INDUSTRIAL RECTIFYING TUBES

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BOOK XIII

INDUSTRIAL RECTIFYING TUBES

INDUSTRIAL RECTIFYING TUBES

BY

MEMBERS OF

PHILIPS ELECTRON TUBE DIVISION

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PREFACE

It is well known that for charging batteries and, in many cases, for feeding arc lamps, welding and various other industrial apparatus, direct current is required. Since, however, most mains are A.C., the power required for such purpose has to be converted into D.C. This is done most reliably and most efficiently with the aid of electronic-tube rectifiers.

In this book details are given of a range of rectifying tubes specially developed to meet the highest requirements. These rectifying tubes have a high efficiency and give reliable service for many years. In their design particular attention has been paid to a strong mechanical construction, so that the tubes can withstand severe shocks, such as may occur in industrial plant. Furthermore, calculations are given for the design of tube rectifiers, together with a number of practical examples and circuit diagrams. A selection chart (see p. 114) greatly facilitates the choice of the circuits and types of tubes suitable for a given design.

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INDUSTRIAL RECTIFYING TUBES

INTRODUCTION

Rectifying tubes are used to convert alternating current into direct current and can be divided into high-vacuum and gas-filled types.

In industrial applications gas-filled rectifying tubes have several advantages over high-vacuum types because of their very low internal resistance resulting in a high current capacity and efficiency. This efficiency is practically independent of the load within a wide range, so that a considerable saving in power consumption is obtained when the installation is in operation under a partial load for an appreciable time, compared with the case when, instead of tubes, motor generators are used. Moreover, for low-voltage installations, such as battery chargers, a tube rectifier requires no foundations for mounting, no moving parts, no auxiliary starting gear etc., nor is any skill needed to operate it, factors which may well outweigh the disadvantage of filament power consumption and arc losses.

In this Bulletin the operation, the construction and the application of hot-cathode gas-filled rectifying tubes in battery chargers, power rectifiers, cinema rectifiers and D.C. arc welders are discussed. Data are given for a range of rectifying tubes suitable for these applications.

PRINCIPLE OF OPERATION

A hot-cathode gas-filled rectifying tube is a diode tube containing inert gas, mercury vapour or sometimes a mixture of both.

Formerly, tungsten cathodes were used, but soon they were superseded by thoriated tungsten cathodes. The latter in turn were superseded by oxide-coated types, as these have not only a lower heating power consumption for the same emission current, but also a longer life with relatively high emission currents.

When a sufficiently A.C. voltage is applied between the anode and cathode, an arc is formed and the tube becomes conductive, but only during the positive half cycle. This makes the tube suitable for use as a rectifier.

Fig. 1 shows the voltages and current of the tube when an A.C. voltage is applied to the anode, the tube being loaded by a resistor R_o *). When the anode voltage is gradually increased, the current/voltage characteristic is at first similar to that in a vacuum diode, and only a very small current will flow. However, the electrons finally acquire sufficient energy to ionize the gas atoms through collision, the anode voltage then being equal to the ignition voltage V_{ign}. At this instant an arc is formed and the voltage across the tube drops to the arc voltage

*) Glossary of symbols on page 112.

V_{arc}. The current through the tube during the positive half cycles of anode voltage depends on the values of the A.C. supply voltage v_{tr}, the voltage across the tube V_{arc} and the load resistor R_o. It is not limited by the negative space charge, as is normally the case in high-vacuum tubes, since this charge is neutralized by the positive ions flowing to the cathode. For this reason and because of the application of an oxide-coated cathode, a high output current can be obtained with only a small voltage drop across the tube.

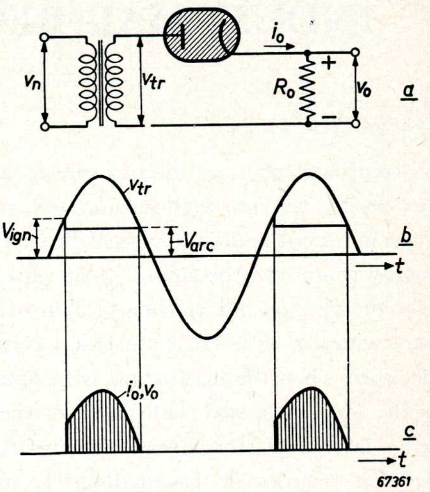

Fig. 1. a. Basic circuit diagram of a rectifier.
b. Voltage diagram.
c. Current diagram.

The potential distribution in the tube under ionized condition can be represented by the curve of fig. 2. Practically all the potential drop occurs in the region immediately adjacent to the cathode. The remaining space is taken up by the so-called "plasma", a region in which positive ions are practically in equilibrium with the negatively charged electrons drifting to the anode.

CONSTRUCTION

The envelopes of the tubes described in this book consist of a glass bulb, which has proved to be able to withstand severe shocks such as may occur in industrial equipment. In general, the geometry of the tube is so chosen that the ignition and arc voltages are low, and the maximum permissible negative voltage which may be applied to the anode, i.e. the peak inverse anode voltage $V_{inv\,p}$, is as high as required for the purpose for which the tube is intended.

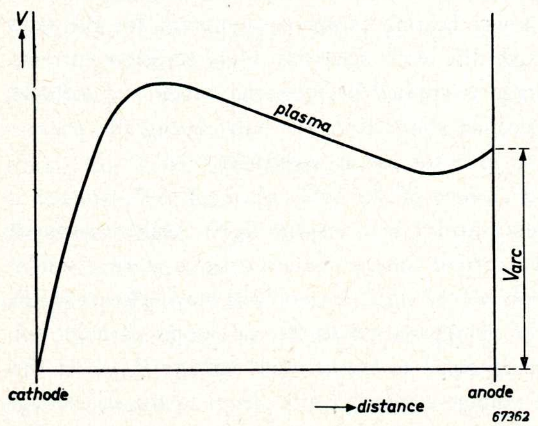

Fig. 2. Potential distribution between anode and cathode in a gas-filled tube under ionized condition.

The cathode is of the oxide-coated, directly heated type. It consists of a coil of tungsten wire over which a nickel wire of much smaller diameter is wound, the latter serving to carry the oxide coating. In some tubes the nickel wire is also spiralized in order to increase the effective surface. The cathode has the form of a helix, giving a high thermal efficiency. The electric field in the tube adapts itself more or less automatically to the cathode surface, so that the electrons can leave it along lines of force considerably deviating from those existing before the ionization of the gas. As a result, the interior part of the helix also emits electrons, and a high emission current per watt of filament power is obtained.

In most tubes the cathode is screened, so that the risk of arcing back to the cathode is considerably reduced and the life of the cathode is extended. When tubes with two anodes are used, an additional screen, placed between the anodes, reduces the possibility of an arc being formed between the anodes. The positive ions always tend to flow to that point in the tube which has the most negative potential, thus, in the case of double-anode tubes, to the momentarily non-conducting anode. If they strike this anode with sufficient energy to produce secondary emission, an arc discharge between the anodes may occur. Since the ions are present in the discharge path, they are prevented from flowing to the negative anode by both screens.

The anodes are usually made of graphite, and the construction is such that heat is dissipated quickly. The work function of graphite is higher than that of all metals, whilst this material has moreover the advantage that mercury does not adhere to it. Owing to these favourable properties it has been possible to increase the peak inverse voltage rating of the tubes considerably.

The wires connecting the electrodes to the terminals are led through the glass either by making use of a pinch construction, such as used in incandescent lamps, or via a chrome-iron seal. The former technique is used for smaller tubes, the latter being applied in the construction of larger tubes. In both cases the glass and the material used for the wires have so been chosen that they have equal coefficients of expansion, so that neither the glass will crack nor leakage will occur at any operating temperature.

TUBE LIFE

Experience has shown that the average life of the tubes of the range described in this book exceeds 10 000 hours of reliable service if used under proper conditions without exceeding the ratings given in the tube data. Definite figures for their life cannot be quoted, as it depends on a large number of factors, such as the number of times the tube is switched on and off, and on several other factors mainly decided by the user; for example, the design of the circuit, the ambient temperature, the constancy of the supply voltages, etc.

In practical operation five or six years of service are not unusual.

EFFICIENCY

Distinction must be made between the efficiency of the complete rectifying installation and that of the tubes. The efficiency of the installation is defined as the D.C. output power divided by the A.C. input power, thus taking into account the tube and transformer losses, A.C. ripple losses and losses in resistors or chokes belonging to the input circuit.

The efficiency of the tube itself is given by the equation:

$$\eta_v = \frac{W_o}{W_o + W_f + W_{arc}}, \quad \text{(1)}$$

where W_o = D.C. output power,
W_f = filament power and
W_{arc} = arc losses.

In the first instance the required filament power is proportional to the maximum value of the current to be drawn from the cathode $I_{o\,p}$. In most practical circuits this current approximately equals the D.C. output current I_o, so that the filament power can be represented by:

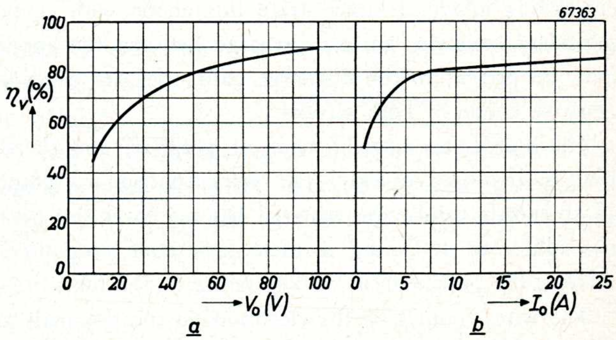

Fig. 3. a The efficiency η_v of the 1849 tube as a function of the D.C. output voltage V_o at constant D.C. output current. b The efficiency η_v of the 1849 tube as a function of the D.C. output current I_o at constant D.C. output voltage.

$$W_f = k_1 I_o, \quad \text{(2)}$$

where k_1 is a proportionality factor.

The arc losses are then given by the product of V_{arc} and I_o, the arc voltage being practically constant. According to eq. (1) the tube efficiency thus becomes:

$$\eta_v = \frac{V_o I_o}{V_o I_o + k_1 I_o + V_{arc} I_o},$$

or

$$\eta_v = \frac{V_o}{V_o + k_1 + V_{arc}} \quad \text{(3)}$$

For the tubes listed in this book, the factor k_1 is approx. 2 to 6 W/A, and V_{arc} is 7—15 V.

According to eq. (3) the efficiency lies between:

$$\frac{V_0}{V_0 + 21} \text{ and } \frac{V_0}{V_0 + 9}, \qquad (4)$$

and thus increases with increasing output voltage. For 25 V D.C. output, for example, the efficiency lies between 54% and 73%, whilst with 220 V D.C. output voltage, the efficiency is 91% to 96%, which is a very high value and cannot be obtained with any other type of rectifier.

Fig. 3*a* shows the efficiency of the rectifying tube type 1849 as a function of the output voltage with constant output current. Fig. 3*b* gives the efficiency as a function of the output current with constant output voltage. It may be seen that with decreasing output current there is only a slight decrease in efficiency. Owing to the arc losses being constant in the case of fig. 3*a*, the efficiency decreases more rapidly with decreasing output voltage.

INSTALLATION

For the correct starting and operating of rectifying tubes filled with rare gas or a mixture of rare gas and mercury, the temperature of either the gas or the mercury should be within certain limits.

Tubes filled with rare gas may be started when the tube is placed in surroundings having a temperature of minimum —55° C and maximum +75° C. In that case the tube will start easily and the temperature during normal operation will stay within safe limits provided adequate natural cooling is ensured (see below).

Tubes filled with rare gas and mercury may be started when the temperature of the *mercury* is between 0° C and +80° C. During operation the temperature of the condensed mercury must remain between +30° C and +80° C, preferably at about +60° C. These temperatures should be measured at the coldest spot of the tube which generally is the exhaust pipe or the auxiliary anode connection, both at the bottom of the tube, using a small thermocouple, a calibrated thermometer or some temperature-sensitive indicator as Tempilaq. Once the tube is started, adequate natural cooling will as a rule be sufficient to keep the temperature of the mercury within safe limits unless otherwise specified (e.g. type 1069 K).

In order to ensure sufficient cooling, the following rules must be observed when designing a cabinet:

1) All tubes must be mounted vertically with their base or filament strips down.
2) The clearance between the tube envelope and the cabinet wall or parts of the circuit should be at least equal to half the maximum tube diameter.
3) When two or more tubes are placed in the same enclosure, the distance between them should be at least equal to ¾ the max. tube diameter.
4) Closed cabinets should have ventilation apertures at the bottom and the top of the cabinet, to ensure natural convection in a stream from the bottom upwards.