube. Frequency is adjusted by means of capacitor C_1 and the inductance of the anode circuit. The feedback voltage is set with capacitor C_2. Capacitors C_3–C_6 ensure that the feedback voltage is evenly distributed between the four cathode connections of the tube, while C_7 earths the grid with respect to the r.f. voltage. The r.f. power passes via capacitor C_8 to the variable load R_a and the dummy aerial. The powers occurring at the anode and at the dummy aerial are measured calorimetrically. Temperatures at the glass and the metal parts of the tube, with the exception of the anode, are checked with the aid of heat-sensitive colours or paper.

Tubes in Anode-Modulated Transmitter Amplifiers

In a transmitter, a high-power tube is subject to very high voltage loadings when the anode current is modulated. With 100 % modulation the peak voltage is nearly four times the direct anode voltage. It is therefore imperative that the tube is also exposed to these extreme conditions during testing. The basic circuit diagram of one of our test transmitters is shown in Fig. 9. The high-frequency carrier signal reaches the grid of the transmitting tube via the input circuit (C_1, C_2 and L_1). This circuit matches the driving stage to the final stage. The anode circuit (C_3, C_4 and L_2) is tuned to the frequency of the driving stage. Modulation is provided by modulation transformer T_m. The load is in the form of a dummy aerial R_a, the resistance of which is held constant by regulating the temperature of the coolant, thus simulating the constant transmitter load through the aerial.

An anode-modulated transmitter of this type has roughly the same power and water requirements as the test oscillator discussed earlier. On the other hand, the transmitter is much more complicated and more expensive, and the space required is about ten times as great.

(DJS) L. EGERSZEGI



Modulator of the 250-kW medium-wave transmitter of the Swiss national broadcasting station in Beromünster

The modulator of this transmitter is equipped with two vapour-cooled triodes types BTS 50–1, while the r.f. final stage has three tubes of the same type.

BROWN BOVERI

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