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.

CONTENTS

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

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*) 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.

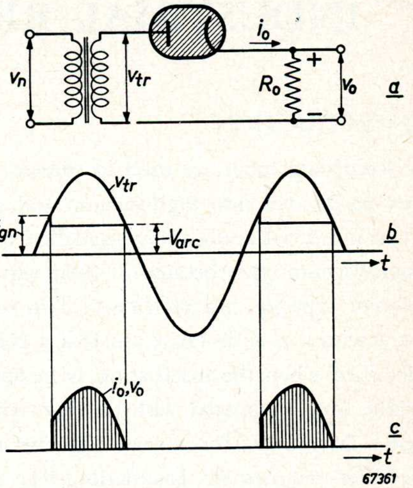

Fig. 1. a. Basic circuit diagram of a rectifier.
b. Voltage diagram.
c. Current diagram.

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.

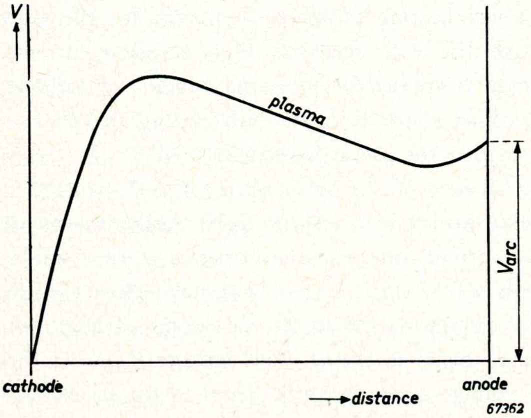

Fig. 2. Potential distribution between anode and cathode in a gas-filled tube under ionized condition.

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:

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

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 $I_{o\,\mathrm{p}}$. In most practical circuits this current approximately equals the D.C. output current I_o, so that the filament power can be represented by:

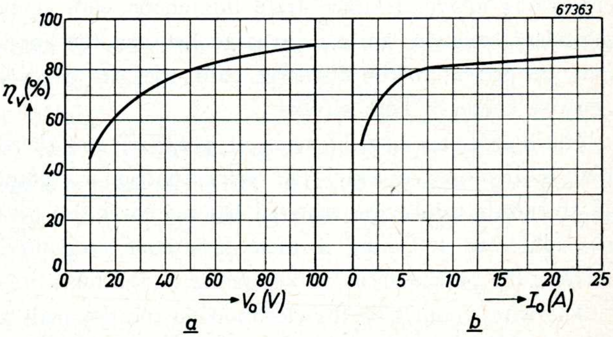

Fig. 3. a The efficiency η_v of the 1849 tube as a function of the D.C. output voltage V_0 at constant D.C. output current. b The efficiency η_v of the 1849 tube as a function of the D.C. output current I_0 at constant D.C. output voltage.

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

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:

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

or

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

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:

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

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 3/4 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.

When wire-mesh or perforated steel is used for the cabinet walls, care should be taken to protect the tubes from extraneous draughts as these may very easily cause condensation of the mercury at a wrong place.

When the air contains agressive gases, vapours, dust or moisture drops, these have free access to the tube and may influence its life unfavourably. It is advisable in these cases to consult us before designing or installing the rectifier.

5) When forced air cooling is used, this should support the natural convection, i.e. it should blow from the bottom upwards.
6) To avoid local overheating all tube connections should have clean surfaces, free of dirt or oxide. Cathode strips should fit the fixing bolts without mechanical stress and should be bolted down firmly. When the anode connections are made with knurled nuts and cable lugs, the nuts should be tightened securely using a screw driver or a pair of pliers. Anode leads should be of sufficient cross-section, as the r.m.s. value of the anode current in rectifier circuits may be 2.5 times the average D.C. value.

Tubes should not be subjected to severe shocks or vibration. In general, if accelerations higher than 0.5 g are to be expected, the tubes should be mounted on some shock-absorbing device and the anode leads should be made of flexible wire.

In normal operation, when the tube is switched on, sufficient time should elapse between the switching on of the filament and that of the anode tension, to allow the filament to reach its full electron-emitting temperature. The minimum prescribed heating-up time T_w is mentioned for every tube type. It may be obtained by two hand-operated switches controlling resp. the filament voltage and the anode voltage, or automatically by the use of some time-delay relay in the anode circuit. For this purpose a bimetal relay type 4152 is available, data of which are given on page 108.

Generally, two values are given for T_w. The longer one is the recommended value, the shorter one may be used when this should be absolutely necessary. An exception to this rule are the small gas-filled tubes 328, 367, 1010 and 1019. These may be started without previous pre-heating of the filament, provided the tube is used for 8 hours after it has been switched on. If the operating times are shorter, the life-expectancy drops with higher switching frequency.

When a tube containing mercury vapour is switched on for the first time after transport or after prolonged periods of non-activity, the tube must be pre-heated for five minutes before applying anode voltage, so that all mercury is removed from the electrodes.

For obtaining optimum life of tubes with directly heated cathodes, the use of a centre-tapped filament transformer is to be recommended. In the case of three-phase supply, a phase difference between 60° and 120° can be obtained by connecting the filament supply transformers and those for the anode supply between different phases, which is of favourable influence on tube life.

The 1173, 1174, 1176, 1177, 1838, 1849 and 1859 tubes are provided with an auxiliary ignition electrode, in order to facilitate the ignition of the tube. This electrode should have a positive potential with respect to the cathode and must be connected, via a current-limiting resistor, to an auxiliary D.C. source delivering some 40 V, 10 mA power. For this purpose the Auxiliary Ignition Unit type 1289, a description of which is given on p. 106, can be used. This unit is already equipped with the current-limiting resistors.

The tubes 1710 and 1725 A are provided with a screen electrode, which must be connected to the cathode via a resistor of 10 kΩ, 0.5 W.

RATINGS

When designing a rectifying installation, there are several important tube ratings to be considered.

The maximum ratings of the tubes are on an absolute maximum basis. When the tube is operated above its limiting values, then its life and satisfactory performance may be impaired. *) Therefore, in order not to exceed these absolute ratings, the equipment designer must determine an average design value for each rating sufficiently below the absolute value, to ensure that the latter will never be exceeded under any normal supply-voltage fluctuation, load variation or production spread in the equipment itself.

The maximum permissible D.C. output current I_o must not be exceeded, as otherwise the tube will be damaged by overheating. This current is the highest average output current, as read on a D.C. meter, that may continuously flow through the tube.

The peak anode current I_{ap} represents the highest current allowed to flow in the anode circuit. Unless otherwise indicated in the tube data, the maximum time over which the anode current (i_a) may be averaged is 10 seconds.

The maximum peak inverse anode voltage $V_{\mathrm{inv\,p}}$ is the highest instantaneous negative voltage that may be applied to the anode. This rating should never be exceeded, so as to avoid arcing back or flashover in the tube.

It is advisable to check the actual peak values of currents and voltages with the aid of an oscilloscope, as there may exist differences between the practical and the theoretically calculated values.

Measures must be taken to limit the surge current, which is the peak value of the current surge that may be caused by a short-circuit or by arc-back of the tubes, below the maximum permissible value. This can be obtained most simply by applying at least the minimum required total resistance (R_t) in the anode circuit. This resistance can be calculated as follows:

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*) An exception is made with tubes for battery chargers, where the D.C. output current rating may be exceeded with 25% when a discharged battery is taken under charge.

$$R_t = R_s + n^2 R_p + R_a,$$

in which R_t is the total resistance; R_s the resistance of the transformer secondary (one half in the case of a full-wave rectifier), n the transformer ratio, R_p the resistance of the primary winding and R_a the value of the resistor connected in series with the anode.

When the value of R_a is thus so chosen that R_t has at least the minimum value given in the tube ratings, the chance of arc-back is practically reduced to zero.

In some cases, however, the additional resistor R_a dissipates too much power, especially in those cases where the r.m.s. value of the anode current is high, for instance in poly-phase circuits with a back-E.M.F. load. It will be clear that from an economical point of view another system of current limiting must be found. This can be obtained by increasing the self-inductance in the anode circuit by means of a series choke, or by using a transformer with purposely increased spreading flux.

In battery chargers, however, it is always advisable to connect a resistor in series with the anodes, because a possible arc-back in the tube is maintained in the form of a D.C. arc fed by the battery under charge. The tubes can further be protected by a circuit breaker or a fuse in the D.C. output circuit, cutting out when an arc-back leads to back feeding by the battery.

Apart from the necessity of incorporating in the circuit the necessary elements to keep the current within the published limits, it is advisable to provide for a damping of voltage surges caused by oscillations or switching manipulations. The following provisions have in practice proved their value.

1) It is advisable to incorporate in all rectifiers for voltages of 120 V and higher a resistor parallel to the load. The value of this resistor should be so calculated that it consumes about 0.5—1% of the nominal load.

2) When measure 1) should be insufficient, the incorporation of an RC element consisting of a capacitor and a resistor in series —this series arrangement being connected in parallel to every secondary winding of the transformer— is advisable, as it suppresses oscillations in the transformer. The following rules for the calculation are given:

If E = voltage per secondary phase,
C = capacity per secondary phase,
L = total leak induction per secondary phase of the transformer,
R = damping resistor,
I = r.m.s. current per secondary phase,
Z = E/I = impedance of phase load,

then: $E^2 \omega C$ = about 1—2 ‰ of the transformer power divided by the number of secondary phases and $R = 2\sqrt{\dfrac{L}{C}}$.

Roughly speaking it can be said that C (in μF)

$\dfrac{3 \div 6}{Z}$, and R (in ohms) $= 14\,Z \div 10\,Z$.

These values for C and R are not very critical and hold good for a mains frequency of 50—60 c/s.

3) Voltage surges caused by the load or switching manipulations can be suppressed by the use of V(oltage) D(ependent) R(esistance) resistors connected in parallel with the load.
As these are used for a reason different from the measures 1) and 2), a combination is very well possible.

4) Anode fuses are advisable in any case, but certainly in the case of rectifiers for output voltages of more than 220 V.

When operation of a battery charger must be stopped, it is recommended first to operate the D.C. switch and subsequently the mains switch. When the latter would be opened first, high voltage surges in the transformer secondary might occur, resulting in arcing back of the tubes.

CIRCUITS

There is little uniformity and considerable confusion in the denomination of rectifying circuits, the circuit of fig. 30, for example being deliberately called a single-phase centre-tap, a single-phase full-wave or a two-phase half-wave rectifier.

In this book the last-mentioned denomination is used for indicating the number of (secondary) phases to be rectified, it being also stated whether only half a wave or the full wave (bridge circuits) of each cycle and of each phase is rectified.

BATTERY CHARGERS

GENERAL

The D.C. current required for battery charging can be obtained with rectifying equipment using rectifying tubes, barrier-layer rectifiers or rotary converters.

The demand for rectifying tubes is still increasing considerably, because they are specially suitable for use in battery chargers. They are light in weight, compact in size and have an efficiency which can never be reached by rotary converters. Moreover, they have the advantage that replacement of a defective tube only takes a few minutes.

Since the battery itself has little resistance, the D.C. current with which the battery is charged must be limited to the value given in the tube data, and for this purpose a resistor, choke or transformer with magnetic shunt can be used. Limiting resistors are employed in case of small chargers, providing a cheap but not economical solution owing to their high power consumption. For bigger chargers use is made of inductors in series with the primary of the mains transformer. The application of a magnetic shunt on the mains transformer becomes very attractive for battery chargers when these are produced in large series. Mains voltage fluctuations and battery voltage variations during the charging period must also be taken into account when designing a current limiting device (see eq. (6)).

Care should be taken that the total resistance R_2 in each anode circuit is equal or higher than the minimum protective resistance R_t given in the tube data, in order to prevent damage of the tube in case of backfire or faulty operation of the equipment.

Tube types 328, 367, 1010, 1048, 1110 and 1119 are primarily intended to be used in trickle chargers and small battery chargers for about 20 lead cells and having a maximum output current of 6 A per tube.

Types 1039, 1049, 1710, 1725 A, 1173, 1174, 1176, 1177, 1838, 1849 and 1859 can be used in larger units for charging more than 20 lead cells and having output currents of up to 50 A per tube.

The tubes of the lower current range are designed for use in private garages and other places where the use of a large changer is not justified. Tubes of the second range are used in battery chargers in large public, municipal and army garages, motorcar and electric car charging stations, telephone exchanges and emergency lighting installations.

CIRCUIT DIAGRAMS

Tubes of the smaller types are normally used in battery chargers fed from single-phase supply, whilst the other tubes are employed in chargers designed for single- and three-phase supply.

The circuit diagrams commonly used are given in figs 4 to 9, where R_a and L are current-limiting resistors or chokes respectively.

DESIGN CONSIDERATIONS *)

CIRCUITS

The basic circuit of a single-phase, half-wave rectifier is given in fig. 10*a*. As the voltage supplied by the transformer increases sinusoidally, a point will be reached where $V_{tr}\sqrt{2}\sin\omega t - V_b = V_{\mathrm{ign}}$, and the tube will then become conducting (point t_1 of fig. 10*b*). The rectifying tube will obviously ignite only if the peak value of the transformer secondary voltage exceeds the battery voltage plus the ignition voltage of the tube, i.e. when:

$$V_{tr}\sqrt{2} > V_b + V_{\mathrm{ign}}\,, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

BASIC CIRCUIT DIAGRAMS FOR BATTERY CHARGERS

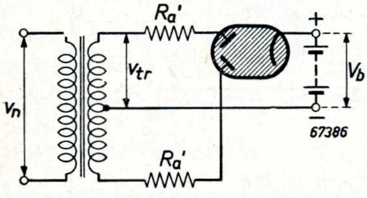

Fig. 4. TWO-PHASE HALF-WAVE

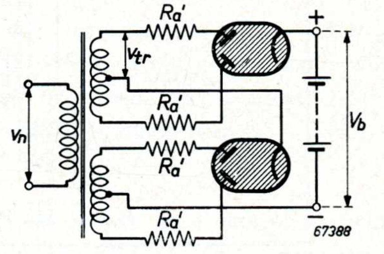

Fig. 6. TWO-PHASE HALF-WAVE IN SERIES CONNECTION

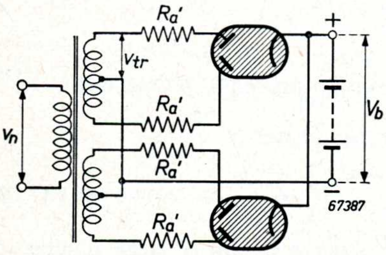

Fig. 5. TWO-PHASE HALF-WAVE IN PARALLEL CONNECTION

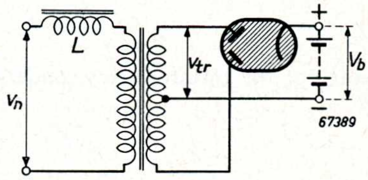

Fig. 7. TWO-PHASE HALF-WAVE

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*) See W. van Doorn, Power Rectifiers with Gas-filled Rectifying Valves, Electr. Appl. Bull. *X*, p. 167 and p. 190, 1949 (Nos. 7 and 8).

BASIC CIRCUIT DIAGRAMS FOR BATTERY CHARGERS

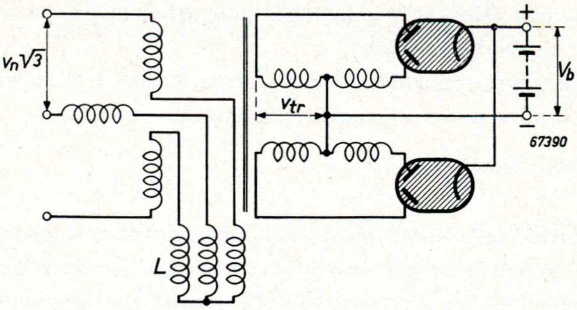

Fig. 8. FOUR-PHASE HALF-WAVE

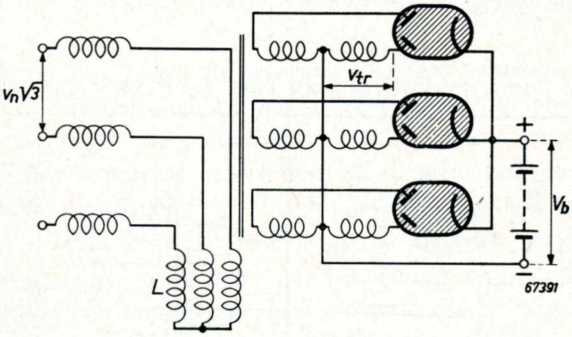

Fig. 9. SIX-PHASE HALF-WAVE

V_{ign} having a value ranging between about 10 and 50 V, depending upon the type of tube.

The ratio between $V_{tr}\sqrt{2}$ and $V_b + V_{\text{ign}}$ is generally expressed by the mains fluctuation safety factor:

$$k_2 = \frac{V_{tr}\sqrt{2}}{V_{b\,\text{max}} + V_{\text{ign}}} > 1\,, \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

giving for the transformer secondary voltage per phase:

$$V_{tr} = \frac{V_{b\,\text{max}} + V_{\text{ign}}}{\sqrt{2}} \,.\, k_2 \quad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

V_{tr} is usually so chosen that k_2 will be from 1.15 for a large number of cells to 1.2 for a small number of cells. In other words, $V_{tr}\sqrt{2}$ exceeds $V_{b\,\text{max}} + V_{\text{ign}}$ by 15 to 20%. This margin is required to ensure satisfactory operation of the rectifier under the most unfavourable conditions of mains voltage fluctuations. The choice of k_2 considerably influences the charging characteristic of the rectifier. In fact, the higher the value selected for V_{tr}, the more stable will be the operation of the rectifier. The stability, however, will be at the expense either of the power factor or of the efficiency of the rectifier, and will render the transformer more expensive.

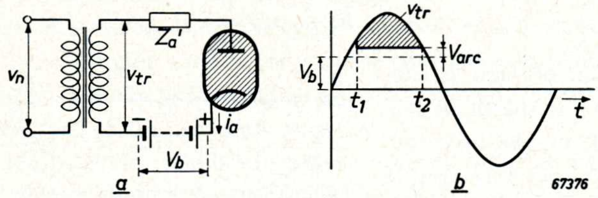

Fig. 10. Basic circuit of a single-phase half-wave rectifier for use as battery charger.
a. Circuit diagram.
b. Voltage diagram. The period of conduction is cross-hatched.

Once the tube is ignited, current starts to flow and charging commences. This current produces a voltage drop V_{arc} in the tube. V_{arc} may be regarded as constant (see fig. 10*b*), its value being between about 7 and 30 V, depending upon the type of tube.

As the transformer secondary voltage further increases, the voltage difference between $V_{tr}\sqrt{2}\sin\omega t$ and $V_b + V_{\mathrm{arc}}$ gives rise to a charging current, which must be limited by a suitable device, so as to provide the required charging current and not to exceed the maximum permissible anode current.

Resistor as current-limiting device

The current-limiting device will first be assumed to be a resistor, in which case the current will cease to flow at point t_2, when $V_{tr}\sqrt{2}\sin\omega t$ has dropped to $V_{tr}\sqrt{2}\sin\omega t_2 = V_b + V_{\mathrm{arc}}$.

Between t_1 and t_2 the instantaneous value of the current will be:

$$i_a = \frac{V_{tr}\sqrt{2}\sin\omega t - (V_b + V_{\mathrm{arc}})}{R_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

By introducing β, representing the D.C./A.C. voltage ratio

$$\frac{V_b + V_{\mathrm{arc}}}{V_{tr}\sqrt{2}} = \beta\,, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

eq. (8) becomes:

$$i_a = \frac{V_{tr}\sqrt{2}\,(\sin\omega t - \beta)}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

For the sake of simplicity, V_{ign} is assumed to be equal to V_{arc}, so that after integration of eq. (10) and by using the abbreviation

$$B = \sqrt{1-\beta^2} - \beta \arccos\beta, \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

the D.C. anode current can be expressed as:

$$I_a = \frac{V_{tr}\sqrt{2}}{\pi} \cdot \frac{B}{R} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(12)}$$

and the total secondary circuit resistance as:

$$R_2 = 0.45\,\frac{V_{tr}}{I_a}\,B \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

The relation between B and β (eq. (11)) is shown in the graph of fig. 11, the most important part of this graph being given on a larger scale occupying the entire width of this diagram.

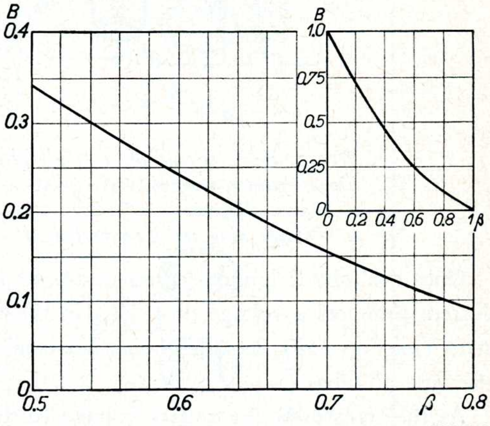

Fig. 11. Graph showing the factor B as a function of the D.C./A.C. voltage ratio β for the case of a resistor used as current limiter.

Since the equivalent resistance of the transformer secondary R_{tr} is included in R_t, the value of the required additional anode resistor R_a will be:

$$R_a = R_t - R_{tr} \;\ldots\; (14)$$

In practice, R_{tr} is usually from 7 to 10% of R_t, so that eq. (14) can be written:

$$R_a \approx 0.9\,R_t \;\ldots\ldots\ldots\ldots\; (15)$$

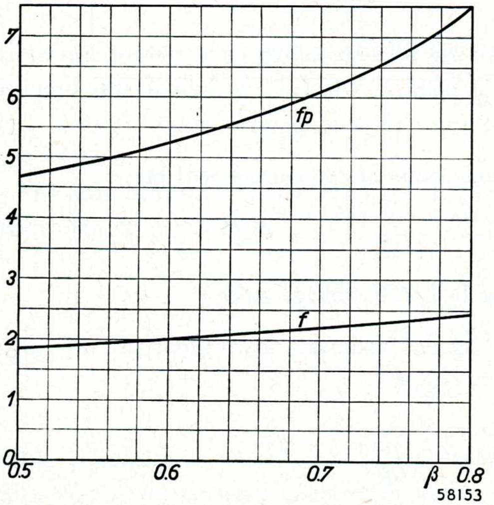

Fig. 12. Graph showing the form factor f and the peak factor f_p as a function of the D.C./A.C. voltage ratio β for the case of a resistor used as current limiter.

The r.m.s. value of the current, by which the heating losses in dissipative resistances and the apparent power of the transformer are determined, is given by:

$$I_{a\,\mathrm{mrs}} = f\,I_a\,, \;\ldots\ldots\ldots\ldots\ldots (16)$$

in which f is called the form factor.

This factor depends only on β, the relation between the two being shown graphically in fig. 12.

The peak factor f_p expresses

the ratio between the peak value of the anode current and its mean value, so that:

$$I_{a\,\mathrm{p}} = f_{\mathrm{p}}\, I_a \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

In fig. 12, f_p is also plotted as a function of β.

If the battery charger has several secondary phases, the different circuits have only the battery in common, and since this is assumed to have a constant voltage independent of the charging current, the separate phase currents will not influence each other. In that case the total charging current I_o through the battery will thus be equal to the sum of the secondary currents.

Fundamentally, it is also possible to connect directly in series with the battery one common resistor limiting the currents of the different phases in succession. By doing so, the advantage of the separate resistors safeguarding the rectifier against internal short circuits would, however, be sacrified; hence, such a circuit is not to be recommended, and we shall refrain from dealing with it here.

Inductor as current-limiting device

In fairly large battery chargers the loss of power in the current-limiting resistors would assume such high values that this solution would no longer be justified. In that case preference will be given to an inductor.

In agreement with what has been stated in the previous section, the effect of the inductor can best be explained by means of the diagram for single-phase half-wave rectification.

The basic circuit is given in fig. 13.

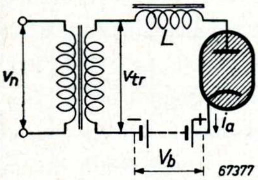

Fig. 13. Basic circuit of single-phase half-wave rectifier with secondary choke for use as battery charger.

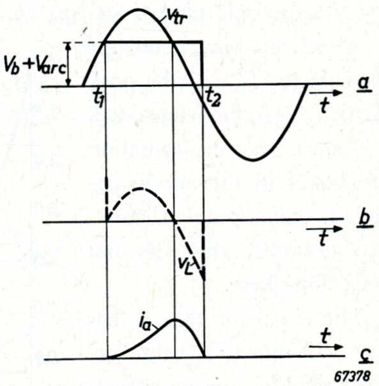

Fig. 14. Voltage- and current diagrams corresponding to the circuit of fig. 13.
a. The transformer secondary voltage v_{rt}.
b. The voltage drop v_L across the choke L.
c. The anode current i_a.

During the interval of conduction, the voltage v_L across the choke L will be equal to $V_{tr}\sqrt{2}\sin\omega t - (V_b + V_{\mathrm{arc}})$, similar to that across a resistor incorporated in the anode circuit.

The instantaneous value of the current is now determined by

$$L\frac{\mathrm{d}i_a}{\mathrm{d}t} = V_{tr}\sqrt{2}\sin\omega t - (V_b + V_{\mathrm{arc}}), \quad \ldots\ldots\ldots\ldots\ldots (18)$$

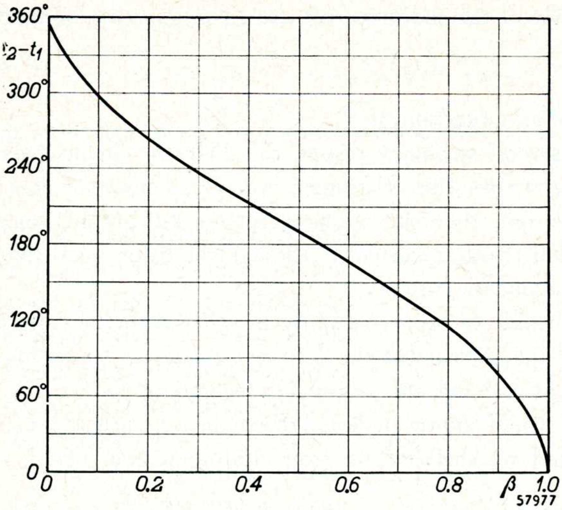

Fig. 15. Graph showing the interval $t_2 - t_1$ as a function of the D.C./A.C. voltage ratio β, for the case of a secondary choke used as current limiter.

if the resistance of the choke is disregarded.

Eq. (18) may be integrated and set equal to zero, thus giving the value of t_2 when i_a has become zero. The interval $t_2 - t_1$, expressed in degrees, is plotted in fig. 15 as a function of β.

The mean of the anode current I_a can now be calculated according to the method described above, giving:

$$I_a = \frac{V_{tr}\sqrt{2}}{\pi\omega L} \cdot B'', \quad \ldots (19)$$

in which B'' again depends on β, the dependency however being different from that of B expressed in eq. (12). A curve for B'' as a function of β is plotted in fig. 16.

Also for this circuit the form factor f'' and the peak factor f_p'' can be determined, but since the incorporation of chokes in the anode circuits is only a purely theoretical example, this has not been done here.

The circuit of fig. 13 has but little practical value because the D.C. output current considerably reduces the self-inductance of the choke. A primary choke is therefore preferred, which offers the additional advantage of only m_1 coils being required even if the secondary number of phases is twice that of the primary number of phases ($m_1 : m_2$ being for instance 1 : 2 of 3 : 6).

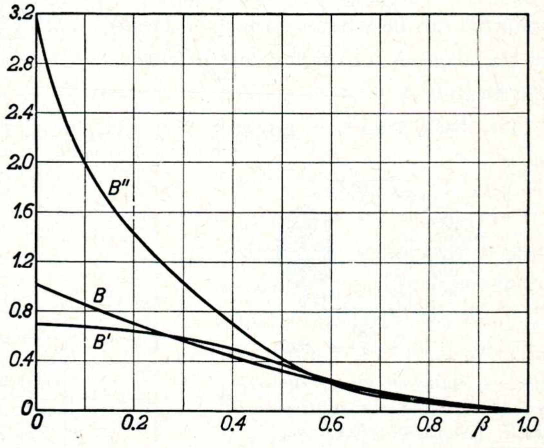

Fig. 16. Graph showing the factor B'' for rectifiers with a secondary choke, B' for rectifiers with a primary choke and B for rectifiers with anode resistor as current-limiting device, as a function of the D.C./A.C. voltage ratio β.

At first sight the only result of shifting the inductor from the secondary to the

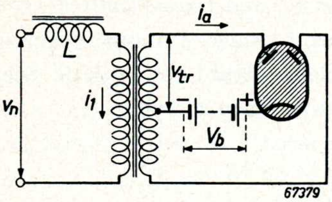

Fig. 17. Basic circuit of a two-phase half-wave rectifier with primary choke for use as battery charger.

primary side is that the reflected value of the impedance must be taken into account at the secondary side. If, however, the mains do not happen to be connected to a star point, the connection of the choke in the primary will result in the primary current, corresponding to the current of two secondary phases flowing through one and the same choke. This will already be the case if a two-phase half-wave transformer is used, as shown in fig. 17.

As long as the interval $t_1 - t_2$, during which current is supplied, is less than 180°, thus if $\beta > 0.54$ (see fig. 15), nothing particular will happen. At the instant t_1 current will start to flow to the left-hand anode of fig. 17, this instant being determined by the condition that $V_{tr}\sqrt{2}\sin\omega t_1 = V_b + V_{\mathrm{arc}}$ (see fig. 14), the ignition voltage V_{ign} being assumed to be equal to $V_b + V_{\mathrm{arc}}$. This gives $t_t = \arcsin\beta$, where t_1 is expressed in degrees, and $\beta = \dfrac{V_b + V_{\mathrm{arc}}}{V_{tr}\sqrt{2}}$. The instant t_2, i.e. the instant at which i_a becomes zero, can now be derived from fig. 15. This also applies for the next half cycle for the right-hand anode during the interval $t_3 - t_4$ (not indicated), where $t_3 = t_1 + 180°$ and $t_4 = t_2 + 180°$.

Summarizing, current will flow in the primary during the interval $t_1 - t_2$, then from t_2 to t_3 the current will be zero, whilst current will flow in the reversed direction during the interval $t_3 - t_4$.

For $\beta = 0.54$, thus if $t_2 - t_1 = 180°$, the instants t_2 and t_3 will coincide and current intervals will not occur.

For $\beta < 0.54$, however, the interval $t_2 - t_1$ is no longer given by the curve of fig. 15. The current in the bottom- and top phase (see fig. 17) will flow during an interval of 180°, even if β becomes lower than 0.54.

Fig. 18 gives the voltages and currents transformed to the primary, corresponding to the circuit of fig. 17. The primary voltage has a rectangular form (see v_1', fig. 18*a*), the voltage across the choke v_L being the difference between the mains voltage v_n and v_1', as shown in fig. 18*b*.

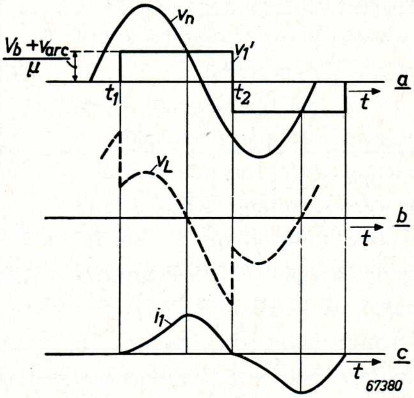

Fig. 18. Voltage and current diagrams corresponding to the circuit of fig. 17.
a. The mains voltage v_n and the transformer primary voltage under load v_1'.
b. The voltage drop v_L across the choke L.
c. The primary current i_1.

For each value of β, a given position of t_1 and t_2, and consequently a given mean value of the anode current I_a, will be found, which can now again be calculated from eq. (18). This calculation will not be worked out in detail here, but the mean value of the current per anode can be represented by

$$I_a = \frac{1}{\mu} \cdot \frac{V_1 \sqrt{2}}{\pi \omega L} \cdot B' \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

The factor B', which for $\beta < 0.54$ differs from the factor B'' of eq. (19), but for $\beta \geqslant 0.54$ coincides with it, is also plotted in fig. 16 as a function of β.

The factor β is almost proportional to V_b (cf. eq. (9)), V_{arc} usually being small as compared with V_b, whilst the D.C. output current per anode I_a is linearly dependent on the factor B, B' or B'', as the case may be, so that the curves given in fig. 16 represent the charging characteristic of the rectifier (charging current as a function of the battery voltage). As long as $t_2 - t_1 < 180°$ ($\beta > 0.54$), the curves B' and B'' (and also B) are almost identical, but in the case of $\beta < 0.54$, the advantage of curve B' (applying to a primary choke *), namely that the short-circuit current is relatively low, can be clearly seen from the graph.

Also in the case of $m_2 > 2$, current will not flow for more than 180° in either phase and, although the theoretical considerations are somewhat different, for common practice the calculations may also be based on the factor B' evaluated above, provided a primary choke be used.

In fig. 19 the value of B' as a function of β is given again on a larger scale for practical use; the corresponding factors f' and f_p' as a function of β, also applying to circuits with a primary choke, are given in fig. 20.

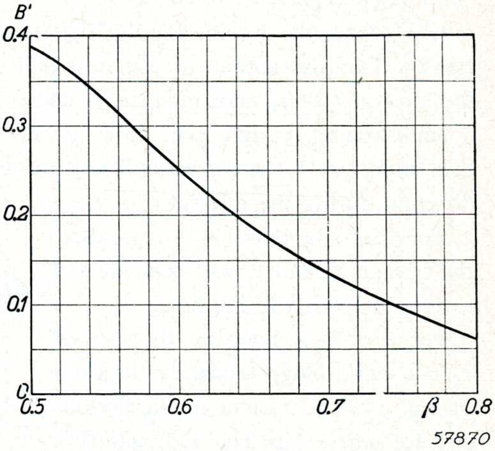

Fig. 19. Graph showing the factor B′ as a function of the D.C./A.C. voltage ratio β for the case of a primary choke used as current limiter.

Summarizing, the constants B, f and f_p written without a prime apply to rectifiers with a resistor incorporated in each anode circuit, those with a single prime applying to rectifiers with an inductor in the primary circuit.

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*) A somewhat different solution, which, however, leads to very similar results, consists in replacing both the normal supply transformer and the primary choke by a strayless transformer.

If the rectifier is used for the normal purpose for which it has been designed, β will seldom reach very low values, and there will be little difference between the quantities B and B'. Only in special cases will it be desired to take advantage of the flat part of the curve B' at small values of β, but this will necessitate the use of a particularly large transformer and choke.

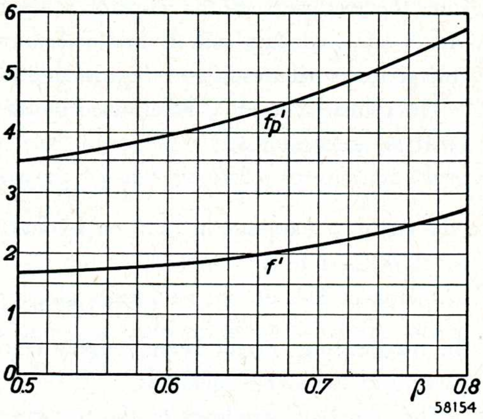

Fig. 20. Graph showing the factors f' and f_p' as a function of the D.C./A.C. voltage ratio β for the case of a primary choke used as current limiter.

COMPONENTS

In the design calculation for the various components it is first of all necessary to ascertain the value of V_b. This depends on the type of battery used, on its condition and, finally, on the number of cells to be charged. The E.M.F. per cell for lead batteries, for nickel-iron batteries and for cadmium-nickel batteries, respectively, is given in table I.

Table I

Battery	E.M.F. per cell (V)		
	minimum	average	maximum
Pb	2.0	2.2	2.7
NiFe	1.2	1.4	1.85
CdNi	1.2	1.4	1.85

Mains transformer

The type of transformer to be used mainly depends upon the power output required. For outputs up to 600 or 800 VA, shell type transformers will generally be used, whilst core type transformers are usually preferred for outputs exceeding 800 VA.

Shell type transformers are normally provided for single-phase supply only; the coils comprising the primary and secondary windings are both placed on the centre core, the secondary winding having a centre tap in the case of two-phase rectification.

Core type transformers, when designed for single-phase supply and two-phase rectification, should have their primary split and distributed over both legs of the core, the two parts of the primary being connected in parallel, whilst each leg carries one secondary coil. If this precaution is not taken, unduly high inductive voltage losses may result and the core and housing may produce troublesome hum.

The primary current is determined by the following formulae:

a) If $m_2 = 2$, 4 or 6:

$$I_1 = 1.07\,\mu\, I_2 \sqrt{2} \quad \ldots\ldots\ldots\ldots (21)$$

(the factor $\sqrt{2}$ appears in (21) on account of the even number of phases).

b) If $m_2 = 1$ or 3:

$$I_1 = 1.07\,\mu\, I_a \sqrt{f^2 - 1}\,, \quad \ldots\ldots\ldots\ldots (22)$$

the magnetizing current being roughly taken into account by the factor 1.07 appearing in the above equations.

The secondary windings of the transformer do not carry current continuously but intermittently, so that the apparent powers in the primary and the secondary windings will be unequal and must be evaluated separately:

$$(VA)_1 = m_1 V_1 I_1\,, \quad \ldots\ldots\ldots\ldots (23)$$

and

$$(VA)_2 = m_2 V_{tr} I_2\,. \quad \ldots\ldots\ldots\ldots (24)$$

The iron core must therefore be calculated for an apparent power:

$$(VA)_t = \frac{(VA)_1 + (VA)_2}{2} \quad \ldots\ldots\ldots\ldots (25)$$

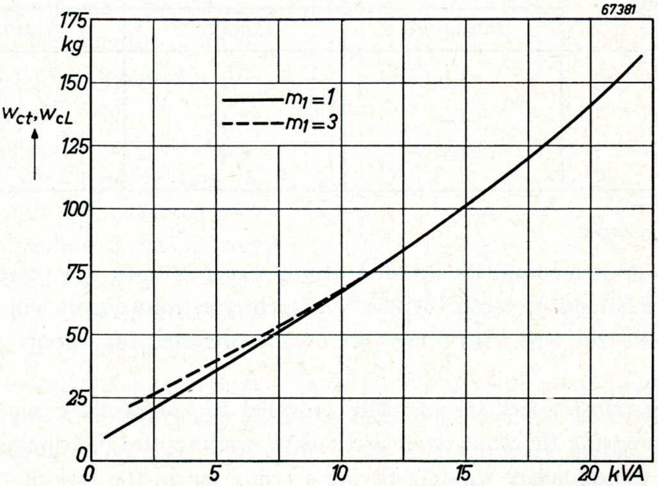

Fig. 21. Approximate weight of the transformer core w_{ct} and of the choke core w_{cL} as a function of the apparent power $(VA)_t$ and $(VA)_L$ respectively.

The approximate weight of the core as a function of the apparent power is given in fig. 21, from which the dimensions of the core can be estimated.

The core losses can be calculated by multiplying the weight of the core (in kg) by the specific iron loss of the transformer sheet used. At a flux density of 1 Wb/m^2 (10 000 gauss) the specific iron losses will range between 1.3 and 1.7 W/kg for transformer sheet, and between 2.5 and 3.0 W/kg for dynamo sheet, both of standard thickness (0,35 to 0.5 mm).

Primary choke

The voltage drop across the primary choke caused by the no-load magnetizing current of the transformer may be assumed to amount to 10% of the mains voltage. The ratio of the transformer should therefore be:

$$\mu = \frac{V_{tr}}{V_1} = \frac{V_{tr}}{0.9\,V_n} = \frac{V_b + V_{\mathrm{arc}}}{0.9\,V_n\,\beta\,\sqrt{2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (26)$$

According to fig. 18a, during the period of conduction of the rectifying tubes the transformer primary voltage under load will be:

$$V_1{}' = \frac{V_b + V_{\mathrm{arc}}}{\mu} = \frac{V_{tr}\,\beta\,\sqrt{2}\,{}^{*)}}{\mu}, \quad \ldots\ldots\ldots\ldots\ldots (27)$$

or, from (26):

$$V_1{}' = 0.9\,V_n\,\beta\,\sqrt{2}\,{}^{*)}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (28)$$

Eq. (28) is thus the expression for the primary transformer voltage under load.

The r.m.s. voltage across the choke may be calculated from the general formula

$$V_L = V_n{}^2 - V_1{}'^2 \,. \quad \ldots\ldots\ldots\ldots\ldots (29)$$

Since the choke is connected in series with the primary of the transformer, the current through the choke will be equal to I_1. The apparent power of the choke is:

$$(VA)_{\mathrm{L}} = \frac{V_L I_1}{2} \,.\, m_1 \,.\, \ldots\ldots (30)$$

Although V_L and I_1 are by no means purely sinusoidal, the value of $(VA)_L$ given by eq. (30) may be used as a good approximation for estimating the weight of the core by means of the graph given in fig. 21 and calculating the dimensions of the choke. The core of the choke should preferably be given the proportions indicated in fig. 22.

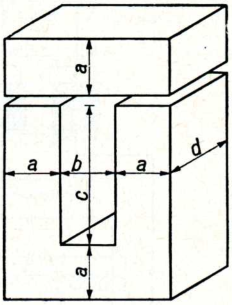

Fig. 22. Proportions of the primary choke.
$b = 1$ to $1.5\,a$.
$c = 2.5$ to $3.0\,a$.
$d = 1.5$ to $2.0\,a$.

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*) These formulae hold with sufficient approximation for most cases occurring in practice.

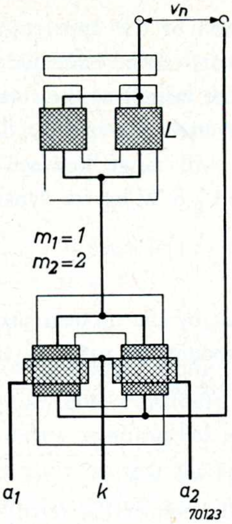

Fig. 23.

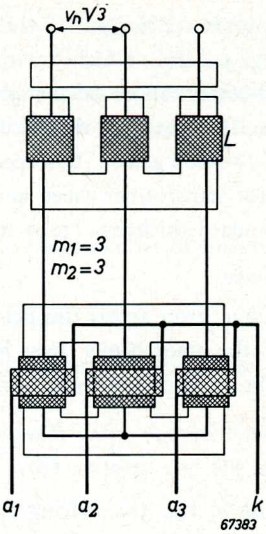

Fig. 24.

Fig. 23. Arrangement of power transformer and primary choke L for a two-phase half-wave rectifying circuit ($m_1 = 1$ and $m_2 = 2$). The points a are connected to the anodes of the rectifying tubes, and the point k via the battery to their cathodes.

Fig. 24. The same as in fig. 23, but for a three-phase half-wave rectifying circuit ($m_1 = 3$ and $m_2 = 3$).

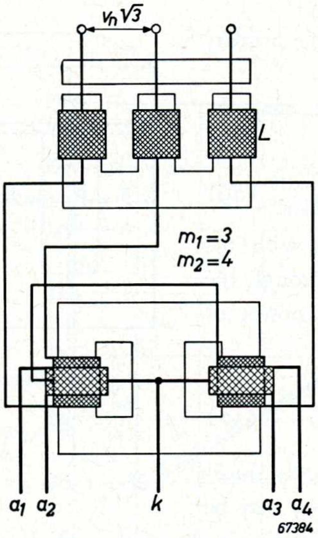

Fig. 25.

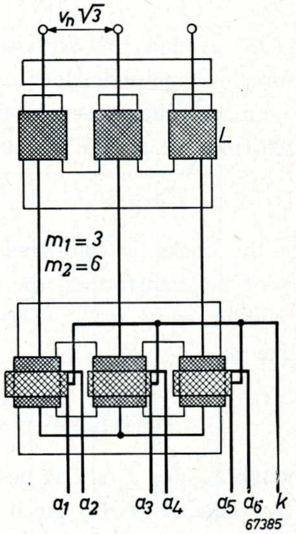

Fig. 26.

Fig. 25. The same as in fig. 23, but for a four-phase half-wave rectifying circuit ($m_1 = 3$ and $m_2 = 4$).

Fig. 26. The same as in fig. 23, but for a six-phase half-wave rectifying circuit ($m_1 = 3$ and $m_2 = 6$).

The output current of the rectifier may be set to the correct value by adjusting the air gap of the choke.

Finally, various methods for connecting the primary choke to the transformers are shown in figs 23, 24, 25 and 26.

Rectifying tubes

Once the choice of the circuit has been decided upon, the rectifying tubes most suitable for the purpose must be selected. To facilitate the choice, use can be made of the table on page 114.

To check that the maximum tube ratings are not exceeded, the peak value of the anode current $I_{a\,\mathrm{p}}$ can be evaluated from eq. (17). It should moreover be ascertained that the maximum peak inverse voltage $V_{\mathrm{inv\,p}}$ of the tube is not exceeded. This value depends on the circuit used and on the transformer secondary voltage per phase V_{tr}. With most rectifying tubes the ratio between the maximum peak inverse voltage $V_{\mathrm{inv\,p}}$ and V_{tr} is such that it will suffice to calculate the latter value from eq. (7).

EXAMPLES

To illustrate the methods of calculation given in the previous section, the following examples have been worked out in detail.

Example 1 deals with a charger for 4 motorcar lead batteries (6 V each), at a current of 6 A; supply voltage 220 V, 50 c/s (single phase).

Example 2 deals with a charger (with primary choke) for 50 cadmium-nickel cells at a current of 50 mA; supply voltage 2 × 380 V, 50 c/s.

Example I

Design of a charger for 4 motorcar lead batteries (6 V each) at a current of 6 A; supply voltage 220 V, 50 c/s (single phase).

Each 6 V battery consists of 3 cells, so that the rectifier has to be designed for $n_b = 12$ lead cells. According to table XII (see p. 114), one 367 tube in a two-phase half-wave rectifying circuit will suffice. The basic circuit is given in fig. 27.

In table II all values for the design are given.

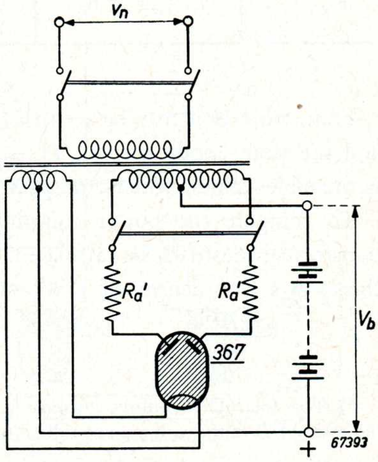

Fig. 27. Basic circuit of the rectifier discussed in example I.

Table II

Quantities	Derived from	Values of V_{bc}			Unit
		2.0 V	2.2 V	2.7 V	
n_b	target value		12		—
V_{bc}	table I	2.0	2.2	2.7	V
V_b	$n_b \times V_{bc}$	24	26.4	32.4	V
k_2	assumed value		1.18		—
V_{ign}	tube data		17		V
V_{tr}	eq. (7)			41	V
β	eq. (9)	0.55	0.60	0.69	—
B	fig. 11	0.300	0.245	0.170	—
f	fig. 12		2.0		—
f_p	fig. 12	4.9	5.3	6.1	—
I_o	see note *)	7.35	6	4.15	A
I_a	$I_o/2$		3		A
$I_{a\ rms}$	eq. (16)		6		A
$I_{a\ p}$	eq. (17)	18	15.9	12.6	A
I_1	eq. (21)		1.69		A
$(VA)_t$	eq. (25)		432		VA
w_{ct}	fig. 21 †)		7.5		kg
μ	V_{tr}/V_1		41/220		—
R_t	eq. (13)		1.5		Ω
R_a	eq. (15)		1.35		Ω
W_{Ra}'	$I_{a\ rms}^2 \times R_a$		48.5		W

From table II it may be seen that the voltage applied to the tube, $V_{tr} = 41$ V, and the peak anode current, $I_{a\ p} = 15.9$ A, are well below the given maximum permissible values, which are 45 V and 18 A respectively.

To compute the power consumption and efficiency, the iron losses of the transformer must first be calculated. With a specific iron loss of 2.5 W/kg (dynamo sheet) at a flux density of 1 Wb/m², the iron losses will be $w_{ct} \times 2.5 = 19$ W.

---

*) The total D.C. output current I_o at different battery voltages V_b is determined by the ratio of B at the voltage per cell considered to B at $V_{bc} = 2.2$ V, multiplied by $I_o = 6$ A.

$$\text{Hence: } I_o\ (2.7) = \frac{0.17}{0.245} \times 6 = 4.15 \text{ A, etc.}$$

†) A shell-type transformer is used.

Hence:

Iron losses $= 19$ W

Filament power $V_f \times I_f$ $= 16$ W

Arc losses $2\,V_{\text{arc}} \times I_a$ $= 54$ W

Copper losses of transformer (estimated) $= 10$ W

Losses in anode resistors $2 \times W_{Ra}$ $= 97$ W

Total $= 196$ W

Output $V_b \times I_o$ $= 158$ W

Input $= 354$ W

The total efficiency of the rectifier is:

$$\eta_i = \frac{\text{output}}{\text{input}} \times 100 = \frac{158}{354} \times 100 = 44.8\%,$$

and the power factor:

$$\cos\varphi = \frac{\text{input}}{V_n\, I_1} = \frac{354}{220 \times 1.69} = 0.95\,.$$

Example 2

Design of a charger (with primary choke) for 50 cadmium-nickel cells at a current of 50 A; supply voltage 3 × 380 V, 50 c/s.

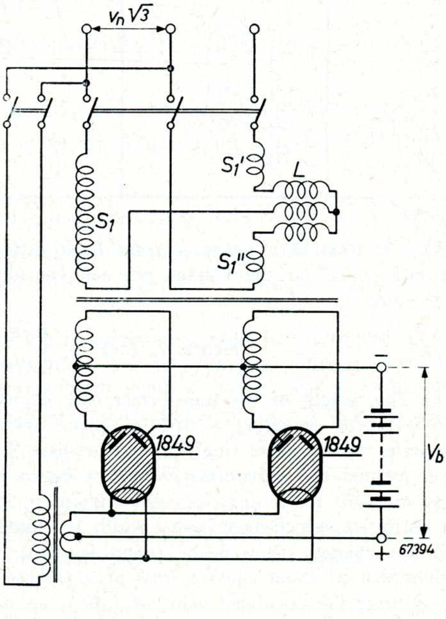

Fig. 28. Basic circuit of the rectifier discussed in example 2.

This charger may be based on the principle of either two-phase rectification or four-phase rectification (see table XII on p. 114).

In the first case, one 1859 tube may be used, whilst in the second case two 1849 tubes will suffice.

The choice will depend upon the cost of the transformer plus tubes. This example will be worked out for the four-phase circuit with two 1849 tubes, the diagram of which is given in fig. 28.

Table III gives all values for the design.

With a specific iron loss of 1.7 W/kg (transformer sheet) for the transformer core, and

Table III

Quantities	Derived from	Values of V_{bc}			Unit
		1.2 V	1.4 V	1.85 V	
n_b	target value		50		—
V_{bc}	table I	1.2	1.4	1.85	V
V_b	$n_b \times V_{bc}$	60	70	92.5	V
k_2	assumed value		1.15		—
V_{ign}	tube data		28		V
V_{tr}	eq. (7)			98	V
β	eq. (9)	0.51	0.58	0.74	—
B'	fig. 19	0.38	0.275	0.10	—
f'	fig. 20		1.85		—
f_p'	fig. 20	3.5	3.8	5.15	—
I_o	see note *)	69	50	18.2	A
I_a	$I_o/4$		12.5		A
$I_{a\ \mathrm{rms}}$	eq. (16)		23.2		A
$I_{a\ p}$	eq. (17)	60.2	47.5	23.4	A
I_1	eq. (21)		11.5		A
$(VA)_t$	eq. (25)		8185		VA
w_{ct}	fig. 21 †)		84		kg
μ	V_{tr}/V_{1h} ‡)		0.33		—
V_1'	eq. (28)		164		V
V_L	eq. (29)		143		V
$(VA)_L$	eq. (30)		2480		VA
W_{cL}	fig. 21		27		kg

*) The total D.C. output current I_o at different battery voltages V_b is determined by the ratio of B' at the voltage per cell considered to B' at $V_{bc} = 1.4$ V, multiplied by $I_o = 50$ A.

$$\text{Hence: } I_o\ (1.2) = \frac{0.38}{0.275} \times 50 = 69 \text{ A, etc.}$$

†) The weight of the transformer core depends on its construction. There are actually two ways for designing a 3-phase/4-phase system. According to one method, the system comprises two separate single-phase/two-phase Scott-connected transformers, whilst with the other method one transformer with a 3-legged core is used, the outer legs of which each carry the coils for a single-phase/two-phase system, as shown in fig. 28. In the latter case the centre leg, which must have a width $\sqrt{2}$ times that of the outer leg, contains no winding, and the magnetic flux in the centre leg will be $\sqrt{2}$ times that of the outer legs. The weight will be about equal to that of a 3-phase transformer, the apparent power of which is 1.5 times the calculated value of $(AV)_t$ according to eq. (25). For $(VA)_t \leqslant 10$ kVA, this method will generally prove to be less expensive than that where two separate transformers are used.

2.5 W/kg (dynamo sheet) for the core of the choke and a flux density of 1 Wb/m², the total iron losses become $w_{ct} \times 1.7 + w_{cL} \times 2.5 = 210$ W.

Hence:

Total iron losses $= 210$ W

Filament power $2 V_f \times I_f$ $= 120$ W

Copper losses of filament transformer (estimated) $= 12$ W

Arc losses $4 V_{\text{arc}} \times I_a$ $= 500$ W

Copper losses of transformer (estimated) $= 165$ W

Copper losses of choke (estimated) $= 62$ W

Total $= 1069$ W

Output $V_b \times I_o$ $= 3500$ W

Input $= 4569$ W

The efficiency of the rectifier is:

$$\eta_i = \frac{\text{output}}{\text{input}} \times 100 = \frac{3500}{4569} \times 100 = 76.5\%,$$

and the power factor:

$$\cos\varphi = \frac{\text{input}}{3 V_n I_1} = \frac{4569}{3 \times 220 \times 11.5} = 0.6\,.$$

CIRCUIT OF A FOUR-IN-ONE BATTERY CHARGER

A practical circuit for a battery charger particularly suitable for use in garages, is given in fig. 29.

According to the position of the switch S_3, the two rectifying tubes type 1048 operate either separately, in parallel or in series. This circuit may be used for the following purposes:

Position 1 — charging of 6 batteries of 3 lead cells in series (18 Pb) at 6 amperes (terminals — and + A), and at the same time 6 batteries of 3 lead cells in series (18 Pb) at 1 to 3 amperes (terminals — and + B);

---

‡) For calculating the primary voltage of the transformer, it must be taken into account that in a three-phase/four-phase transformer there are two unequal primary windings, viz. S_1 and $(S_1' + S_1'')$, the latter consisting of two identical halves. The ratio of these windings is $S_1' = S_1'' : S_1 = 1 : \sqrt{3}$. The values of the voltages across $S_1' + S_1''$ $(= V_{1b})$ and S_1 $(= V_{1h})$ are:

$$V_{1b} = 0.9\, V_n \sqrt{3} = 342 \text{ V},$$

and

$$V_{1h} = 0.5\, V_{1b} \sqrt{3} = 297 \text{ V}.$$

In the case of a Scott-connected transformer ($m_1 = 3$, $m_2 = 4$), the calculation of the transformer ratio will preferably be based on the voltage V_{1b} across the coil S_1, the coils S_1' and S_1'' being traversed by the sum of two currents.

Therefore:

$$\mu = \frac{V_{tr}}{V_{1h}}\,.$$

Position 2 — charging of 6 batteries of 3 lead cells in series at 12 amperes (terminals — and + A);

Position 3 — charging of 12 batteries of 3 lead cells in series at 6 amperes (terminals — and + A);

Terminal + B is specially intended for reconditioning batteries which suffer from sulphating. The charging current can then be adjusted by means of the variable resistor R_2 of 6 Ω, 50 W in series with the fixed resistors R_1 of 1.5 Ω, 25 W. With switch S_3 in the positions 2 and 3, terminal + B is disconnected.

The secondaries of the anode supply transformers should be designed for a voltage of 2 × 56 V at a current of 6.3 A (r.m.s. values). The r.m.s. value of the primary current is then:

$$I_1 = \frac{1050}{V_1} \text{ (A)},$$

where V_1 denotes the supply voltage of the mains.

The anode resistors R_a should have a value of 1.5 Ω, 50 W. The fuses in the primary should be rated for twice the primary current I_1.

The switch S_2 serves for switching on the anode supply transformer one to two minutes after switch S_1 has been closed, so as to give the rectifying tubes time to heat up. Alternatively, a time-delay circuit, employing for example a thermo-relay type 4152 in combination with a contactor, can be used.

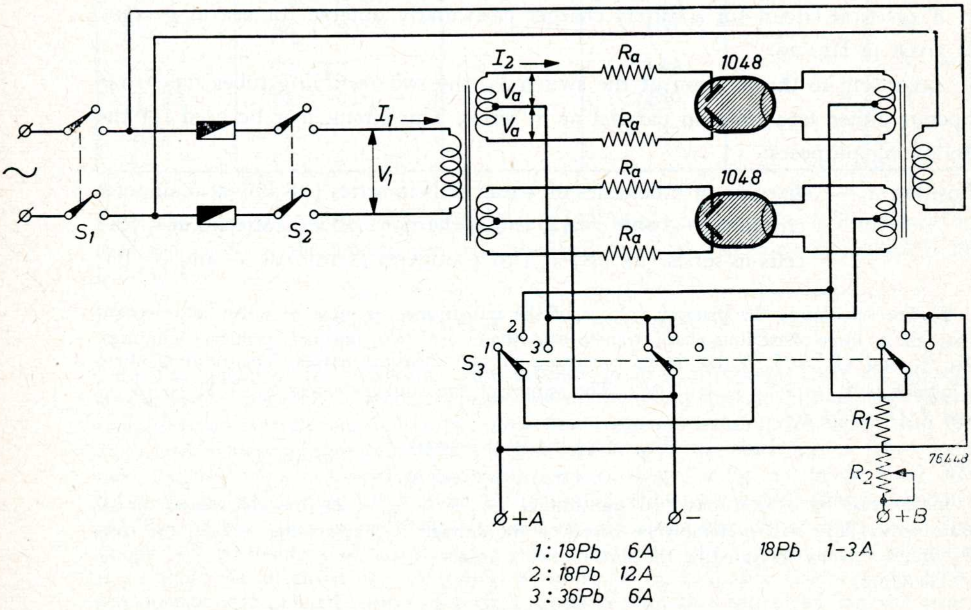

Fig. 29. Circuit diagram of the four-in-one battery charger.

INDUSTRIAL RECTIFIERS

GENERAL

In times when D.C. distribution systems were generally used, no need was felt for rectification, but since A.C. supply systems were introduced, conversion to D.C. became very essential for particular purposes.

The demand for rectifying tubes is still increasing, because they are considered to be specially suitable for this purpose. Moreover, as already stated on p. 10, they offer several advantages when compared with rotary converters and barrier-layer rectifiers.

According to their D.C. output voltage, rectifiers for industrial purposes may be classified into two groups, viz.

a) rectifiers with a D.C. output voltage lower than 220 V, such as for feeding electromagnetic chucks, electromagnetic separators, electromagnets, small D.C. motors, etc.;
b) rectifiers with a D.C. output voltage of 220 V or higher, such as for feeding D.C. mains, electromagnets, D.C. motors, power station auxiliaries, etc.

The rectifying tubes types 328, 367, 1010, 1039, 1048, 1049, 1110, 1119, 1710, 1725A, 1838, 1849 and 1859 are suitable for use in the rectifiers mentioned under a).

In the rectifiers mentioned under b) the rectifying tubes type 1173, 1174, 1176 and 1177 can be used.

CIRCUIT DIAGRAMS

The diagrams given in figs 30 to 39 cover all the basic circuits ordinarily encountered in industrial applications. When double-anode rectifying tubes are used, each pair of tubes represented in the diagrams has to be replaced by one tube having two anodes. This is not possible in the circuits of figs 31, 33, 35, 38 and 39, since there each rectifying section must have a separate cathode.

Table IV (see p. 36) gives the voltage and current ratios for the circuits of figs 30 to 39, assuming zero transformer resistance and leakage inductance, zero tube resistance and a resistive load.

DESIGN CONSIDERATIONS

CIRCUITS

The choice of the circuit depends on the output power required and the limits set upon the value of the ripple voltage. The ripple can, of course, be reduced to a lower level by introducing a filter, but as this is a rather expensive solution, it may be of advantage to use a polyphase circuit as represented in figs 32 to 37.

The circuit of fig. 30 is commonly used for D.C. output powers below approx. 2 kW, provided no special requirements are set as regards the ripple voltage. It is used for feeding electromagnetic devices and for small D.C. motors, but in the latter case an additional choke, connected in series with the output, may be necessary.

The bridge circuit of fig. 31 gives a greater D.C. power output in proportion to the transformer kVA rating than the circuit of fig. 30, but it has the disadvantage of requiring a filament transformer having three well insulated windings instead of a single winding.

The three-phase half-wave circuit of fig. 32 is commonly used for an output power range of 2 to 10 kW when the ripple is of less importance. If this circuit is used to feed a D.C. motor, an additional filter with choke input may be necessary.

The bridge circuit of fig. 33 gives twice the output voltage of the circuit of fig. 32. The ripple is very low, amounting to only 4%.

BASIC CIRCUIT DIAGRAMS FOR INDUSTRIAL RECTIFIERS

Circuits	Output current and output voltage wave form	Anode current wave form

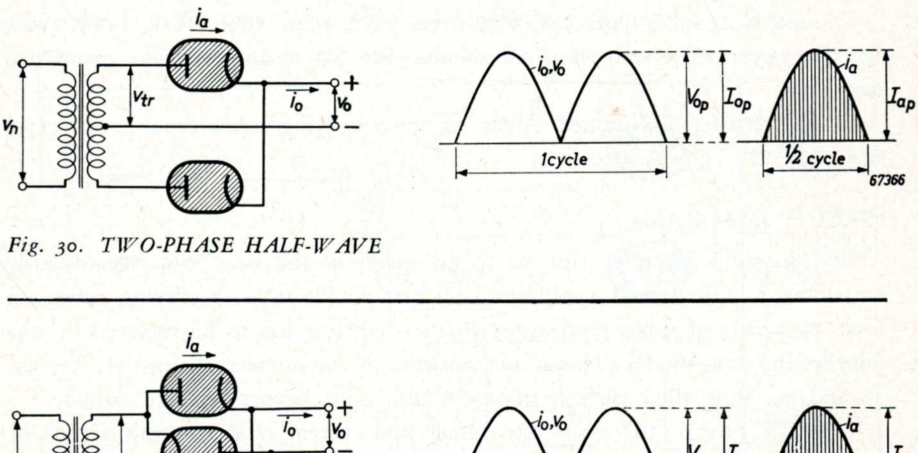

Fig. 30. TWO-PHASE HALF-WAVE

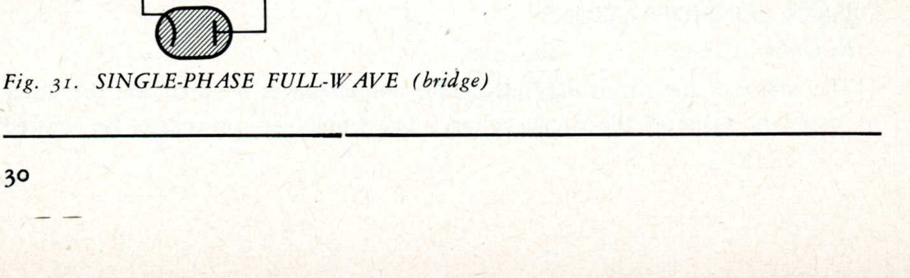

Fig. 31. SINGLE-PHASE FULL-WAVE (bridge)

Circuits

Output current and output voltage wave form

Anode current wave form

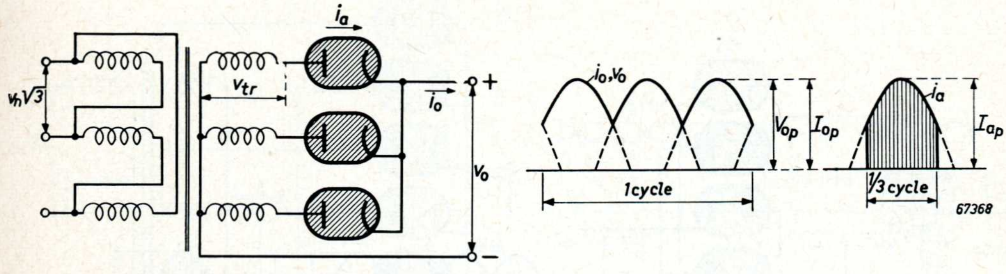

Fig. 32. THREE-PHASE HALF-WAVE

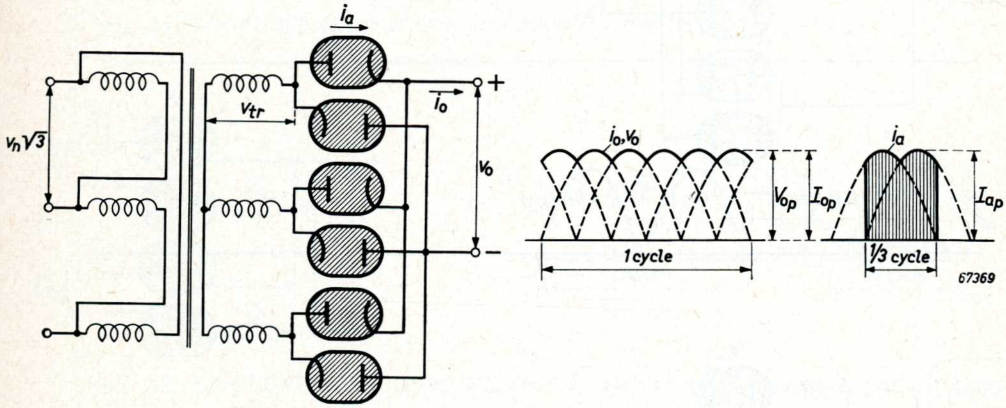

Fig. 33. THREE-PHASE FULL-WAVE (bridge)

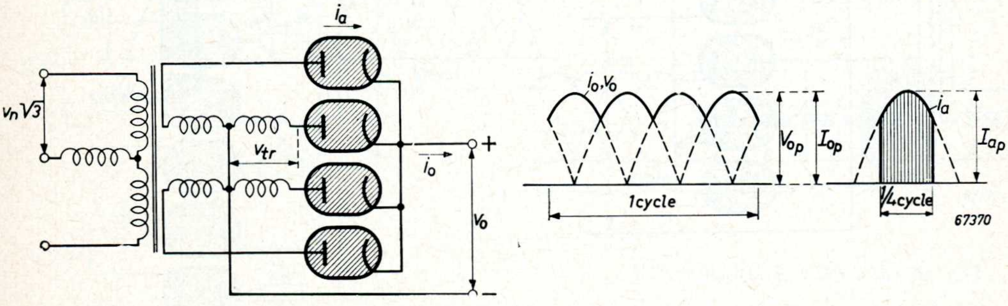

Fig. 34. FOUR-PHASE HALF-WAVE

Circuits

Output current and output voltage wave form

Anode current wave form

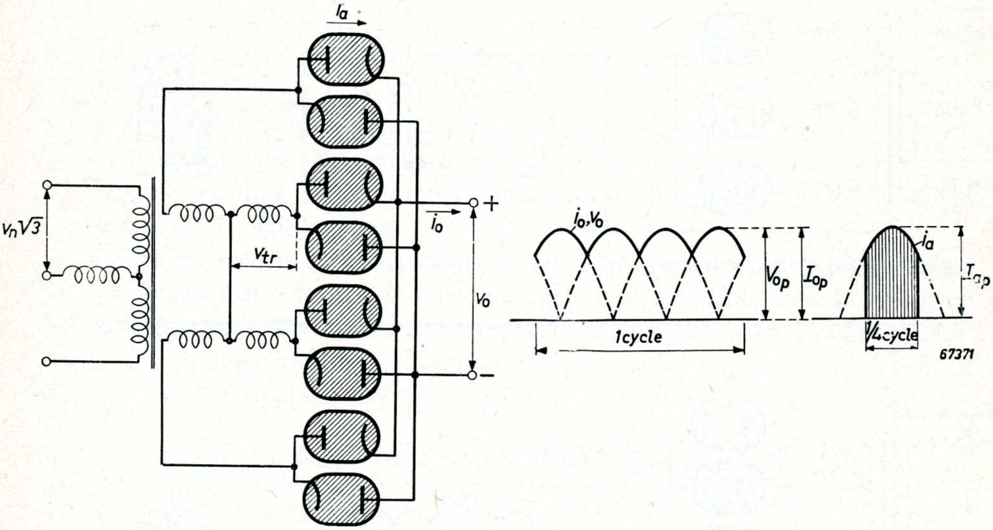

Fig. 35. FOUR-PHASE FULL-WAVE (bridge)

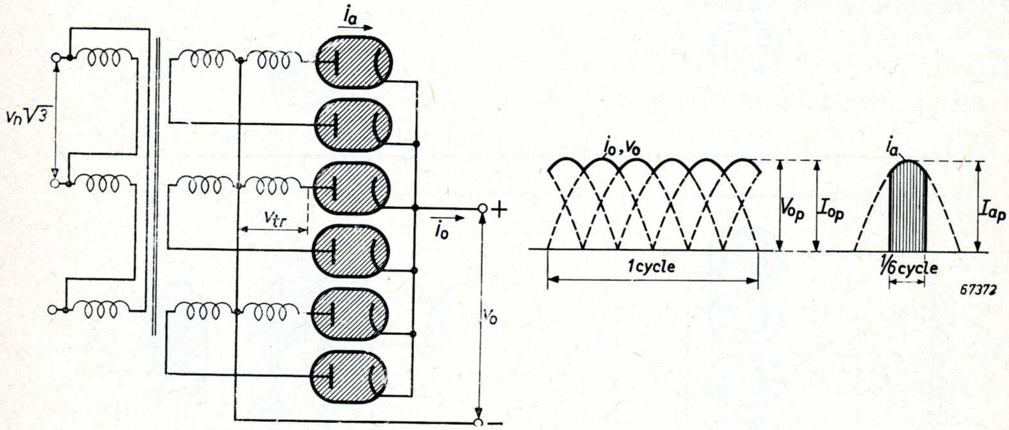

Fig. 36. SIX-PHASE HALF-WAVE

Circuits

Output current and output voltage wave form

Anode current wave form

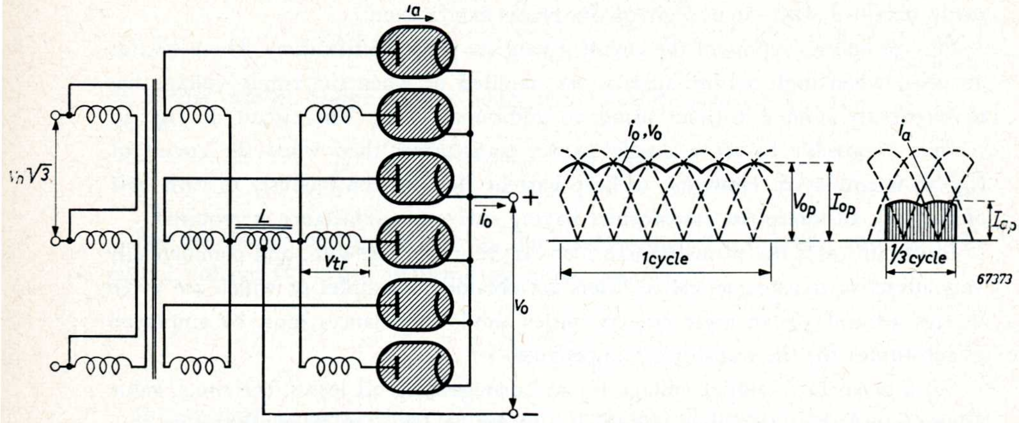

Fig. 37. SIX-PHASE HALF-WAVE with interphase transformer

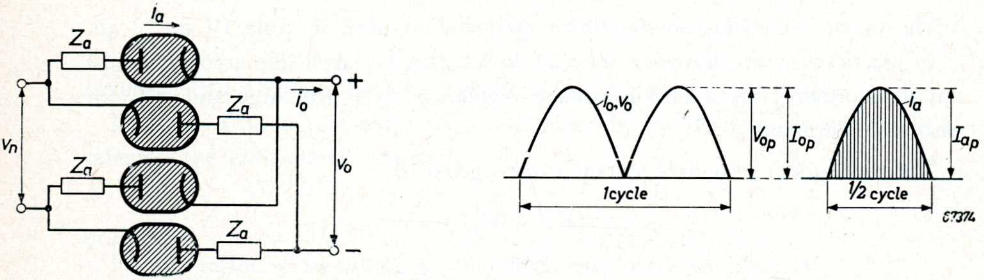

Fig. 38. SINGLE-PHASE FULL-WAVE (bridge) without mains transformer

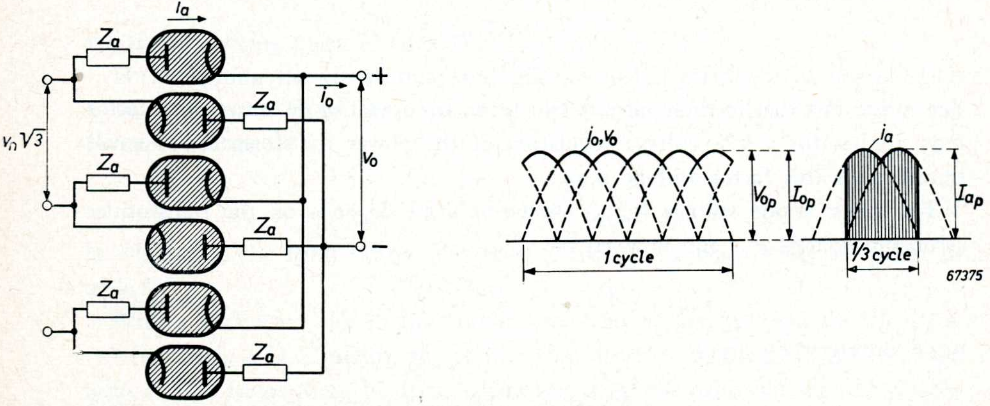

Fig. 39. THREE-PHASE FULL-WAVE (bridge) without mains transformer

The four-phase rectifying circuits of figs 34 and 35 have a low ripple voltage (9.5%), but in most practical cases, the required D.C. output current is more easily obtained with circuits giving six-phase rectification.

Figs 36 and 37 represent the circuit giving six-phase rectification. These circuits are used when high output currents are required or when the ripple voltage has to be strictly limited without using an additional filter. The circuit of fig. 37 renders it possible to use a smaller power transformer than when the circuit of fig. 36 is employed. However, to keep current flowing continuously to each half of the coil, an interphase transformer having sufficient inductance is required.

In certain cases the mains transformer can be dispensed with, and commercially very attractive transformerless rectifiers are obtained, examples of which are given in figs 38 and 39. In these circuits, series anode impedances must be employed as substitutes for the transformer impedance.

For a given D.C. output voltage V_o and disregarding all losses, the r.m.s. value of the transformer secondary voltage V_{tr} under no load can be expressed as:

$$V_{tr} = \gamma V_o . \qquad \text{(31)}$$

The factor γ depends on the circuit used and is given in table IV on p. 36.

In practical circuits, however, the tube losses must be taken into account, whilst the transformer gives a certain voltage regulation (5% for large and 7% for small transformers).

The transformer secondary voltage is then given by:

$$V_{tr} = \frac{\gamma\,(V_o + V_{arc})}{0.95}, \qquad \text{(32)}$$

for the circuits of figs 30, 32, 34, 36 and 37.

For the bridge circuits of figs 31, 33 and 35 this becomes:

$$V_{tr} = \frac{\gamma\,(V_o + 2V_{arc})}{0.95}, \qquad \text{(33)}$$

due to the fact that in these circuits two tubes are operating in series. The factor 0.95 applies for a 5% voltage regulation of the power transformer. For small transformers this factor will be 0.93.

The r.m.s. anode voltage $V_{a\,rms}$ under no load depends on the transformer secondary voltage V_{tr} and is given by:

$$V_{a\,rms} = \delta V_{tr}, \qquad \text{(34)}$$

or, according to eq. (31):

$$V_{a\,rms} = \gamma \delta V_o . \qquad \text{(35)}$$

The factor δ depends on the circuit used and is given in table IV.

For practical circuits eq. (35) becomes, according to eq. (32):

$$V_{a\,rms} = \frac{\gamma\,\delta\,(V_o + V_{arc})}{0.95}\,, \qquad (36)$$

or, in the case of bridge circuits being used, according to eq. (33):

$$V_{a\,rms} = \frac{\gamma\,\delta\,(V_o + 2V_{arc})}{0.95}\,. \qquad (37)$$

For the circuits of figs 38 and 39, the mains voltage V_n is given, and the D.C. output voltage V_o, when ignoring all losses, becomes:

$$V_o = \frac{V_n}{\gamma}. \qquad (38)$$

In practical circuits, thus taking into account all losses, the D.C. output voltage is given by:

$$V_o = \frac{V_n}{\gamma} - 2\,(V_{arc} + I_o\,R_a), \qquad (39)$$

assuming that a current-limiting resistor R_a is inserted in each anode circuit.

From the D.C. output current I_o, determined by the designer, it is possible to calculate the D.C. anode current I_a:

$$I_a = \tau\,I_o\,. \qquad (40)$$

For the factor τ, depending on the circuit employed, see table IV.

The peak anode current $I_{a\,\mathrm{p}}$ is given by:

$$I_{a\,\mathrm{p}} = f_{\mathrm{p}}\,I_a\,, \qquad (41)$$

the factor f_{p} being given in table IV.

For designing the transformer and calculating the efficiency of the rectifier, it is necessary to know the r.m.s. value of the anode current. This value can be expressed as:

$$I_{a\,\mathrm{rms}} = f\,I_a\,, \qquad (42)$$

in which f is the form factor. Values of f for the various circuits are given in table IV.

With a back-e.m.f. V_b in the output circuit, as occurs for example when the rectifier feeds a D.C. motor, the form factor depends on the D.C./A.C. voltage ratio β. This factor β can be derived with the aid of the expressions given in table IV, whilst the peak- and form factors f_p and f, respectively, are given in fig. 40 as functions of β.

Table IV

Fig.	Circuit	Number of secondary phases m_2	$\gamma = \frac{V_{tr}}{V_o}$	$\delta = \frac{V_{a\,\text{rms}}}{V_{tr}}$	$\sigma = \frac{V_{\text{inv p}}}{V_{tr}}$	$\tau = \frac{I_a}{I_o}$	$f_p = \frac{I_{a\,\text{p}}}{I_a}$		$f = \frac{I_{a\,\text{rms}}}{I_a}$		β	r.m.s. ripple (% of V_o)	$\frac{\text{Ripple frequency}}{\text{Mains frequency}}$
30	Two-phase half-wave	2	1.11	1	2.83	0.5	3.14	2	1.57	1.41	$(V_b + V_{\text{arc}})/V_{tr}\sqrt{2}$	47	2
31	Single-phase full-wave (bridge)	1	1.11	0.5	1.41	0.5	3.14	2	1.57	1.41	$(V_b + 2V_{\text{arc}})/V_{tr}\sqrt{2}$	47	2
32	Three-phase half-wave	3	0.86	1	2.45	0.33	3.63	3	1.76	1.73	$(V_b + V_{\text{arc}})/V_{tr}\sqrt{2}$	18	3
33	Three-phase full-wave (bridge)	3	0.43	0.86	2.45	0.33	3.14	3	1.76	1.73	$(V_b + 2V_{\text{arc}})/V_{tr}\sqrt{6}$	4	6
34	Four-phase half-wave	4	0.79	1	2.83	0.25	4.44	4	2.01	2	$(V_b + V_{\text{arc}})/V_{tr}\sqrt{2}$	9.5	4
35	Four-phase full-wave (bridge)	4	0.39	1	2.83	0.25	4.44	4	2.01	2	$(V_b + 2V_{\text{arc}})/2V_{tr}\sqrt{2}$	9.5	4
36	Six-phase half-wave	6	0.74	1	2.83	0.17	6.28	6	2.45	2.45	$(V_b + 2V_{\text{arc}})/V_{tr}\sqrt{2}$	4	6
37	Six-phase half-wave with interphase transformer	6	0.86	1	2.83	0.17	3.14	3	1.76	1.73	$2(V_b + V_{\text{arc}})/V_{tr}\sqrt{6}$	4	6
38	Single-phase full-wave (bridge) without mains transformer	1	1.11	0.5	1.41	0.5	3.14	2	1.57	1.41	$(V_b + 2V_{\text{arc}})/V_n\sqrt{2}$	47	2
39	Three-phase full-wave (bridge) without mains transformer	3	0.43	0.86	2.45	0.33	3.14	3	1.76	1.73	$(V_b + 2V_{\text{arc}})/V_n\sqrt{6}$	4	6
Remarks		For figs 37 and 38, V_a should be substituted for V_{tr}, where $V_n = \frac{\text{voltage between lines}}{\sqrt{3}}$.				Resistive load		For inductive load or filter with choke input, for all values of β.	Resistive load	For inductive load or filter with choke input, for all values of β.	For capacitive load, β can be assumed to be approx. 0.8 to 0.9 for all circuits.		

The values given in this table apply for zero transformer resistance and leakage inductance, zero tube resistance and a resistive load. For other loads, see column Remarks.

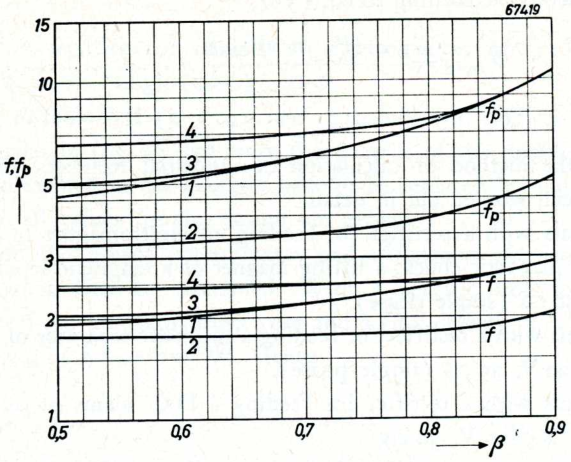

Fig. 40. Graph showing the form factor f and the peak factor f_p as a function of the D.C./A.C. voltage ratio β, for the case where a back-e.m.f. is present in the output circuit of the rectifier.

Curve 1: For the circuits of figs 30, 31, 32 and 38.
Curve 2: For the circuits of figs 33, 37 and 39.
Curve 3: For the circuits of figs 34 and 35.
Curve 4: For the circuits of fig. 36.

COMPONENTS

Mains transformer

The design of the mains transformer has already been described on p. 19 under "Battery Chargers".

Rectifying tubes

The rectifying tubes most suitable for the purpose can be selected with the aid of table XII, p. 114.

To check that the maximum tube ratings are not exceeded, the average and peak values of the anode current, I_a and $I_{a\,\mathrm{p}}$ respectively, can be evaluated from eqs (40) and (41). It should, moreover, be ascertained that the maximum peak inverse anode voltage $V_{\mathrm{inv\,p}}$ of the tube is not exceeded. This value depends on the transformer secondary voltage V_{tr} and the circuit used. When disregarding all losses, the relation is given by:

$$V_{\mathrm{ivn\,p}} = \sigma V_{tr} \; . \ldots\ldots\ldots\ldots\ldots\ldots \quad (43)$$

The factor σ is given in table IV. In practical circuits it becomes, according to eq. (32):

$$V_{\mathrm{inv\,p}} = \frac{\gamma \sigma (V_o + V_{\mathrm{arc}})}{0.95} \, , \ldots\ldots\ldots\ldots\ldots\ldots \quad (44)$$

or, for bridge circuits, acccording to eq. (33):

$$V_{\mathrm{inv\,p}} = \frac{\gamma\,\sigma\,(V_o + 2V_{\mathrm{arc}})}{0.95} \quad \ldots\ldots\ldots\ldots \quad (45)$$

EXAMPLES

To illustrate the method of calculation of industrial rectifiers, the following examples have been worked out in detail.

Example 1 deals with a rectifier for feeding an electromagnet of 110 V, 3 A, as for example a magnetic chuck, a lifting magnet of a magnetic separator; supply voltage 220 V, 50 c/s (single phase).

Example 2 deals with a rectifier for feeding a magnetic separator of 65 V, 25 A; supply voltage 220 V, 50 c/s (single phase).

Example 3 deals with a rectifier for feeding a D.C. mains of 220 V, 150 A; supply voltage 3 × 220 V, 50 c/s.

Example 4 deals with a rectifier for feeding a D.C. motor of 440 V, 25 h.p.; supply voltage 3 × 380 V, 50 c/s.

Table V

Quantities	Derived from	Values	Unit
V_o	target value	110	V
V_{arc}	tube data	12	V
γ	table IV	1.11	—
δ	table IV	1	—
σ	table IV	2.83	—
τ	table IV	0.5	—
f_{p}	table IV	3.14	—
f	table IV	1.57	—
V_{tr}	eq. (32)	143	V
μ	V_{tr}/V_1	143/220	—
$V_{a\,\mathrm{rms}}$	eq. (36)	143	V
$V_{\mathrm{inv\,p}}$	eq. (44)	405	V
I_o	target value	3	A
I_a	eq. (40)	1.5	A
$I_{a\,\mathrm{p}}$	eq. (41)	4.7	A
$I_{a\,\mathrm{rms}}$	eq. (42)	2.37	A
I_1	eq. (21)	2.36	A
$(VA)_t$	eq. (25)	600	VA
w_{ct}	fig. 21 *)	11	kg

---

*) A shell-type transformer is used.

Example 1

Design of a rectifier for feeding an electromagnet of 110 V, 3 A; supply voltage 220 V, 50 c/s (single phase).

According to table XII (p. 114), one 1710 tube will suffice. The basic circuit diagram is given in fig. 30, but since the 1710 is of the double-anode type, the two tubes represented in the diagram have to be replaced by one tube type 1710.

In table V all values for the design are given.

To compute the power consumption and efficiency, the iron losses of the transformer must first be calculated. With a specific iron loss of 2.5 W/kg (dynamo sheet) for the transformer core and a flux density of 1 Wb/m², the iron loss will be $w_{ct} \times 2.5 = 27.5$ W. Hence:

Iron losses		=	27.5 W
Filament power	$V_f \times I_f$	=	15 W
Arc losses	$2V_{\text{arc}} \times I_a$	=	36 W
Copper losses of transformer (estimated)		=	25 W
Total		=	103.5 W
Output	$V_o \times I_o$	=	330 W
Input		=	433.5 W

The total efficiency of the rectifier is:

$$\eta_i = \frac{\text{output}}{\text{input}} \times 100 = \frac{330}{433.5} \times 100 = 76\%,$$

and the power factor:

$$\cos\varphi = \frac{\text{input}}{V_n I_1} = \frac{433.5}{220 \times 2.36} = 0.83\%.$$

Example 2

Design of a rectifier for feeding a magnetic separator of 65 V, 25 A; supply voltage 220 V, 50 c/s (single phase).

According to table XII (p. 114), one 1849 tube will suffice. The basic circuit diagram is given in fig. 30, but, since the 1849 is of the double-anode type, the two tubes represented in the diagram have to be replaced by one tube type 1849.

In table VI all values for the design are given.

With a specific iron loss of 2.5 W/kg (dynamo sheet) for the transformer core and a flux density of 1 Wb/m², the total iron losses become $w_{ct} \times 2.5 = 70$ W.

Hence:

Iron losses $= 70$ W
Filament power $V_f \times I_f = 60$ W
Arc losses $2V_{\mathrm{arc}} \times I_a = 250$ W
Copper losses of transformer (estimated) $= 95$ W
Total $= 475$ W
Output $V_o \times I_o = 1625$ W
Input $= 2100$ W

Table VI

Quantities	Derived from	Values	Unit
V_o	target value	65	V
V_{arc}	tube data	10	V
γ	table IV	1.11	—
δ	table IV	1	—
σ	table IV	2.83	—
τ	table IV	0.5	—
f_p	table IV	3.14	—
f	table IV	1.57	—
V_{tr}	eq. (32)	88	V
μ	V_{tr}/V_i	88/220	—
$V_{a\,\mathrm{rms}}$	eq. (36)	88	V
$V_{\mathrm{inv\,p}}$	eq. (44)	250	V
I_o	target value	25	A
I_a	eq. (40)	12.5	A
$I_{a\,\mathrm{p}}$	eq. (41)	39	A
$I_{a\,\mathrm{rms}}$	eq. (42)	19.6	A
I_1	eq. (21)	12	A
$(VA)_t$	eq. (25)	3045	VA
w_{ct}	eq. (21)	28	kg

The total efficiency of the rectifier is:

$$\eta_i = \frac{\text{output}}{\text{input}} \times 100 = \frac{1625}{2100} \times 100 = 77\%,$$

and the power factor:

$$\cos\varphi = \frac{\text{input}}{V_n I_1} = \frac{2100}{220 \times 12} = 0.79.$$

Example 3

Design of a rectifier for feeding a D.C. mains of 220 V, 150 A; supply voltage 3 × 220 V, 50 c/s.

For this power range a six-phase rectifying circuit with interphase transformer is chosen. According to table XII (see p. 114), six 1177 tubes will suffice. The basic circuit diagram is represented in fig. 37.

In table VII all values for the design are given.

Table VII

Quantities	Derived from	Values	Unit
V_o	target value		V
V_{arc}	tube data	12	V
γ	table IV	0.86	—
δ	table IV	1	—
σ	table IV	2.83	—
τ	table IV	0.17	—
f_{p}	table IV	3.14	—
f	table IV	1.76	—
V_{tr}	eq. (32)	210	V
μ	V_{tr}/V_1	210/220	—
$V_{a\ \mathrm{rms}}$	eq. (36)	210	V
$V_{\mathrm{inv\ p}}$	eq. (44)	595	V
I_o	target value	150	A
I_a	eq. (40)	25	A
$I_{a\ \mathrm{p}}$	eq. (41)	79	A
$I_{a\ \mathrm{rms}}$	eq. (42)	44	A
I_1	eq. (21)	63	A
$(VA)_t$	eq. (25)	48250	VA
w_{ct}	fig. 21 *)	300	kg
V_L	$0.42\ V_{tr}$ †)	88	V
I_L	$I_o/2$	75	A
$(VA)_L$	$V_L V_L\ 2$ ‡)	3300	VA

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*) An air-cooled transformer is used. The weight of the core has been calculated by extrapolation.

†) The evaluation of this equation which is valid for six-phase rectifiers with interphase transformers is rather complicated and is not taken up in this Bulletin.

‡) The size of the interphase transformer is determined by 3300/3 = 1100 VA, because the frequency of the current is three times the mains frequency.

With a specific iron loss of 1.3 W/kg (transformer sheet) for the transformer core and a flux density of 1.1 Wb/m², the total iron losses become $w_{ct} \times 1.3 \times 1.1^2 = 470$ W. Hence:

Iron losses		= 470 W
Filament power	$6V_f \times I_f$	= 805 W
Losses of filament transformer (estimated)		= 70 W
Arc losses	$6V_{arc} \times I_a$	= 1800 W
Copper losses of transformer (estimated)		= 600 W
Losses in auxiliary equipment (estimated)		= 100 W
Total		= 3845 W
Output	$V_o \times I_o$	= 33000 W
Input		= 36845 W

The total efficiency of the rectifier is thus:

$$\eta_i = \frac{\text{output}}{\text{input}} \times 100 = \frac{33000}{36845} \times 100 = 90\%,$$

and the power factor:

$$\cos \varphi = \frac{\text{input}}{3 I_1 V_n \sqrt{3}} = \frac{36845}{3 \times 63 \times 127 \times \sqrt{3}} = 0.89.$$

Example 4

Design of a rectifier for feeding a D.C. motor of 440 V, 25 h.p.; supply voltage 3 × 380 V, 50 c/s.

According to European continental standards, 1 h.p. = 736 W, and assuming that the D.C. motor has an efficiency of 0.85, the output current I_o is given by:

$$I_o = \frac{25 \times 736}{0.85 \times 440} = 50 \text{ A}.$$

For this D.C. voltage range the three-phase full-wave bridge circuit of fig. 33 is suitable. According to table XII, p. 114, six 1176 tubes will suffice.

In table VIII all values for the design are given.

With a specific iron loss of 1.3 W/kg (transformer sheet) for the transformer core, and a flux density of 1.1 Wb/m², the iron loss will become $w_{ct} \times 1.3 \times 1.1^2 = 280$ W. Hence:

Table VIII

Quantities	Derived from	Values	Unit
V_o	target value	440	V
V_{arc}	tube data	10	V
γ	table IV	0.43	—
δ	table IV	0.86	—
σ	table IV	2.45	—
τ	table IV	0.33	—
f_{p}	fig. 40	4	—
f	fig. 40	1.84	—
μ	V_{tr}/V_1	210/380	—
β	table IV *)	0.82	—
V_{tr}	eq. (32)	210	V
$V_{a\,\text{rms}}$	eq. (36)	183	V
$V_{\text{inv p}}$	eq. (44)	515	V
I_o	target value	50	A
I_a	eq. (40)	16.6	A
$I_{a\,\text{p}}$	eq. (41)	66.7	A
$I_{a\,\text{rms}}$	eq. (42)	30.7	A
I_1	eq. (21) †)	24.8	A
$(VA)_t$	eq. (25)	28000	VA
w_{ct}	fig. 21	180	kg

Iron losses = 280 W

Filament power $6V_f \times I_f$ = 325 W

Losses of filament transformer (estimated) = 140 W

Arc losses $6V_{\text{arc}} \times I_a$ = 1200 W

Copper losses of transformer (estimated) = 400 W

Losses in auxiliary equipment (estimated) = 100 W

Total = 2445 W

Output $V_o \times I_o$ = 22000 W

Input = 24445 W

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*) The back-e.m.f. voltage $V_b = 440 - I_oR$. Assuming at the voltage drop in the armature, I_oR is 10%, V_b becomes 400 V.

†) Since each secondary winding is connected to two tubes, the r.m.s. value of the secondary current per phase, I_2, is equal to $\sqrt{2}$ times the r.m.s. current per tube $I_{a\,\text{rms}}$.

The total efficiency of the rectifier is:

$$\eta_i = \frac{\text{output}}{\text{input}} \times 100 = \frac{22000}{24445} \times 100 = 90\%\,,$$

and the power factor:

$$\cos\varphi = \frac{\text{input}}{3 I_1 V_n \sqrt{3}} = \frac{24445}{3 \times 24.6 \times 220 \times \sqrt{3}} = 0.87.$$

INDUSTRIAL RECTIFIERS WITHOUT POWER TRANSFORMER

A large proportion of the cost of rectifier equipment is formed by the power transformer, so that considerable saving may be obtained by omitting this component or replacing it by a comparatively small and inexpensive auto-transformer. This is permissible in certain cases, provided suitable impedances are connected in series with the rectifying tubes. The entire rectifier thus becomes extremely simple, compact and inexpensive, but, as shown below, the direct output voltage is determined by the mains voltage and cannot be varied to any appreciable extent, which greatly limits the applicability of these rectifiers.

Fig. 41 shows the most simple circuit of a transformerless rectifier. Each rectifying tube is simply connected between one phase (U, V or W) and the neutral wire (O) of the A.C. mains via the load, a suitable impedance Z_a being connected in series with each tube.

This type of rectifier cannot, however, be used in many cases, owing to the fact that the D.C. circuit is completed via the mains; in other words, the return lead of the D.C. circuit is connected to the neutral point of the A.C. mains. This may conflict with the regulations imposed by the electricity supply authorities who often prohibit the use of the neutral wire for carrying the total direct current.

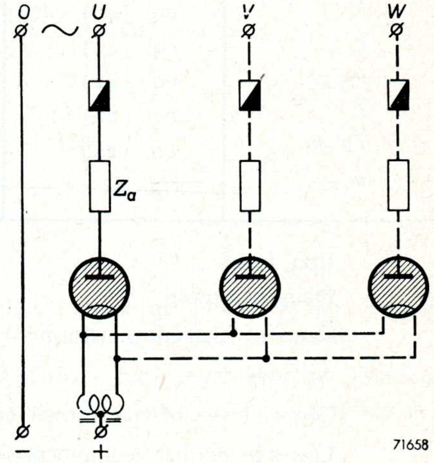

Fig. 41. Circuit of a transformerless rectifier, the D.C. circuit of which is completed via the mains.

If the premises in which the rectifier is to be used are connected to the mains via a supply transformer, this objection does not hold, but then this transformer must be able to supply the power required, which increases the cost of the installation.

In view of these greatly differing conditions, the design of this simple type of rectifier will not be discussed in detail.

The above-mentioned difficulties can be avoided by using a bridge circuit (see fig. 42) in which the D.C. circuit is confined to the rectifier, and then no direct current flows through the neutral wire.

Since in a bridge circuit the filaments of the tubes are not all at the same potential, single-anode tubes must be used. These must, moreover, have a fairly high maximum permissible anode voltage, as they are connected directly to the mains. Tubes of the 1170 series which comply with these requirements, are recommended for this purpose.

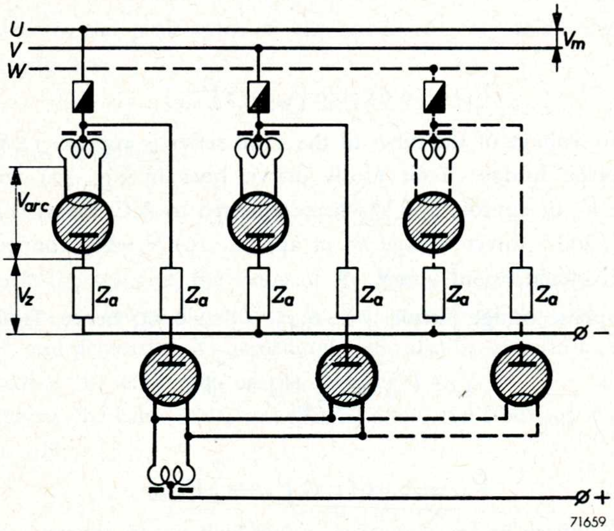

Fig. 42. Bridge circuit of a transformerless rectifier, the D.C. circuit of which is connected to the rectifier.

OUTPUT CURRENT

The output current in the bridge circuit of fig. 42 is obviously equal to

$$I_o = m I_a \,, \tag{46}$$

where m denotes the number of phases (i.e. two or three respectively in the circuit of fig. 42) and I_a is the D.C. value of the anode current of the tubes used.

OUTPUT VOLTAGE

The output voltage V_o of the rectifier is given by the expression:

$$V_o = \frac{1}{\gamma} V_m - 2(V_{arc} + V_Z) = \frac{1}{\gamma} V_m - 2V_{arc} - 2V_Z \,,$$

in which $1/\gamma$ is a factor which depends on the number of phases, V_m is the r.m.s. value of the mains voltage, V_{arc} is the arc voltage of the rectifying tubes and V_Z

the voltage drop across the impedance Z_a incorporated in the anode circuit of each tube. In practice, $2V_Z$ should be approximately 7% of the output voltage, which gives:

$$1.07\,V_o = \frac{1}{\gamma} V_m - 2V_{\text{arc}} \; . \;\ldots\ldots\ldots\ldots (47)$$

In two-phase bridge circuits, $\gamma = 1.11$, which gives:

$$1.07\,V_{o2} = \frac{1}{1.11} V_m - 2V_{\text{arc}} \, ,$$

or:

$$V_{o2} = 0.93\,(0.9\,V_m - 2V_{\text{arc}}) \; . \;\ldots\ldots\ldots\ldots (47a)$$

Since the arc voltage of the tubes of the 1170 series is approx. 12 V, a rectifier with a two-phase bridge circuit (fully drawn lines in fig. 42) will supply a direct voltage V_o of approx. 296 V when connected to A.C. mains with a voltage V_m of 380 V, and a direct voltage V_o of approx. 161 V when connected to A.C. mains with a voltage V_m of 220 V.

In a three-phase bridge circuit, $\gamma = 0.43\sqrt{3} = 0.74$; hence, from eq. (47):

$$1.07\,V_{o3} = \frac{1}{0.74} V_m - 2V_{\text{arc}} \, ,$$

which gives:

$$V_{o3} = 0.93\,(1.35\,V_m - 2V_{\text{arc}}) \; . \;\ldots\ldots\ldots\ldots (47b)$$

In the three-phase bridge circuit an output voltage of approx. 464 V is thus obtained when the mains voltage between lines is 380 V.

ANODE IMPEDANCE

An impedance Z_a must be included in each anode circuit to safeguard the tubes against possible overloading and to damp transients. This impedance must perform the functions of both the inductance X_L provided by the power transformer in conventional circuits and of the rated minimum anode resistance R_t (quoted on the data sheet of the tube concerned). The required inductance X_L is obtained by including a coil in the anode circuit, whilst in case of need a dissipative resistance is added to make up the prescribed value of R_t. The coil should preferably be air-wound to ensure adequate cooling, and must not contain a core, since this would be saturated by the D.C. component of the current flowing through the circuit.

Z_a is obviously equal to the dissipative and reactive components added in quadrature, i.e.:

$$Z_a = \sqrt{R_t^2 + V_L^2} \, ,$$

or

$$X_L = \sqrt{Z_a^2 - R_t^2}\,. \quad \ldots\ldots\ldots\ldots \quad (48)$$

As mentioned above, $2\,V_Z$ should be approximately $0.07\,V_o$; hence:

$$V_Z = 0.035\,V_o\,. \quad \ldots\ldots\ldots\ldots \quad (49)$$

The anode current may very roughly be taken to have a square-wave form, so that:

$$V_Z \approx I_{ap} \cdot Z_a\,,$$

where I_{ap} denotes the peak value of the anode current. And since $I_{ap} \approx I_o$, in the circuit of fig. 42:

$$V_Z \approx I_o \cdot Z_a\,. \quad \ldots\ldots\ldots\ldots \quad (50)$$

From eqs (49) and (50):

$$Z_a = 0.035\,\frac{V_o}{I_o}\,. \quad \ldots\ldots\ldots\ldots \quad (51)$$

In designing the rectifier, the value of R_t should preferably be made equal to the rated value. A lower value may be detrimental to the life of the tubes. Increasing R_t and decreasing X_L accordingly may also be harmful to the tubes and, moreover, reduce the efficiency of the rectifier.

R_t being given, the value of V_L can thus be calculated from eqs. (48) and (51). Expressed in μH:

$$L = \frac{10^6}{\omega} \cdot X_L = \frac{10^4}{\pi} \cdot X_L\,, \quad \ldots\ldots\ldots\ldots (52)$$

when the mains frequency is 50 c/s.

The dimensions of the coil can be calculated from the following formula:

$$L = \frac{n^2\,d^2}{440\,d + 1000\,l}\,, \quad \ldots\ldots\ldots\ldots (53)$$

which holds to a sufficient approximation for single-layer coils, of which $1 > 0.4\,d$. In this formula (see fig. 43):

L = inductance in μH,

n = number of turns of the winding,

d = diameter of the coil in mm from centre to centre of the winding,

l = length of the coil in mm.

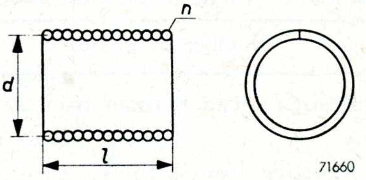

Fig. 43. Dimensions of the air-core coil.

For the sake of simplicity, l will be taken to be equal to d, so that eq. (53) becomes:

$$L = \frac{n^2 l^2}{1440\, l} = \frac{1}{1440}\, n^2 l \,. \quad \text{(53a)}$$

Moreover,

$$l = d = k\, n\, d_{cu}\,, \quad \text{(54)}$$

where k is the space factor which may be taken to be 1.1, and d_{cu} is the wire diameter in mm.

This gives:

$$L = \frac{1.1}{1440}\, n^3 d_{cu} = \frac{1}{1300}\, n^3 d_{cu}\,, \quad \text{(53b)}$$

or

$$n = \sqrt[3]{1300 \cdot \frac{L}{d_{cu}}} \,. \quad \text{(53c)}$$

The cross section of the wire in mm² is given by:

$$Q_{cu} = \frac{I_{a\,\mathrm{rms}}}{i_{cu}}\,, \quad \text{(55)}$$

where $I_{a\,\mathrm{rms}}$ is the r.m.s. value of the anode current and i_{cu} is the permissible current density of copper wire, which may be up to 5 A/mm² for such coils. Since, with round conductors, $Q_{cu} = 1/4\, \pi\, d_{cu}^2$, eq. (55) may be rewritten:

$$1/4\, \pi\, d_{cu}{}^2 = \frac{I_{a\,\mathrm{rms}}}{I_{cu}}\,,$$

or, at $i_{cu} = 5$ A/mm²:

$$d_{cu} = \sqrt{\frac{4\, I_{a\,\mathrm{rms}}}{\pi\, i_{cu}}} = 0.5\, \sqrt{I_{a\,\mathrm{rms}}} \,. \quad \text{(56)}$$

The value of $I_{a\,\mathrm{rms}}$ can be calculated from the expression:

$$I_{a\,\mathrm{rms}} = f \cdot \frac{I_o}{\sqrt{m}}\,, \quad \text{(57)}$$

where f is the form factor depending on the circuit and the type of load. The values of f are quoted in the table below for various cases.

Table IX Values of the form factor f.

Number of phases m		2	3
Resistive load without back e.m.f.		1.11	1.00
Resistive load with back e.m.f. at	$\beta = 0.6$	1.41	1.00
	$\beta = 0.7$	1.56	1.01
	$\beta = 0.8$	1.72	1.03
	$\beta = 0.9$	2.05	1.18
Reactive load abt.		1.00	1.00

The value of β is given by the formula

$$\beta = \frac{E_o + 2V_{\mathrm{arc}}}{0.5\sqrt{2}\,V_{a\,\mathrm{rms}}}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (58)$$

in which E_o is the back e.m.f. and $V_{a\,\mathrm{rms}}$ is the r.m.s. value of the anode voltage, i.e. half the r.m.s. voltage between lines in the circuit of fig. 42.

The diameter of the copper wire d_{cu}, the number of turns n and the length l (= diameter d) of the air-core coil are thus given by eqs (56), (53*c*) and (54) respectively.

Example

A rectifier for driving small D.C. motors is required to supply a direct current I_o of 75 A at a direct voltage of approximately 440 V, a three-phase mains with a voltage of 380 V, 50 c/s between lines being available.

According to eq. (46), the anode current I_a per tube is 75/3 = 25 A. Six 1177 tubes should be used in a three-phase bridge circuit.

It will be assumed in the first instance that the output voltage of 464 V given by eq. (47*b*) is satisfactory.

The required value of Z_a can be calculated from eq. (51), i.e.:

$$Z_a = 0.035\frac{464}{75} = 0.22\ \Omega.$$

Since $R_t = 0.1\ \Omega$, from eq. (48):

$$X_L = \sqrt{0.22^2 - 0.1^2} = 0.19\ \Omega,$$

whence, from eq. (52), at 50 c/s:

$$L = \frac{10^6}{314}\,0.19 = 600\ \mu\mathrm{H}.$$

The r.m.s. value of the anode current is given by eq. (57). Assuming β to be 0.7, this gives:

$$I_{a\,\mathrm{rms}} = 1.01\ \frac{75}{\sqrt{3}} = 44\ \mathrm{A}.$$

Hence, from eq. (56):

$$d_{\mathrm{cu}} = 0.5\ \sqrt{44} \approx 3.3\ \mathrm{mm},$$

so that, according to eq. (53*c*):

$$n = \sqrt[3]{1300\ \frac{600}{3.3}} = 62\ \text{turns},$$

whilst from eq. (54):

$$l = d = 1.1 \times 62 \times 3.3 = 225\ \mathrm{mm}.$$

The dissipative resistance of this coil is obviously given by:

$$R_{cu} = \varrho_{cu} \cdot \frac{l_{cu}}{Q_{cu}},$$

where the specific resistance of copper $\varrho_{cu} = 0.0178\ \Omega/\mathrm{m}/\mathrm{mm}^2$,
the length of the wire $l_{cu} = \pi\, n\, d\ 10^{-3} = 44$ m,
the cross section of the wire $Q_{cu} = \pi/4\ d_{cu}{}^2 = 8.6\ \mathrm{mm}^2$. Hence:

$$R_{cu} = 0.0178 \frac{44}{8.6} = 0.092\ \Omega.$$

The required value of $R_t = 0.1\ \Omega$, so that it is not necessary to connect an additional resistor in series with each coil. If the output voltage of 464 V is slightly too high for the purpose in view, it may be reduced to, say, 440 V, by adding additional resistors, so that Z_a is increased accordingly. This will, however, be at the expense of the efficiency.

RECTIFIERS WITH AUTO-TRANSFORMERS

To obtain an output voltage V_o which differs appreciably from the value given by eq. (47), the rectifier may be connected to the mains via an auto-transformer (see fig. 44). The dimensions of such a transformer are very much smaller than those of a conventional double-wound mains transformer, as is illustrated by the following example.

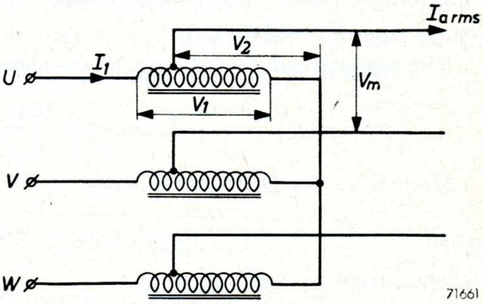

Fig. 44. Auto-transformer for connection between the mains and the rectifier.

Example

A rectifier for feeding a D.C. motor is required to supply a direct voltage of 440 V at 45 A, the available mains voltage between lines being 400 V, 50 c/s.

According to eq. (46) the anode current per tube should be $45/3 = 15$ A. Six 1176 tubes can be used.

The required alternating line voltage V_m can be calculated from eq. (47*b*), which gives:

$$440 = 0.93\ (1.35\ V_m - 2 \times 10),$$

whence $V_m = 368$ V.

The secondary phase voltage V_2 is therefore $368/\sqrt{3} = 212$ V, whilst the primary phase voltage V_1 is $400/\sqrt{3} = 230$ V.

According to eq. (57), at $\beta = 0.8$, the r.m.s. value of the anode current is:

$$I_{a\,\mathrm{rms}} = 1.03 \frac{45}{\sqrt{3}} = 27\ \mathrm{A},$$

which gives for the primary line current:

$$I_1 = \frac{V_2}{V_1} \cdot I_{a\,\mathrm{rms}} \sqrt{2} = \frac{212}{230} 27 \sqrt{2} = 35\ \mathrm{A}.$$

The apparent power of the auto-transformer is therefore:

$$(VA)_{\mathrm{core}} = (VA)_1 = (VA)_2 = 3 \times 35\,(230 - 212) = 1.9\ \mathrm{kVA},$$

whereas with a normal mains transformer the apparent power would have been:

$$(VA)'_{\mathrm{core}} = 3 \times 230 \times 35 = 24\ \mathrm{kVA},$$

i.e. 12 times that of the auto-transformer.

The required value of Z_a is calculated from eq. (51):

$$I_{a\,\mathrm{rms}} = 0.035 \frac{440}{45} = 0.34\ \Omega\,.$$

Since $R_t = 0.2\ \Omega$, from eq. (48):

$$X_L = \sqrt{0.34^2 - 0.2^2} = 0.26\ \Omega,$$

whence, from eq. (52), at 50 c/s:

$$L = \frac{10^6}{314} \cdot 0.26 = 830\ \mu\mathrm{H}.$$

Since the r.m.s. value of the anode current is 27 A, according to eq. (56):

$$d_{\mathrm{cu}} = 0.5 \sqrt{27} \approx 3\ \mathrm{mm}\,,$$

so that from eq. (53*c*):

$$n = \sqrt[3]{1300 \frac{830}{3}} = 71\ \text{turns}\,,$$

whilst from eq. (54):

$$l = d = 1.1 \times 71 \times 3 = 235\ \mathrm{mm}\,.$$

The dissipative resistance of this coil is given by:

$$R_{\mathrm{cu}} = \varrho_{\mathrm{cu}} \cdot \frac{l_{cu}}{Q_{cu}} = 0.0178 \cdot \frac{52}{7} = 0.13\ \Omega\,.$$

To obtain the required value of $R_t = 0.2\ \Omega$, it is therefore necessary to connect an additional resistor of $0.2 - 0.13 = 0.07\ \Omega$ in series with each choke.

RECTIFIERS FOR LARGER OUTPUTS

When a larger output is required than that obtainable with a set of 1177 rectifying tubes, it is possible to replace each tube in the circuit of fig. 42 by two tubes connected in parallel. It is then necessary to connect a balancing inductor L_{bal} with centre tap between the tube anodes (see fig. 45), to ensure simultaneous operation of the two tubes and to balance their anode currents.

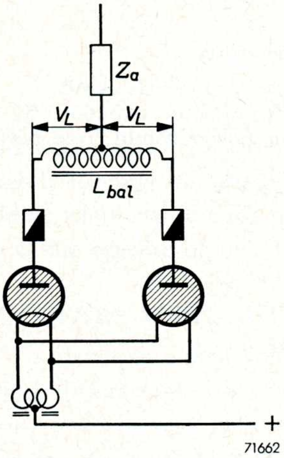

Fig. 45. The rectifying tubes connected in parallel via a balancing inductor L_{bal}.

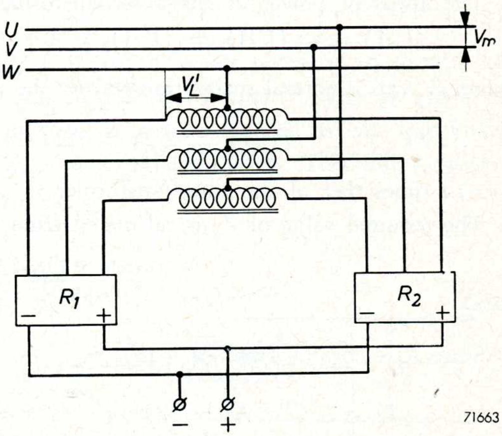

Fig. 46. Two rectifiers R_1 and R_2 connected in parallel via a three-phase balancing inductor.

The design calculations should be carried out on the same lines as shown in the previous sections, and in particular in calculating Z_a the effect of the balancing inductor should be disregarded, since, owing to the opposed direction of the currents flowing through the two halves of the winding during normal operation, the resulting flux, and therefore also the inductance of L_{bal} and the voltage drop, are practically zero.

The balancing inductor must be so designed that V_L is approximately 3% of V_m, with a minimum of 12 V. Assuming V_L to be 12 V, this gives for the apparent power of the balancing inductor:

$$(VA)_{\text{bal}} = 12\, I_{a\,\text{rms}}\,. \quad \ldots\ldots\ldots\ldots (59)$$

For conventional Si-steel, the cross-sectional area of the core can be taken to be:

$$Q = 1.2\,\sqrt{(VA)_{\text{bal}}} = 4.15\,\sqrt{I_{a\,\text{rms}}}\ (\text{cm}^2)\,, \quad \ldots\ldots\ldots\ldots (60)$$

whilst the required number of turns n per volt is:

$$\frac{n}{V_L} = \frac{10^8}{4.44\, Q\, \nu\, B_{\max}},$$

which, for $V_L = 12$ V, $\nu = 50$ c/s and $B_{\max} = 12\,000$ gauss, gives per half winding:

$$n = \frac{108}{\sqrt{I_{a\,\mathrm{rms}}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (61)$$

It is necessary to connect a fuse in series with the anode of each rectifying tube. The rated fusing current should preferably be such that the fuse blows as soon as possible at twice the normal anode current $I_{a\,\mathrm{rms}}$.

Instead of doubling the number of tubes of the circuit of fig. 42 and connecting the rectifying tubes two by two in parallel via a single-phase balancing inductor (fig. 45), the output terminals of two identical rectifiers, R_1 and R_2, may be interconnected, to obtain the required current, but then a three-phase balancing inductor must be connected between the mains and the input terminals of the rectifiers as indicated in fig .46.

In this way it is also possible to connect in parallel, via a three-phase balancing inductor, two rectifiers equipped with a double set of rectifying tubes and single-phase balancing inductors, the output current thus being quadrupled.

The voltage drop V_L' (see fig. 46) across each half winding should be about 6% of the voltage V_m between lines. For the calculation of this three-phase balancing inductor, reference is made to the above formulae.

Example

What are the data of the balancing inductor required for connecting two 1177 rectifying tubes in parallel if the voltage between lines is 380 V and the r.m.s. value of the anode current is 60 A?

Since 3% of 380 V is smaller than 12 V, V_L should be 12 V, so that, according to eq. (15), the cross-sectional area of the core should be:

$$Q = 4.15\sqrt{I_{a\,\mathrm{rms}}} = 32 \text{ m}^2.$$

The number of turns per half winding is given by eq. (61):

$$n = \frac{108}{\sqrt{I_{a\,\mathrm{rms}}}} = 14.$$

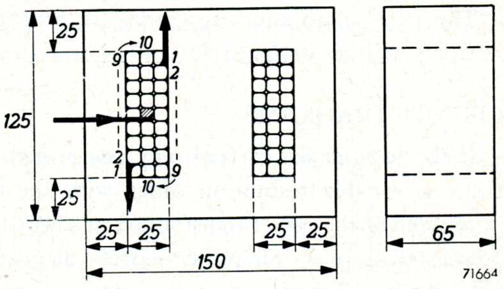

Fig. 47. Dimensions of the balancing inductor and arrangement of the winding consisting of 2 × 14 turns.

The specific current density should be less than 2.5 A/mm² for inductors with iron core, so that the cross section of the wire should be at least 60/2.5 = 24 mm²; rectangular wire of, for example, 6.2 mm × 4.4 mm = 27.3 mm² may be used for this purpose.

The core may thus be given the dimensions indicated in fig. 47, the winding consisting of 3 layers of wire of 9 turns each, arranged as drawn in this figure.

CINEMA RECTIFIERS

GENERAL

For obtaining a steady light output from the arc lamp of a cinema projector, D.C. supply is required, which consequently involves the use of rectifying or converting equipment. Tube rectifiers, rotary converters and selenium rectifiers may be used, but as the first-mentioned rectifiers have several advantages over the other two types, most cinema projectors are provided with a tube rectifier. The noiseless operation of these rectifiers renders their use more attractive than that of rotary converters, whilst their efficiency is also considerably higher. Compared with selenium rectifiers, a tube rectifier is lighter in weight, occupies less space, is easier to replace, whilst no voltage compensation for ageing is needed.

Four- and six-phase rectifying circuits are generally used, the D.C. output current then having but a small ripple, so that no additional filters are required to smooth the current through the arc lamp.

The rectifiers must be provided with a current-limiting device as previously described, as also a control device, so as to be able to adjust the image brightness on the projection screen. This can be effected by controlling the current through the arc lamp, and for this purpose a variable resistor, a variable choke or a transformer with a variable magnetic shunt may be used, either of which serve at the same time as current-limiting device.

The 1838, 1849 and 1859 tubes are primarily intended to be used in cinema rectifiers and are designed for 15, 25 and 50 A D.C. output current respectively.

CIRCUIT DIAGRAMS

If the rectifier has to feed only one projector, rectifying circuits are used with either a variable resistor in series with the output, a variable magnetic shunt in the core of the power transformer, or a variable inductance in the primary of the power transformer. Simplified circuit diagrams for each method are given in figs 48, 49 and 50.

The so-called twin rectifiers are used when two arc lamps have to be operated simultaneously for about five minutes, as will be the case, for example, during each change-over period. A basic circuit diagram is represented in fig.51. The output currents are independently adjustable by means of the variable resistors R_1 and R_2. These resistors also serve to balance the output currents I_{o1} and I_{o2}, when the arc lamps are operated simultaneously for a short interval. Replacement of these resistors by a primary choke or a transductor for controlling the output currents is not possible in this circuit. The transformer kVA rating is usually calculated for one arc lamp, provided it can withstand every 30 minutes an overload of 100% during about 5 minutes.

As the use of variable resistors in the output circuits results in a considerable loss of power, it is advantageous to build two separate rectifiers, the output currents of which are controlled by a variable choke, a transductor or a transformer with a magnetic shunt. Either of these two rectifiers can feed either of the two arc lamps, whilst during the change-over period both arc lamps will operate simultaneously without overloading the transformer. It is also possible to use one power transformer in combination with three double-anode rectifying tubes. The basic circuit of such a twin rectifier is given in fig. 52. With this circuit two arc lamps can be fed in turn, or simultaneously, during a short interval, for example when changing over one projector to the other. One part of the rectifier may also serve as reserve. The direct current for each arc lamp can be adjusted separately with the corresponding transductor by varying the resistors R_1 and R_2 respectively.

When remote control of the output currents is required, use can be made of a servo-motor in combination with a current-limiting device or a transductor.

A very attractive solution in this respect is provided by the application of grid-controlled gas-filled rectifying tubes, called thyratrons, for example type PL 150. This electronic control has the advantage of operating practically without losses, thus ensuring a high total efficiency of the installation at all loads. Because the application of thyratrons falls outside the scope of this Bulletin, the description of such a circuit has not been taken up.

DESIGN CONSIDERATIONS

For the design of a cinema rectifier, use can be made of the formulae given in the previous sections.

EXAMPLES

Below, an example is given dealing with a rectifier for feeding an arc lamp at 70 V, 45 A; supply voltage 3 × 380 V, 50 c/s.

On account of the required low ripple voltage, a four- or six-phase rectifying circuit should be used. According to table XII, p. 114, two 1849 tubes or three 1883 tubes respectively will suffice.

For comparison, the calculations are given for both rectifiers.

1) Four-phase half-wave rectifying circuit with two 1849 tubes

The basic circuit diagram is represented in fig. 48, whilst all values for the design are listed in table X.

With a specific iron loss of 1.3 W/kg (transformer sheet) for the transformer core and a flux density of 1.2 Wb/m², the iron losses will be $w_{ct} \times 1.3 \times 1.2^2 = 112$ W.

BASIC CIRCUIT DIAGRAMS FOR CINEMA RECTIFIERS

Circuits

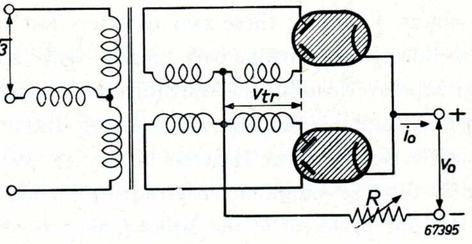

Fig. 48. FOUR-PHASE HALF-WAVE

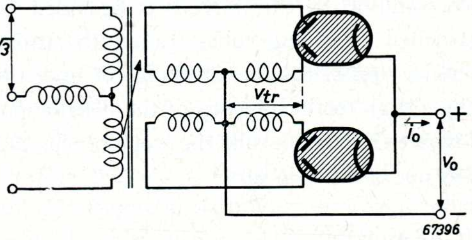

Fig. 49. FOUR-PHASE HALF-WAVE

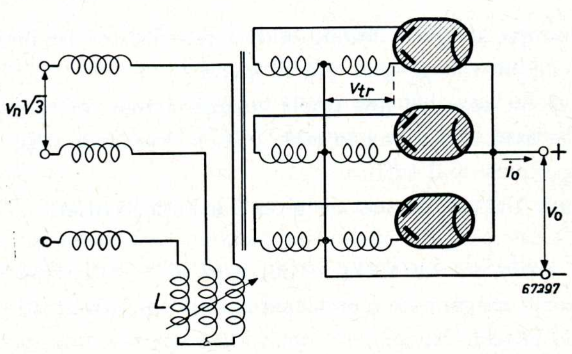

Fig. 50. SIX-PHASE HALF-WAVE

BASIC CIRCUIT DIAGRAMS FOR CINEMA RECTIFIERS

Circuits

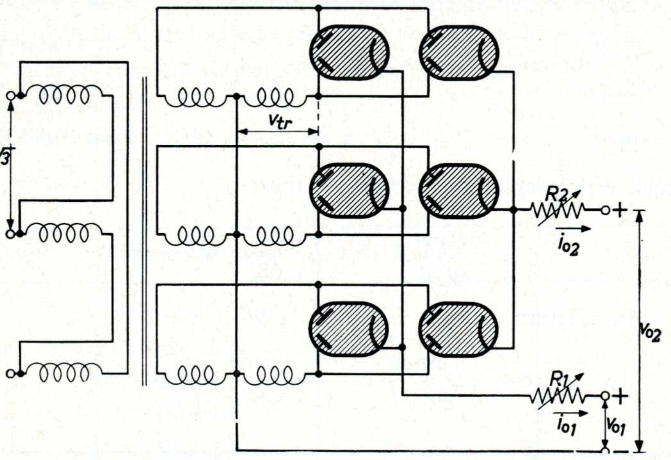

Fig. 51. SIX-PHASE HALF-WAVE

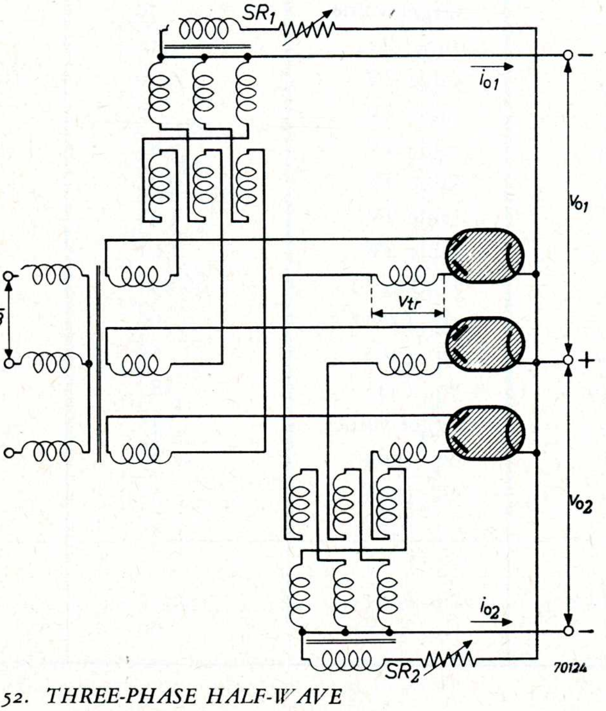

Fig. 52. THREE-PHASE HALF-WAVE

Iron losses		= 112 W
Filament power	$2V_f \times I_f$	= 116 W
Arc losses	$4V_{\text{arc}} \times I_a$	= 450 W
Copper losses of transformer (estimated)		= 140 W
Total		= 818 W
Output	$V_o \times I_o$	= 3150 W
Input		= 3968 W

The total efficiency of the rectifier is thus:

$$\eta_i = \frac{\text{output}}{\text{input}} \times 100 = \frac{3150}{3968} \times 100 = 79\%,$$

and the power factor:

$$\cos\varphi = \frac{\text{input}}{3V_n I_1} = \frac{3968}{3 \times 220 \times 7.5} = 0.80.$$

Table X

Quantities	Derived from	Values	Unit
V_o	target value	70	V
V_{arc}	tube data	10	V
γ	table IV	0.79	—
δ	table IV	1	—
σ	table IV	2.83	—
τ	table IV	0.25	—
f_{p}	table IV	4.44	—
f	table IV	2.01	—
μ	V_{tr}/V_{1h} *)	66/297	—
V_{tr}	eq. (32)	66	V
$V_{a\ \text{rms}}$	eq. (36)	66	V
$V_{\text{inv p}}$	eq. (44)	187	V
I_o	target value	45	A
I_a	eq. (40)	11.25	A
$I_{a\ \text{p}}$	eq. (41)	50	A
$I_{a\ \text{rms}}$	eq. (42)	22.6	A
I_1	eq. (21)	7.5	A
$(VA)_t$	eq. (25)	5375	VA
w_{ct}	fig. 21 †)	60	kg

*) See note ‡ on p. 27.

†) See note † on p. 26.

2) *Six-phase half-wave rectifying circuit with interphase transformer using three 1838 tubes*

The basic circuit diagram is given in fig. 37, but since the 1838 is of the double anode type, each pair of tubes represented in the diagram has to be replaced by one 1838 tube. Control of the output current can be obtained by means of a resistor, a magnetic shunt in the transformer or a primary choke, examples of which are given in figs 48, 49 and 50.

In table XI all values for the design are given.

Table XI

Quantities	Derived from	Values	Unit
V_o	target value	70	V
V_{arc}	tube data	10	V
γ	table IV	0.86	—
δ	table IV	1	—
σ	table IV	2.83	—
τ	table IV	0.17	—
f_{p}	table IV	3.14	—
f	table IV	1.76	—
μ	V_{tr}/V_1	73/380	—
V_{tr}	eq. (32)	73	V
$V_{a\ \mathrm{rms}}$	eq. (36)	73	V
$V_{\mathrm{inv\ p}}$	eq. (44)	206	V
I_o	target value	45	A
I_a	eq. (40)	7.5	A
$I_{a\ \mathrm{p}}$	eq. (41)	23.5	A
$I_{a\ \mathrm{rms}}$	eq. (42)	13.2	A
I_1	eq. (21)	3.8	A
$(VA)_t$	eq. (25)	5020	VA
w_{ct}	fig. 21	44	kg
V_L	$0.42\ V_{tr}$ *)	31	V
I_L	$I_o/2$	22.5	A
$(VA)_L$	$V_L/I_L/2$ †)	345	VA

---

*) The evaluation of this equation is rather complicated and is not taken up in this book.

†) The size of the interphase transformer is determined by $345/3 = 115$ VA, because the frequency of the current is three times the mains frequency.

With a specific iron loss of 1.3 W/kg (transformer sheet) for the transformer core and a flux density of 1,2 Wb/m², the iron losses will be $w_{ct} \times 1.3 \times 1.2^2 = 83$ W. Hence:

Iron losses = 83 W
Filament power $3 V_f \times I_f$ = 125 W
Arc losses $6 V_{\text{arc}} \times I_a$ = 450 W
Copper losses of transformer (estimated) = 125 W
Total = 783 W
Output $V_o \times I_o$ = 3150 W
Input = 3933 W

The total efficiency of the rectifier is:

$$\eta_i = \frac{\text{output}}{\text{input}} \times 100 = \frac{3150}{3933} \times 100 = 80\%,$$

and the power factor:

$$\cos \varphi = \frac{\text{input}}{3 I_1 V_n \sqrt{3}} = \frac{3933}{3 \times 3.8 \times 220 \times \sqrt{3}} = 0.9.$$

WELDING RECTIFIERS

GENERAL

Arc welding is the joining or welding together of pieces of metal by means of an electric arc used for melting the material of a welding rod into a pool of metal.

The electric power for the arc may be A.C. or D.C., but the D.C. system has the advantage of giving a steadier arc, resulting in a more constant heating of the material. For current values higher than 500 A, the D.C. system cannot be used, owing to the blowing of the arc caused by the magnetic deflection of the lines of current in the arc.

The D.C. power for welding can be supplied by a rotary converter, a selenium rectifier or a tube rectifier. D.C. arc welders equipped with rectifying tubes have several advantages, as may be seen from the following. The equipment is compact in size, has a light weight and needs no foundation, so that it can easily be transported. A stepless control of the output current intensity is possible. As there are no moving parts and no inertia in the adjustment of the current intensity, a smooth flowing of the current is ensured, thereby avoiding any sputtering, extinguishing of the arc or risk of sticking. The installation operates without noise, can be used in all climates, at all temperatures, and needs no special maintenance.

Another advantage of D.C. arc welders compared with A.C. welders is that the former are commonly connected to a three-phase power supply system, all phases then being equally loaded. The power factor of these welders is about 0.7, whereas, in the case of A.C. sets, it amounts to about 0.4, if no power factor capacitors be used.

The 1069K tube has been specially designed for D.C. arc welding rectifiers and has an output current of 60 A.

CIRCUIT DIAGRAMS

Figs 53 and 54 represent two basic circuit diagrams of a D.C. arc welder using 1069K tubes. In the circuit of fig. 53, a variable primary choke *L* is used to control the output current, whereas in fig. 54 a saturable core reactor *SR* is employed for this purpose. A magnetic shunt in the power transformer may also be used in these two circuits for controlling the output current.

It should be noted that, when high output currents are required, the tubes must be cooled by forced air, the maximum permissible output current per tube being in that case 60 A.

BASIC DIAGRAMS FOR WELDING RECTIFIERS

Circuit

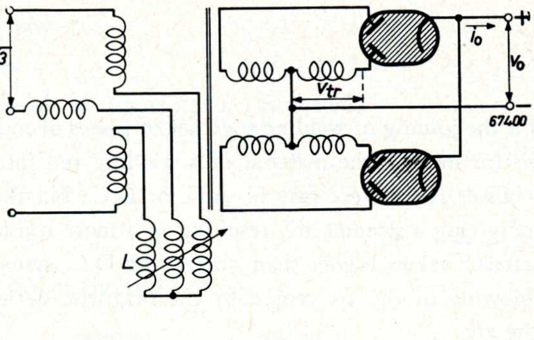

Fig. 53. FOUR-PHASE HALF-WAVE

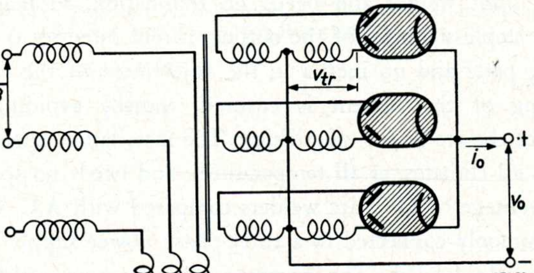

Fig. 54. SIX-PHASE HALF-WAVE

RECTIFYING TUBE TYPE 328

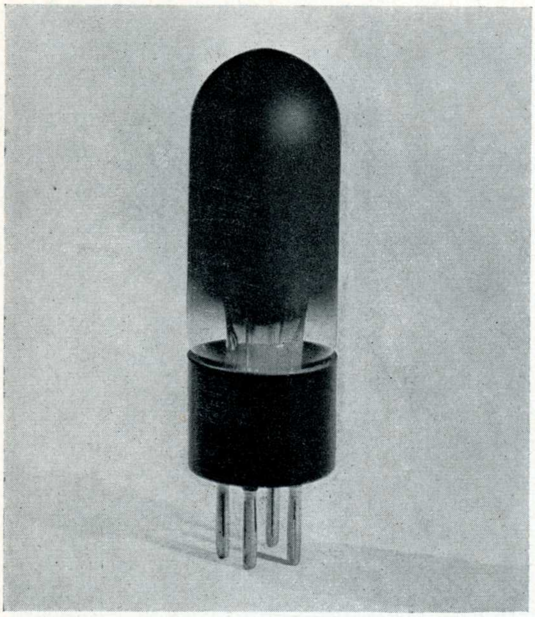

Fig. 55. *The rectifying tube type 328.*

The 328 is a directly heated, gas-filled, double-anode rectifying tube intended for use in trickle chargers and small battery chargers, and has been designed for an output current of 1.3 A.

The conditions under which this tube should be operated are described on p. 10 under "Battery Chargers", and the commonly used circuit diagrams are represented in figs 4 to 7.

The maximum number of Pb-cells which can be charged in series with this tube is 6.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		3.0 A
Heating-up time	T_h	min.	15 sec *)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	7 V
Ignition voltage	V_{ign}	16 V

---

*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 0 sec.

TYPICAL OPERATING CONDITIONS AS BATTERY CHARGER

Transformer voltage	V_{tr}		2 × 28		V_{rms}
Battery		discharged	nom.	charged	
Battery voltage	V_b	11	13	16	V
D.C. output current	I_o	1.5	1.3	1.0	A
Peak anode current	I_{ap}		3		A
Total anode resistance	R_t		6.5		Ω

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	90	V
D.C. output current (per anode)	I_a	max.	0.65	A
Peak anode current	I_{ap}	max.	4	A
Ambient temperature	t_{amb}	—55 to	+75	°C
Anode resistance	R_t	min.	3	Ω

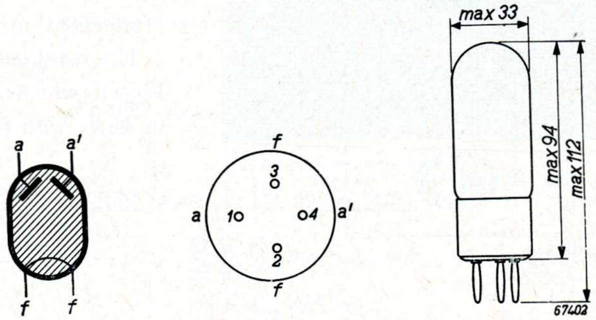

Fig. 56.

BASE CONNECTIONS AND DIMENSIONS (in mm)
(see fig. 56)

Mounting position	vertical, base down
Base	A-type
Socket	40465
Net weight	35 g
Shipping weight (50 tubes)	2500 g

RECTIFYING TUBE TYPE 367

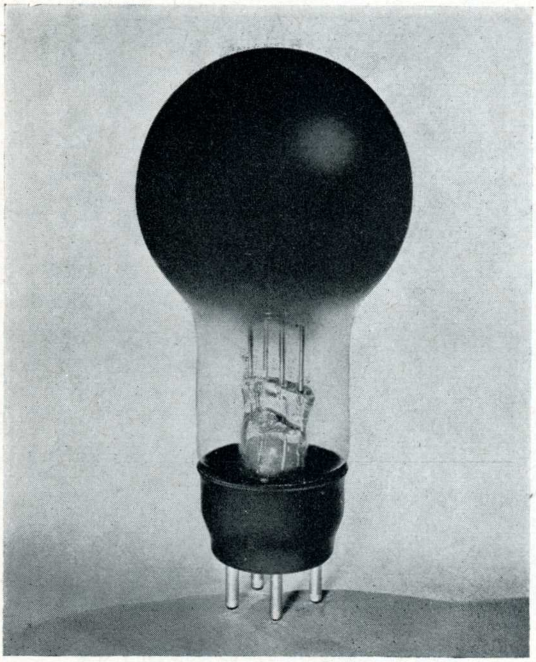
69639

Fig. 57. The rectifying tube type 467.

The 367 is a directly heated, gas-filled, double-anode rectifying tube intended for use in trickle chargers and small battery chargers, and has been designed for a maximum D.C. output current of 6 A.

The conditions under which this tube should be used are given on p. 10 under "Battery Chargers", and the commonly used circuit diagrams are represented in figs 4 to 7.

The maximum number of Pb-cells which can be charged in series with this tube is 12.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		8 A
Heating-up time	T_h	min.	30 sec *)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	9 V
Ignition voltage	V_{ign}	16 V

---

*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 0 sec.

TYPICAL OPERATING CONDITIONS AS BATTERY CHARGER

Transformer voltage	V_{tr}		2 × 45		V_{rms}
Battery		discharged	nom.	charged	
Battery voltage	V_b	22	26	32	V
D.C. output current	I_o	7.2	6	4	A
Peak anode current	I_{ap}		15		A
Total anode resistance	R_t		1.9		Ω

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	140	V
D.C. output current (per anode)	I_a	max.	3	A
Peak anode current	I_{ap}	max.	18	A
Ambient temperature	t_{amb}	—55 to	+75	°C
Anode resistance	R_t	min.	1	Ω

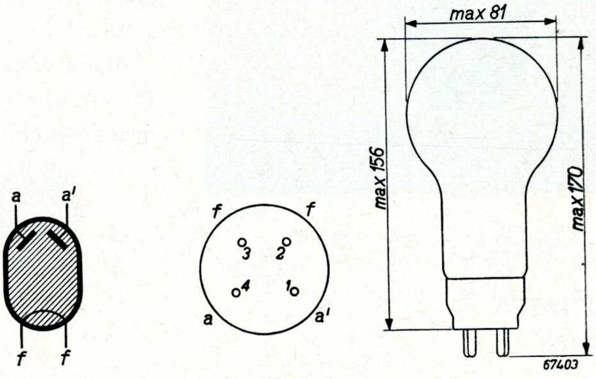

Fig. 58.

BASE CONNECTIONS AND DIMENSIONS (in mm)
(see fig. 58)

Mounting position	vertical, base down
Base	W-type
Socket	40221
Net weight	90 g
Shipping weight (25 tubes)	3500 g

RECTIFYING TUBE TYPE 1010

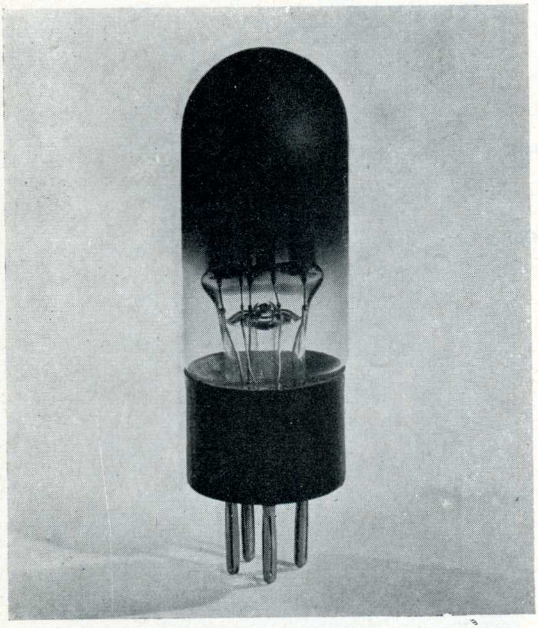
69638

Fig. 59. The rectifying tube type 1010.

The 1010 is a directly heated, gas-filled, double-anode rectifying tube intended for use in trickle chargers and small battery chargers, and has been designed for a maximum D.C. output current of 1.3 A.

The conditions under which this tube should be used are given on p. 10 under "Battery Chargers", and the commonly used circuit diagrams are represented in figs 4 to 7.

The maximum number of Pb-cells which can be charged in series with this tube is 20.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		3.5 A
Heating-up time	T_h	min.	15 sec *)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	9 V
Ignition voltage	V_{ign}	16 V

---

*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 0 sec.

TYPICAL OPERATING CONDITIONS AS BATTERY CHARGER

Transformer voltage	V_{tr}		2 × 60		V_{rms}
Battery		discharged	nom.	charged	
Battery voltage	V_b	36	44	54	V
D.C. output current	I_o	1.7	1.2	0.7	A
Peak anode current	I_{ap}		3.2		A
Total anode resistance	R_t		10		Ω

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	185	V
D.C. output current (per anode)	I_a	max.	0.65	A
Peak anode current	I_{ap}	max.	4	A
Ambient temperature	t_{amb}	—55 to	+75	°C
Anode resistance	R_t	min.	10	Ω

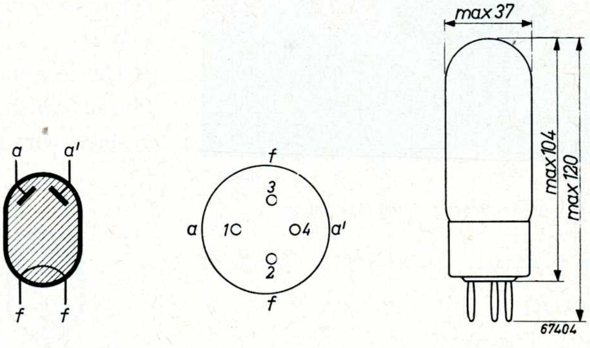

Fig. 60.

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 60)

Mounting position	vertical, base down
Base	A-type
Socket	40465
Net weight	50 g
Shipping weight	80 g

RECTIFYING TUBE TYPE 1039

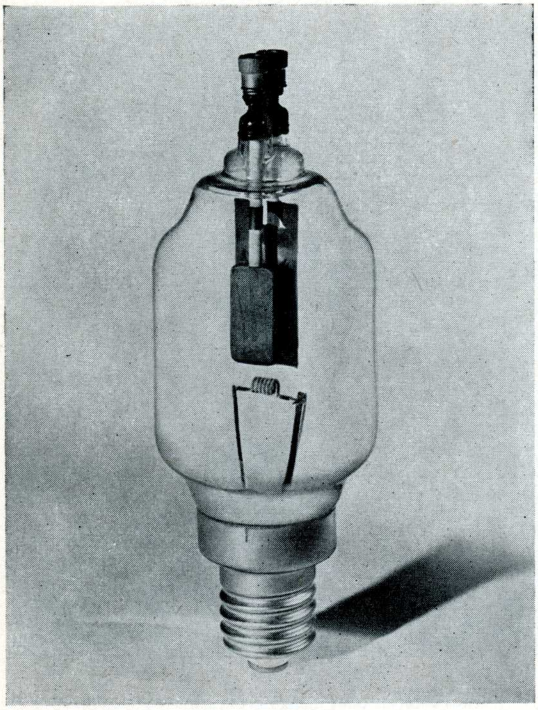
69637

Fig. 61. The rectifying tube type 1039.

The 1039 is a directly heated, mercury vapour and inert gas-filled, double-anode rectifying tube intended for use in large battery chargers, and has been designed for a maximum D.C. output current of 15 A.

The conditions under which this tube should be used are given on p. 10 under "Battery Chargers", and the commonly used circuit diagrams are represented in figs 4 to 9.

The maximum number of Pb-cells which can be charged in series with this tube is 20.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.	
Filament voltage	V_f	1.9 V
Filament current	I_f	28 A
Heating-up time	T_h	min. 1—2 min

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	9 V
Ignition voltage	V_{ign}	16 V

TYPICAL OPERATING CONDITIONS AS BATTERY CHARGER

Transformer voltage	V_{tr}		2×60		V_{rms}
Battery		discharged	nom.	charged	
Battery voltage	V_b	36	44	54	V
D.C. output current	I_o	19	13.5	8	A
Peak anode current	I_{ap}		37		A
Total anode resistance	R_t		0.85		Ω

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	185	V
D.C. output current (per anode)	I_a	max.	7.5	A
Peak anode current	I_{ap}	max.	45	A
Temperature of mercury vapour	t_{Hg}		30—80	°C
Anode resistance	R_t	min.	0.75	Ω

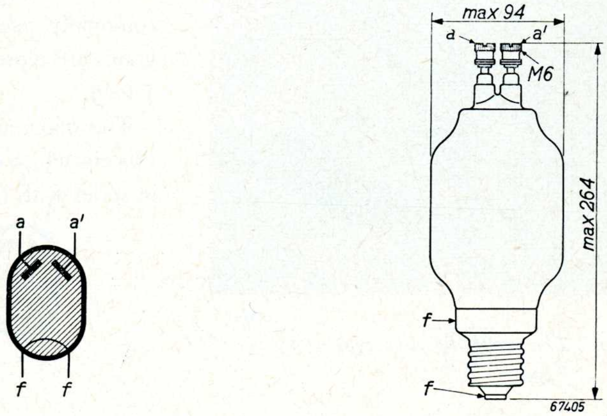

Fig. 62.

BASE CONNECTIONS AND DIMENSIONS (in mm)
(see fig. 62)

Mounting position	vertical, base down
Base	Goliath
Socket	65909BG/01
Net weight	340 g
Shipping weight	1100 g

RECTIFYING TUBE TYPE 1048

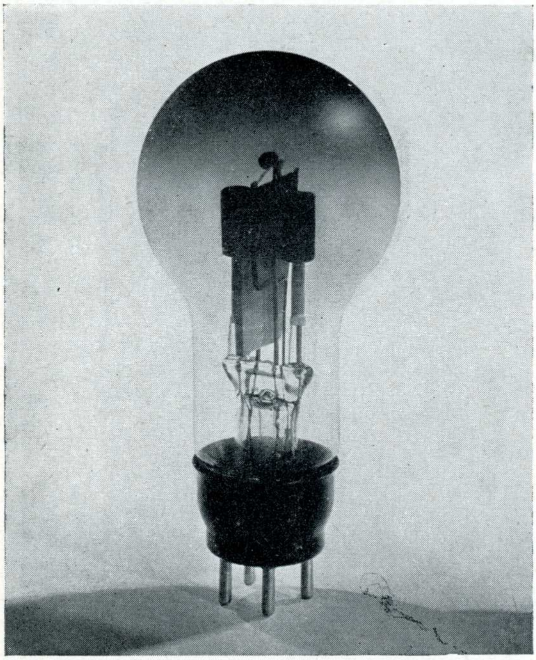
69636

Fig. 63. The rectifying tube type 1048.

The 1048 is a directly heated, gas-filled, double-anode rectifying tube intended for use in trickle chargers and small battery chargers, and has been designed for a maximum D.C. output current of 6 A.

The conditions under which the 1048 should be operated are described on p. 10 under "Battery Chargers", and the commonly used circuit diagrams are represented in figs 4 to 7.

The maximum number of Pb-cells which can be charged in series with this tube is 20.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		7 A
Heating-up time	T_h	min.	30 sec *)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	9 V
Ignition voltage	V_{ign}	16 V

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*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 15 sec.

TYPICAL OPERATING CONDITIONS AS BATTERY CHARGER

Transformer voltage	V_{tr}		2 × 60		V_{rms}
Battery		discharged	nom.	charged	
Battery voltage	V_b	36	44	54	V
D.C. output current	I_o	7.7	5.5	3.2	A
Peak anode current	I_{ap}		15		A
Total anode resistance	R_t		2.1		Ω

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	185	V
D.C. output current (per anode)	I_a	max.	3	A
Peak anode current	I_{ap}	max.	18	A
Ambient temperature	t_{amb}	−55 to	+75	°C
Anode resistance	R_t	min.	1.75	Ω

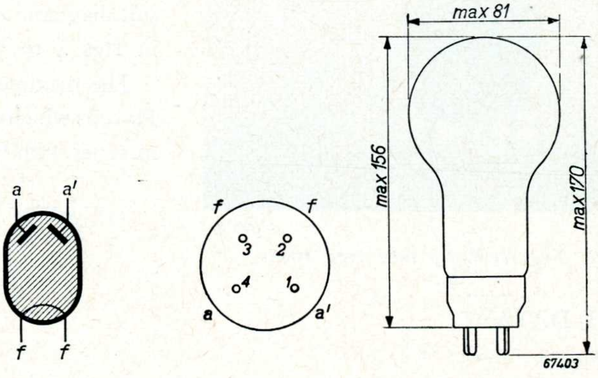


Fig. 64.

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 64)

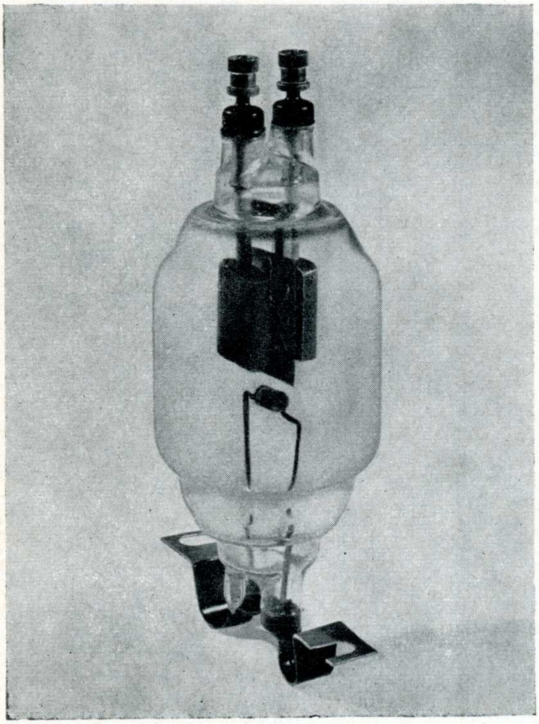
Mounting position	vertical, base down
Base	W-type
Socket	40221
Net weight	90 g
Shipping weight (50 tubes)	7500 g

RECTIFYING TUBE TYPE 1049

The 1049 is a directly heated, mercury vapour and inert gas-filled, double-anode rectifying tube intended for use in large battery chargers, and has been designed for a maximum D.C. output current of 25 A.

The conditions under which this tube should be used are given on p. 10 under "Battery Chargers", and the commonly used circuit diagrams are represented in figs 4 to 9.

The maximum number of Pb-cells which can be charged in series with this tube is 20.



69634

Fig. 65. The rectifying tube type 1049.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		28.5 A
Heating-up time	T_h	min.	120 sec *)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	9 V
Ignition voltage	V_{ign}	16 V

---

*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 60 sec.

TYPICAL OPERATING CONDITIONS AS BATTERY CHARGER

Transformer voltage	V_{tr}		2 × 60		V_{rms}
Battery		discharged	nom.	charged	
Battery voltage	V_b	36	44	54	V
D.C. output current	I_o	32	22	13	A
Peak anode current	I_{ap}		60		A
Total anode resistance	R_t		0.5		Ω

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	185	V
D.C. output current (per anode)	I_a	max.	12.5	A
Peak anode current	I_{ap}	max.	75	A
Temperature of mercury vapour	t_{Hg}		30—80	°C
Anode resistance	R_t	min.	1.3	Ω

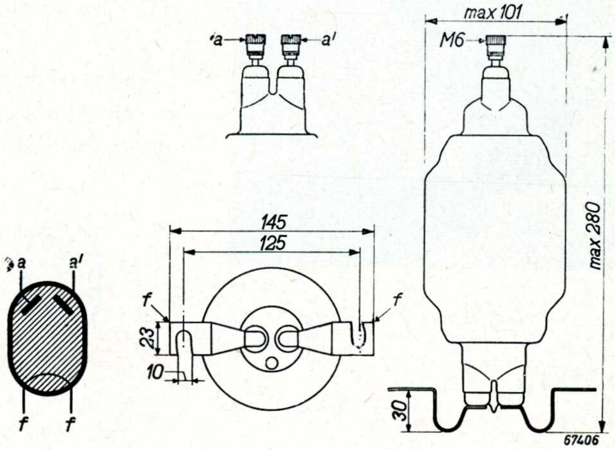


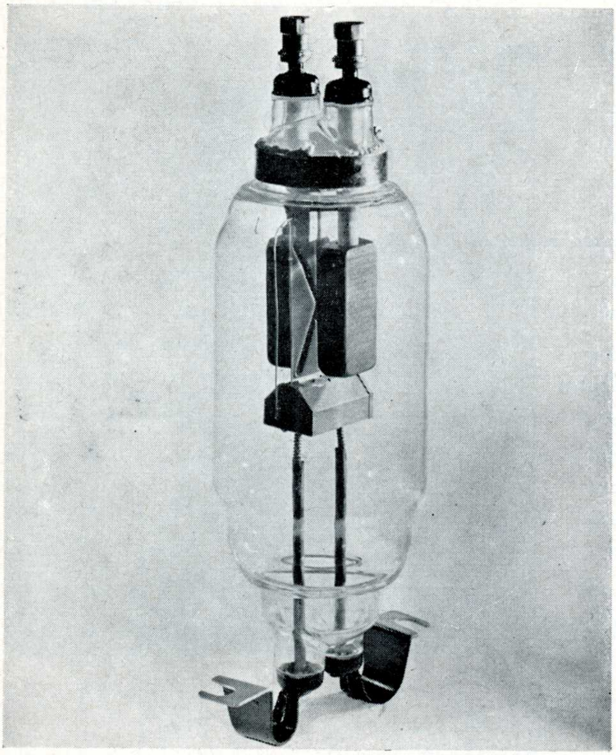
Fig. 66.

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 66)

Mounting position	vertical, base down
Net weight	520 g
Shipping weight	2400 g

RECTIFYING TUBE TYPE 1069K



69640

Fig. 67. The rectifying tube type 1069K.

The 1069K is a directly heated mercury vapour and inert gas-filled, double-anode rectifying tube for use in welding equipment. With this tube a maximum D.C. output current of 60 A can be obtained, provided the tube is sufficiently cooled by forced air.

If the tube is used in transportable equipment, care must be taken to mount it in such a way that the envelope will not be damaged due to vibrations or shocks. For these applications the tube must also be supported at the top end; for this purpose the 1069K has been provided with a metal ring, which can serve, for example, for resilient mounting with the aid of a spring connected to the chassis.

The conditions under which this tube should be used are described on p. 61, and the commonly used circuit diagrams are represented in figs 53 and 54. The maximum values of the D.C. welding currents of these circuits are 120 and 180 A respectively.

TECHNICAL DATA

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	10 V
Ignition voltage	V_{ign}	16 V

FILAMENT DATA

Heating	direct by **A.C.**		
Filament voltage	V_f		3.25 **V**
Filament current	I_f		70 A
Heating-up time	T_h	min.	120 sec *)

TYPICAL OPERATING CONDITIONS

Circuit		Fig. 53	Fig. 54
Transformer voltage	V_{tr}	55	55 V
Output voltage	V_o	50	55 V
Output voltage	I_o	120	180 A

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max. 170 V
D.C. output current (per anode)	I_a	max. 30 A †) ‡)
Peak anode current	I_{ap}	max. 200 A
Temperature of mercury vapour	t_{Hg}	30—75 °C
Anode resistance	R_t	min. 0.12 Ω

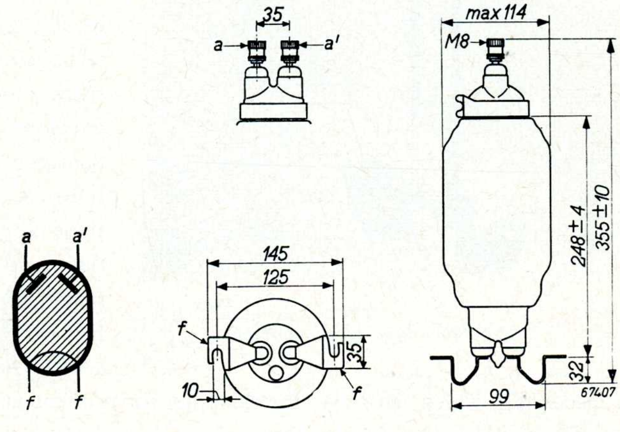


Fig. 68.

BASE CONNECTIONS AND DIMENSIONS (in mm)

Mounting position	vertical, base down
Net weight	1000 g
Shipping weight	3200 g

---

*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 60 sec.

†) Maximum average time 15 sec.

‡) With forced cooling.

RECTIFYING TUBE TYPE 1110

The 1110 is a directly heated, gas-filled, double-anode rectifying tube intended for use in trickle chargers and small battery chargers, and has been designed for a D.C. output current of 2 A.

The conditions under which this tube should be operated are given on p. 10 under "Battery Chargers", and the circuit diagrams commonly used are represented in figs 4 to 7.

The maximum number of Pb-cells which can be charged in series with this tube is 20.

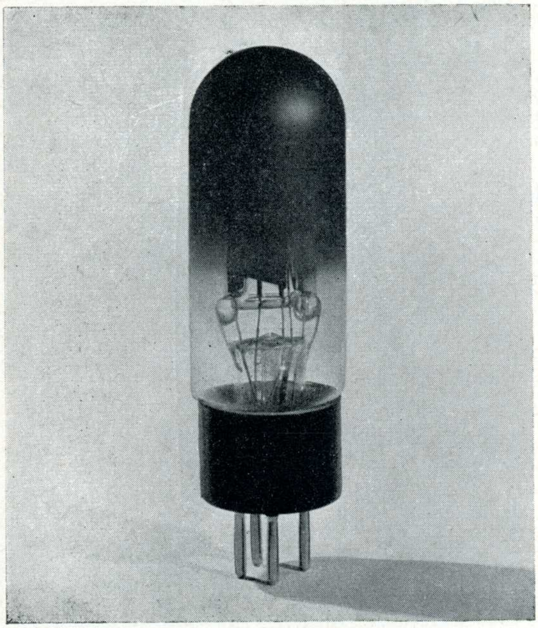


Fig. 69. The rectifying tube type 1110.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		3.5 A
Heating-up time	T_h	min.	15 sec *)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	9 V
Ignition voltage	V_{ign}	16 V

---

*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 0 sec.

TYPICAL OPERATING CONDITIONS AS BATTERY CHARGER

Transformer voltage	V_{tr}		60		V_{rms}
Battery		discharged	nom.	charged	
Battery voltage	V_b	36	44	54	V
D.C. output current	I_o	2	1.4 †)	0.85	A
Peak anode current	I_{ap}		3.8		A
Total anode resistance	R_t		8		Ω

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	185	V
D.C. output current (per anode)	I_o	max.	0.85	A
Peak anode current	I_{ap}	max.	5	A
Ambient temperature	t_{amb}	—55 to	+75	°C
Anode resistance	R_t	min.	4	Ω

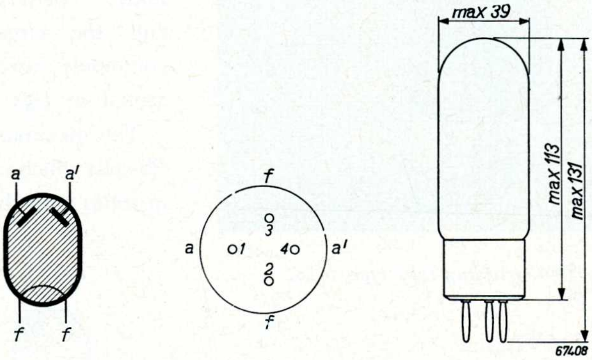


Fig. 70.

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 70)

Mounting position	vertical, base down
Base	A-type
Socket	40465
Net weight	55 g
Shipping weight (100 tubes)	7100 g

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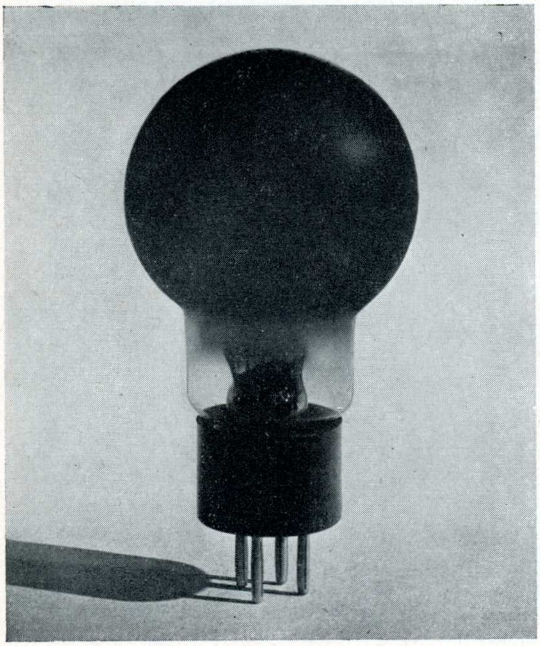
†) If a barretter is used, I_o may under nominal conditions be increased to 2 A.

RECTIFYING TUBE TYPE 1119



69642

Fig. 71. The rectifying tube type 1119.

The 1119 is a directly heated, gas-filled, double-anode rectifying tube intended for use in trickle chargers and small battery chargers. It has been designed for a maximum D.C. output current of 3 A.

The conditions under which this tube should be used are described on p. 10 under "Battery Chargers", and the commonly used circuit diagrams are represented in figs 4 to 7.

The maximum number of Pb-cells which can be charged in series with this tube is 12.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		5.8 A
Heating-up time	T_h	min.	30 sec *)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	9 V
Ignition voltage	V_{ign}	16 V

---

*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 15 sec.

TYPICAL OPERATING CONDITIONS AS BATTERY CHARGER

Transformer voltage	V_{tr}		46		V_{rms}
Battery		discharged	nom.	charged	
Battery voltage	V_b	22	26	32	V
D.C. output current	I_o	3.6	3.0	2.1	A
Peak anode current	I_{ap}		7.5		A
Total anode resistance	R_t		3.75		Ω

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	140	V
D.C. output current (per anode)	I_o	max.	1.5	A
Peak anode current	I_{ap}	max.	9	A
Ambient temperature	t_{amb}	—55 to	+75	°C
Anode resistance	R_t	min.	1.8	Ω

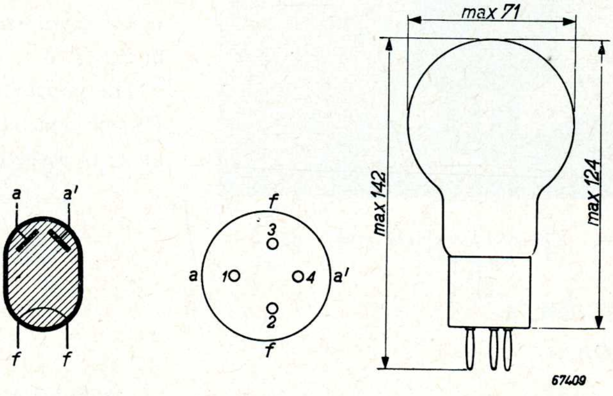
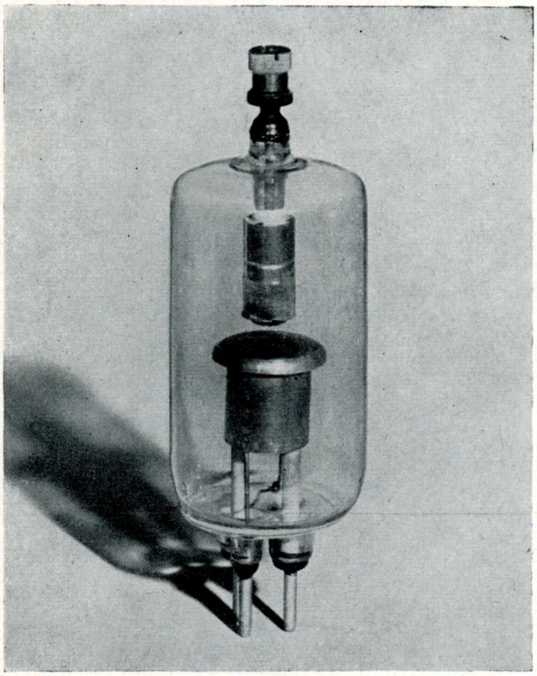


Fig. 72.

BASE CONNECTIONS AND DIMENSIONS (in mm)
(see fig. 68)

Mounting position	vertical, base down
Base	A-type
Socket	40465
Net weight	75 g
Shipping weight (50 tubes)	5200 g

RECTIFYING TUBE TYPE 1173



69628

Fig. 73. The rectifying tube type 1173.

The 1173 is a directly heated, mercury-vapour and inert gas-filled, single-anode rectifying tube specially designed for industrial applications in the voltage range up to 540 V D.C. The permissible inverse peak anode voltage is 685 V or 850 V. The tube is capable of delivering a D.C. output current of 4 A. It has a long life and is very suitable for use in equipment where quick starting and stability of operation are essential.

The tube is provided with an auxiliary ignition electrode, a_h, which should be connected to an auxiliary D.C. source, as for example the Auxiliary Ignition Unit type 1289, a description of which is given on p. 63.

The maximum values of the D.C. voltages and currents obtainable with the 1173 used as industrial rectifier in the circuits of figs 30 to 39 are given below. When it is required to reduce the value of the ripple to a lower level, a filter with choke input should be used. The figures stated in the data have been obtained from practical circuits and thus take into account all losses occurring in the circuit used.

Contrary to the rectifying tubes previously mentioned in the technical data, there are two columns of limiting values. The maximum permissible peak inverse voltage depends upon the peak anode current and upon the temperature of the mercury vapour.

The conditions under which the tube should operate when employed in a battery charger are described on p. 10 under "Battery Chargers", and the circuit diagrams commonly used are represented in figs 4 to 9. In these circuits each tube must be replaced by two 1173 tubes, these being of the single-anode type. The maximum number of Pb-cells which can be charged in series with this tube is 85.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		13 A
Heating-up time	T_h	min.	1 min*)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	12 V
Ignition voltage	V_{ign}	22 V†)

BASE CONNECTIONS AND DIMENSIONS (in mm) (see fig. 72)

Mounting position	vertical, base down
Base	special 3-pin
Socket	1287
Net weight	165 g
Shipping weight	390 g

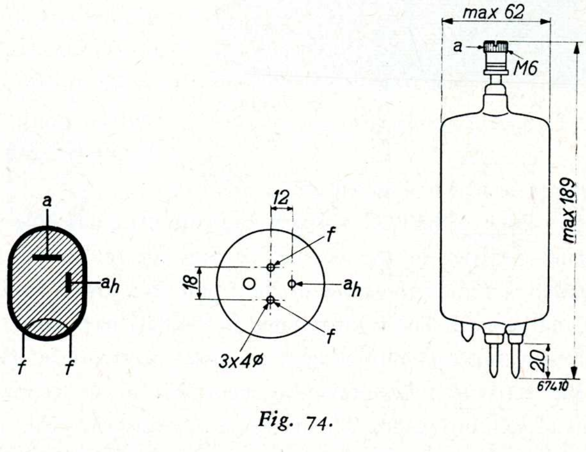


Fig. 74.

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*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 45 sec.

†) In order to obtain the low ignition voltage of 22 V, an auxiliary D.C. supply unit delivering at least 40 V, 10 mA should be connected to the auxiliary ignition electrode a_h, via a current-limiting resistor.

TYPICAL OPERATING CONDITIONS AS INDUSTRIAL RECTIFIER

Circuit	Transformer voltage V_{tr} (V_{rms})	Output voltage V_o (V)	D.C. output current I_o (A)
Fig. 30	275	230	8
Fig. 31	540	440	8
Fig. 32	220	240	12
Fig. 33	210	440	12
Fig. 34	205	240	16
Fig. 36	200	240	24
Fig. 37	220	240	24

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	685	850	V
D.C. output current	I_a	max.	4	4	A *)
Peak anode current	I_{ap}	max.	24	20	A
Surge current	I_{surge}	max.	240	200	A †)
Temperature of mercury vapour .	t_{Hg}		30—80	30—75	°C
Ambient temperature	t_{amb}		10—50	10—45	°C
Anode resistance	R_t	min.	0.75	0.75	Ω

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*) Maximum averaging time (T_{av}) 5 sec.

†) Maximum duration 0.1 sec.

RECTIFYING TUBE TYPE 1174

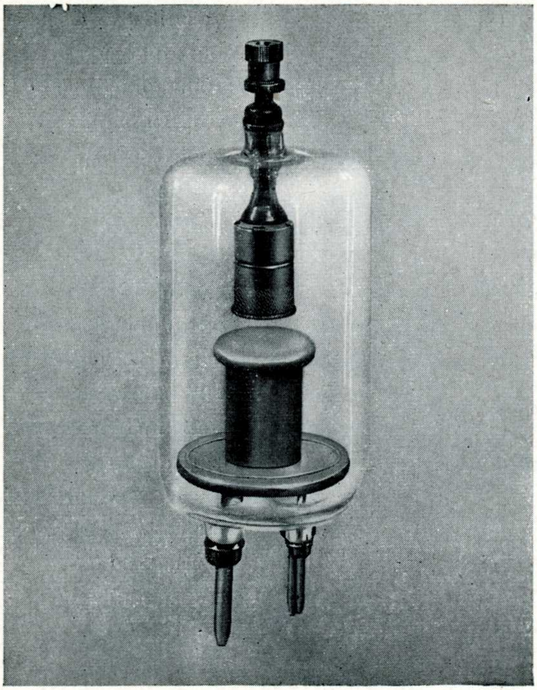

Fig. 75. The rectifying tube type 1174.

The 1174 is a directly heated, mercury-vapour and inert gas-filled, single-anode rectifying tube specially designed for industrial applications in the voltage range up to 540 V. It will withstand a peak inverse voltage of 685 V, or of 850 V, depending upon the peak anode current, and deliver a D.C. output current of 6 A.

This tube gives years of reliable service thanks to its rigid construction and special design. It can be used advantageously in equipment where quick starting and stability are important factors.

To facilitate ignition, the tube has been provided with an auxiliary ignition electrode, a_h, which should be connected to an auxiliary D.C. source, as for example the Auxiliary Ignition Unit type 1289, a description of which is given on p. 106.

The 1174 can be used in industrial rectifiers feeding, for example, small D.C. motors or electromagnets, in battery chargers and similar equipment. Table XII shows the maximum values of the D.C. output voltages and currents which can be obtained with the 1174 when used as industrial rectifier. The fundamental circuit diagrams are represented in figs 30 to 39. In the table, allowance is made for all losses which may occur in the circuit used. If it is required to reduce the ripple voltage to a lower level, a filter with choke input should be employed.

The conditions under which the tube should operate as battery charger are described on p. 10 under "Battery Chargers", and the circuit diagrams commonly used are represented in figs 4 to 9. Each tube figuring in these circuits must be replaced by two 1174 tubes, since the latter are of the single-anode type. The maximum number of Pb-cells which can be charged in series with this tube is 85.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		12 A
Heating-up time	T_h	min.	1 min *)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	12 V
Ignition voltage	V_{ign}	22 V †)

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 74)

Mounting position	vertical, base down
Base	special three-pin
Socket	1285
Net weight	285 g
Shipping weight	665 g

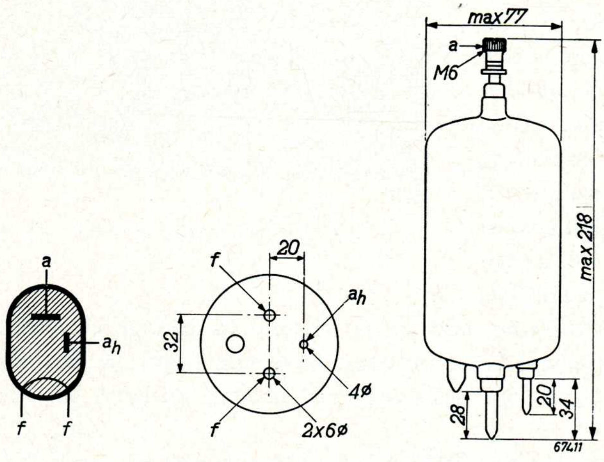

Fig. 76.

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*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 45 sec.

†) In order to obtain the low ignition voltage of 22 V, an auxiliary D.C. supply unit delivering at least 40 V, 10 mA D.C. should be connected to the auxiliary ignition anode a_h, via a current-limiting resistor.

TYPICAL OPERATING CONDITIONS AS INDUSTRIAL RECTIFIER

Circuit	Transformer voltage V_{tr} (V_{rms})	Output voltage V_o (V)	D.C. output current I_o (A)
Fig. 30	275	230	12
Fig. 31	540	440	12
Fig. 32	220	240	18
Fig. 33	210	440	18
Fig. 34	205	240	24
Fig. 36	200	240	36
Fig. 37	220	240	36

LIMITING VALUES (absolute maxima)

Peak inverse voltage	$V_{inv\,p}$	max.	685	850 V
D.C. output current	I_a	max.	6	6 A ‡)
Peak anode current	I_{ap}	max.	36	30 A
Surge current	I_{surge}	max.	360	300 A §)
Temperature of mercury vapour .	t_{Hg}		30—80	30—75 °C
Ambient temperature			10—50	10—45 °C
Anode resistance	R_t	min.	0.5	0.5 Ω

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‡) Maximum averaging time (T_{av}) 5 sec.

§) Maximum duration 0.1 sec.

RECTIFYING TUBE TYPE 1176

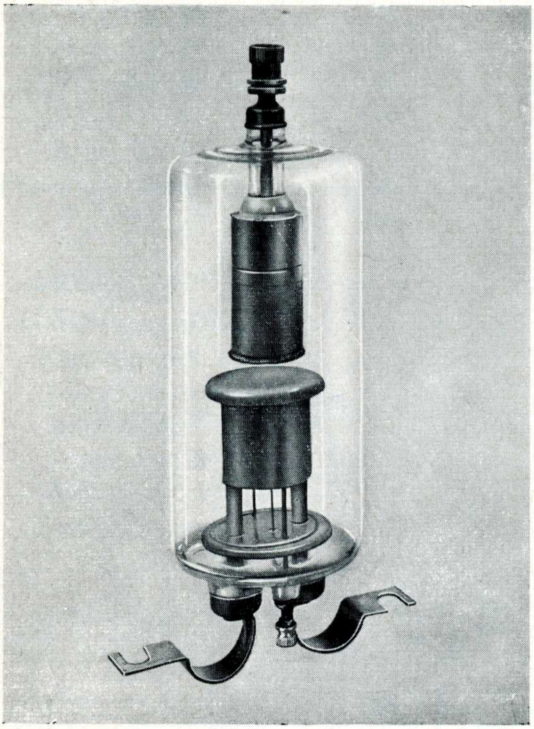

Fig. 77. The rectifying tube type 1176.

The 1176 is a directly heated mercury-vapour and inert gas-filled, single-anode rectifying tube specially designed for industrial applications in the voltage range up to 540 V D.C. It is capable of delivering a D.C. output current of 15 A and of withstanding a peak inverse voltage of 685 V or 850 V, depending upon the peak anode current.

The tube has a long life, due to its rigid construction and special design. It can be used to advantage in cases where quick starting and stability are required.

The 1176 is designed for application in industrial rectifiers such as are used for feeding D.C. mains and D.C. motors for battery chargers and similar equipment.

To facilitate the ignition of the tube, it has been provided with an auxiliary ignition electrode a_h, which should be connected to an auxiliary D.C. source, as for example the Auxiliary Ignition Unit type 1289, the description of which is given on p. 106.

Table XII shows the maximum values of the D.C. output voltage and currents which can be obtained with the 1176 when used as industrial rectifier. The fundamental circuit diagrams are represented in figs 30 to 39. In the table, allowance is made for all losses which may occur in the circuit used. If it is required to reduce the ripple voltage to a lower level, a filter with choke input should be employed.

The conditions under which the tube should operate as battery charger are described on p. 10 under "Battery Chargers", and the circuit diagrams commonly used are shown in figs 4 to 9. Each tube represented in these circuits must be replaced by two 1176 tubes, since the latter are of the single-anode type. The maximum number of Pb-cells which can be charged in series with this tube is 85.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		28 A
Heating-up time	T_h	min.	2 min *)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	12 V
Ignition voltage	V_{ign}	22 V †)

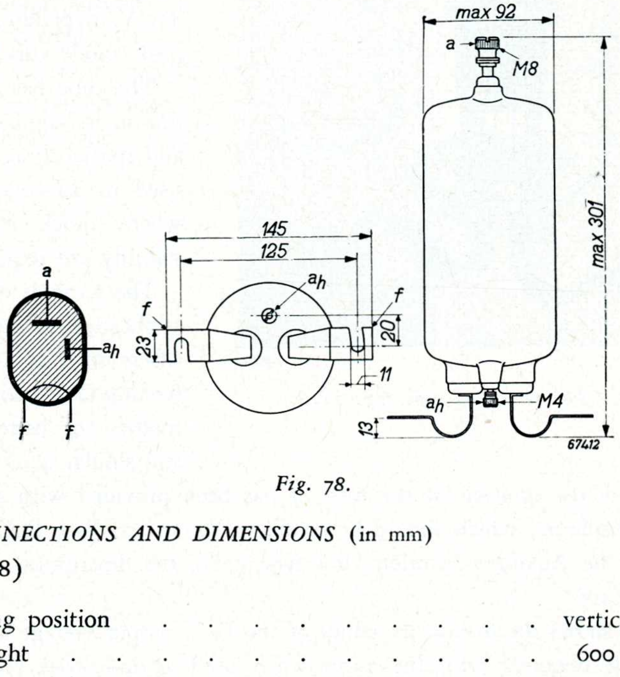

Fig. 78.

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 78)

Mounting position	vertical, base down
Net weight	600 g
Shipping weight	1190 g

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*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 60 sec.

†) In order to obtain the low ignition voltage of 22 V, an auxiliary D.C. supply unit delivering at least 40 V, 10 mA D.C. should be connected to the auxiliary ignition electrode a_h, via a current-limiting resistor.

TYPICAL OPERATING CONDITIONS AS INDUSTRIAL RECTIFIER

Circuit	Transformer voltage V_{tr} (V_{rms})	Output voltage V_o (V)	D.C. output current I_o (A)
Fig. 30	275	230	30
Fig. 31	540	440	30
Fig. 32	220	240	45
Fig. 33	210	440	45
Fig. 34	205	240	60
Fig. 36	200	240	90
Fig. 37	220	240	90

LIMITING VALUES (absolute maxima)

Peak inverse voltage	$V_{inv\,p}$	max.	685	850	V
Output current	I_a	max.	15	15	A *)
Peak anode current	$I_{a\,p}$	max.	90	75	A
Surge current	I_{surge}	max.	900	750	A †)
Temperature of mercury vapour .	t_{Hg}		30—80	30—75	°C
Ambient temperature	t_{amb}		10—50	10—45	°C
Anode resistance	R_t	min.	0.2	0.2	Ω

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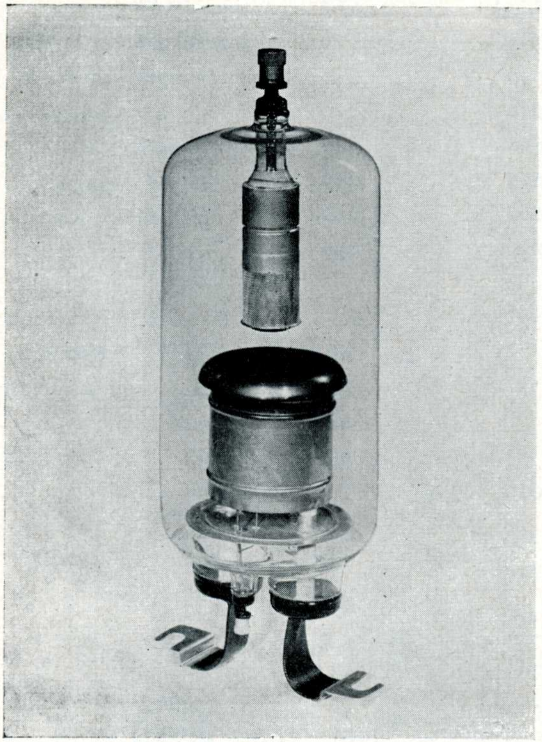
*) Maximum averaging time (T_{av}) 15 sec.

†) Maximum duration 0.1 sec.

RECTIFYING TUBE TYPE 1177



69626

Fig. 79. The rectifying tube type 1177.

The 1177 is a directly heated, mercury vapour and inert gas-filled, single-anode rectifying tube specially designed for industrial applications in the voltage range up to 540 V D.C. It is capable of withstanding a peak inverse voltage of 685 V or of 850 V, depending upon the peak anode current, and delivering a D.C. output current of 25 A.

The tube has a long life, thanks to its rigid construction and special design. It lends itself well for meeting the requirements of quick starting and stability.

To facilitate the ignition of the tube, it has been provided with an auxiliary ignition electrode a_h, which should be connected to an auxiliary D.C. source, as for example the Auxiliary Ignition Unit type 1289, the description of which is given on p. 106.

The 1177 is designed for applications in industrial rectifiers such as are used for feeding D.C. mains and D.C. motors, in battery chargers and similar equipment.

Table XII (see p. 114) shows the maximum values of the D.C. output voltages and currents which can be obtained with the 1177 as power rectifier. In this table allowance is made for all losses which may occur in the circuit used. The fundamental circuit diagrams are represented in figs 30 to 39.

The conditions under which the tube should operate as battery charger are described on p. 10 under "Battery Chargers", and the circuit diagrams commonly used are shown in figs 4 to 9. Each tube represented in these circuits must be replaced by two 1177 tubes, since the latter are of the single-anode type. The maximum number of Pb-cells which can be charged in series is 85, and the maximum D.C. output current that can be delivered to the battery is 25 A per tube.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		60 A
Heating-up time	T_h	min.	2 min *)

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 80)

Mounting position	vertical, base down
Net weight	1060 g
Shipping weight	2720 g

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	12 V
Ignition voltage	V_{ign}	28 V †)

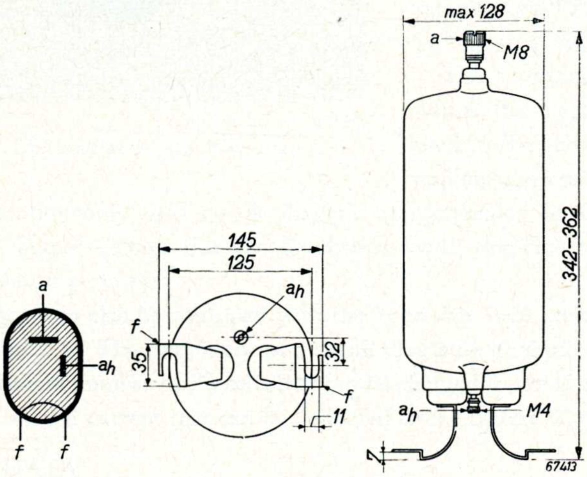


Fig. 80.

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*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 60 sec.

†) In order to obtain the low ignition voltage of 28 V, an auxiliary D.C. supply unit delivering at least 40 V, 10 mA D.C. should be connected to the auxiliary anode a_h, via a current-limiting resistor.

TYPICAL OPERATING CONDITIONS AS INDUSTRIAL RECTIFIER

Circuit	Transformer voltage V_{tr} (V_{rms})	Output voltage V_o (V)	D.C. output current I_o (A)
Fig. 30	275	230	50
Fig. 31	540	440	50
Fig. 32	220	240	75
Fig. 33	210	440	75
Fig. 34	205	240	100
Fig. 36	200	240	150
Fig. 37	220	240	150

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	685	850	V
Output current	I_a	max.	25	25	A ‡)
Peak anode current	I_{ap}	max.	150	135	A
Surge current	I_{surge}	max.	1500	1250	A §)
Ambient temperature	t_{Hg}		30—80	30—75	°C
Temperature of mercury vapour .	t_{amb}		10—50	10—45	°C
Anode resistance	R_t	min.	0.1	0.1	Ω

---

‡) Maximum averaging time (T_{av}) 15 sec.

§) Maximum duration 0.1 sec.

RECTIFYING TUBE TYPE 1710

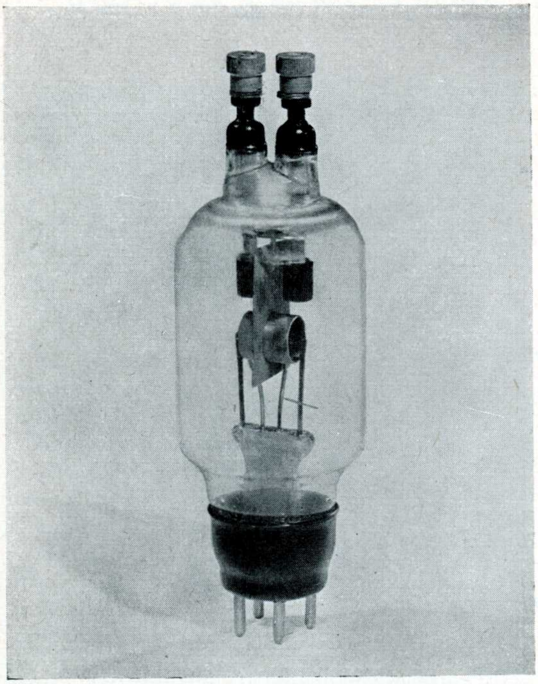


Fig. 81. The rectifying tube type 1710.

The 1710 is a directly heated, mercury vapour and inert gas-filled, double-anode rectifying tube specially designed for use in rectifiers feeding magnetic chucks and separators. The permissible peak inverse anode voltage is 470 V, and the tube is capable of delivering a D.C. output current of 3 A. The special design combined with a rigid construction ensures years of reliable service.

The tube is provided with an internal screen, *s*, which must be connected to the cathode via a resistor of 10 kΩ, 0.5 W.

The conditions under which the 1710 should be used in the above-mentioned applications are described on p. 29, and the commonly used circuit diagram is represented in fig. 30. The maximum D.C. output voltage that can be obtained with this circuit amounts to 115 V (see table on p. 114).

Battery chargers can also be equipped with the 1710, but then under the conditions described on p. 10. The commonly used circuit diagrams are represented in figs 4 to 7. The maximum number of Pb-cells that can be charged in series is 60, and the maximum D.C. output current that can be delivered to the battery is 3 A per tube.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.	
Filament voltage	V_f	1.9 V
Filament current	I_f	7 A
Heating-up time	T_h	min. 30 sec *)

---

*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 15 sec.

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	10 V
Ignition voltage	V_{ign}	22 V

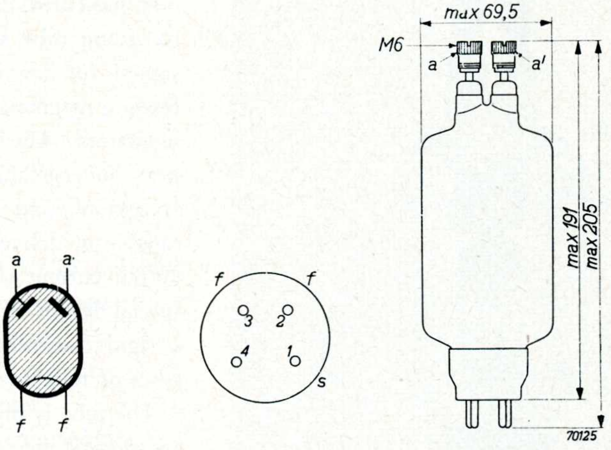


Fig. 82.

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 82)

Mounting position	vertical, base down
Base	W-type
Socket	40221
Net weight	170 g
Shipping weight (10 tubes)	3300 g

TYPICAL OPERATING CONDITIONS

Circuit	Fig. 30	
Transformer voltage	V_{tr}	2×150 V_{rms}
Output voltage	V_o	110 V
Output current	I_o	3 A

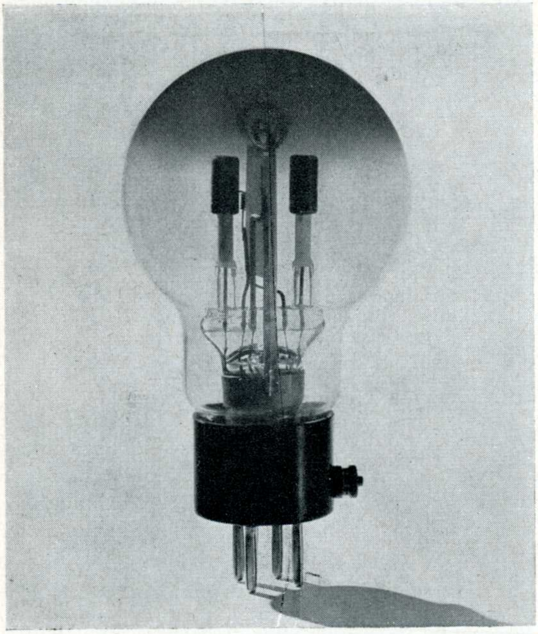
LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	470 V
Output current (per anode)	I_a	max.	1.5 A *)
Peak anode current	I_{ap}	max.	9 A
Temperature of mercury vapour	t_{Hg}		30—80 °C
Anode resistance	R_t	min.	2.5 Ω

---

*) Maximum averaging time (T_{av}) 5 sec.

RECTIFYING TUBE TYPE 1725 A



69633

Fig. 83. The rectifying tube type 1725 A.

The 1725 A is a directly heated, gas-filled, double-anode rectifying tube intended for use in rectifiers feeding magnetic chucks and separators. It is designed for a maximum D.C. output current of 1.3 A and is capable of withstanding a maximum peak inverse anode voltage of 470 V.

The tube is provided with an internal screen, *s*, which must be connected to the cathode via a resistor of 10 kΩ, 0.5 W.

The conditions under which this tube should be used are described on p. 29, and the commonly used circuit diagram is represented in fig. 30. The maximum D.C. output voltage which can be obtained with this circuit amounts to 115 V (see table on p. 114).

In battery chargers, the 1725 A should be used under the conditions given on p. 10 under "Battery Chargers". The circuit diagrams are represented in figs 4 to 7; the maximum number of Pb-cells that can be charged in series with this tube is 60.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		3.5 A
Heating-up time	T_h	min.	15 sec *)

---

*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 60 sec.

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	10 V
Ignition voltage	V_{ign}	22 V

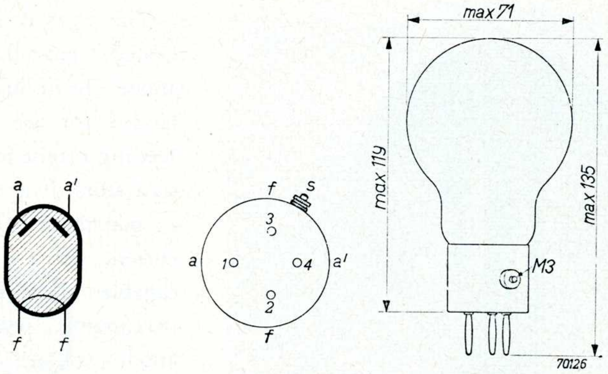


Fig. 84.

BASE CONNECTIONS AND DIMENSIONS (in mm)
(see fig. 84)

Mounting position	vertical, base down
Base	A-type
Socket	40465
Net weight	75 g
Shipping weight (25 tubes)	5500 g

TYPICAL OPERATING CONDITIONS

Circuit		
Transformer voltage	V_{tr}	2×150 V_{rms}
Output voltage	V_o	110 V
Output current	I_o	1.3 A

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	470 V
Output current (per anode)	I_a	max.	0.65 A *)
Peak anode current	I_{ap}	max.	4 A
Ambient temperature	t_{Hg}	—55 to +75 °C	
Anode resistance	R_t	min.	5 Ω

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*) Maximum averaging time (T_{av}) 5 sec.

RECTIFYING TUBE TYPE 1838

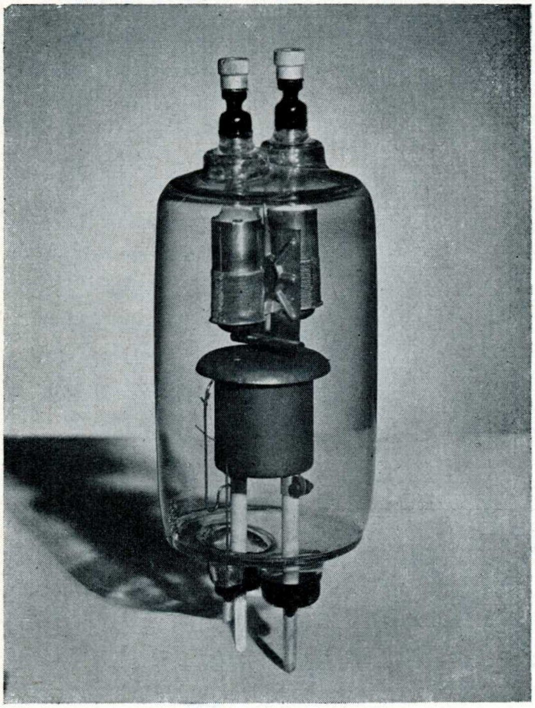

69627

Fig. 85. The rectifying tube type 1838.

The 1838 is a directly heated mercury vapour and inert gas-filled, double-anode rectifying tube specially designed for use in cinema rectifiers. It is also suitable for application in rectifiers such as are used for book-keeping machines and in battery chargers.

The special design together with a rigid construction give the tube years of reliable service. The maximum permissible peak inverse voltage is 360 V, and the tube is capable of delivering a D.C. output current of 15 A.

The tube is provided with an auxiliary ignition electrode, a_h, which should be connected to an auxiliary D.C. source, as for example the Auxiliary Ignition Unit type 1289, a description of which is given on p. 103.

The conditions under which this tube should be used in cinema rectifiers are described on p. 54, and the commonly used circuit diagrams are represented in figs 48 to 52.

In industrial applications the 1838 should be used under the conditions mentioned on p. 29 under "Industrial Rectifiers". The circuit diagrams are shown in figs 30, 34, 36 and 37, but since the 1838 is of the double-anode type, each pair of tubes represented in these circuits must be replaced by one 1838 tube. The maximum D.C. output voltages and currents obtainable are given in the table on p. 114, the figures being derived from practical circuits.

Circuit diagrams for the use of the 1838 in battery chargers are represented in figs 8 and 9. The maximum number of Pb-cells which can be charged in series with this tube is 40.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		21.5 A
Heating-up time	T_h	min.	2 min *)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	10 V
Ignition voltage	V_{ign}	22 V †)

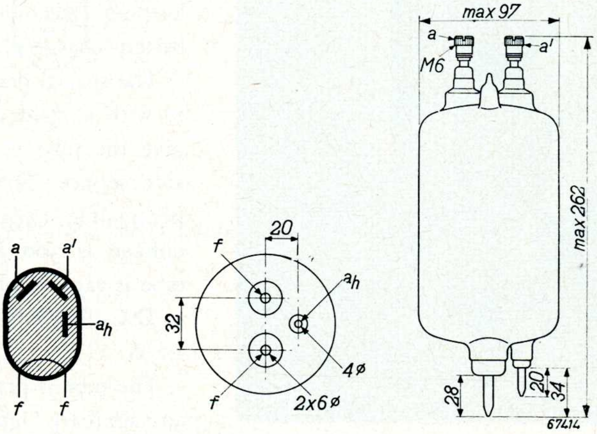


Fig. 86.

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 86)

Mounting position	vertical, base down
Base	special 3-pin
Socket	1285
Net weight	500 g
Shipping weight	1400 g

---

*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 60 sec.

†) In order to obtain the low ignition voltage of 22 V, an auxiliary D.C. supply unit delivering at least 40 V, 10 mA should be connected to the ignition electrode a_h, via a current-limiting resistor.

TYPICAL OPERATING CONDITIONS

Circuit	Transformer voltage V_{tr} (V_{rms})	Output voltage V_o (V)	Output current I_o (A)
Fig. 30	115	85	15
Fig. 34	115	120	30
Fig. 36	105	120	45
Fig. 37	115	110	45

LIMITING VALUES (absolute maxima)

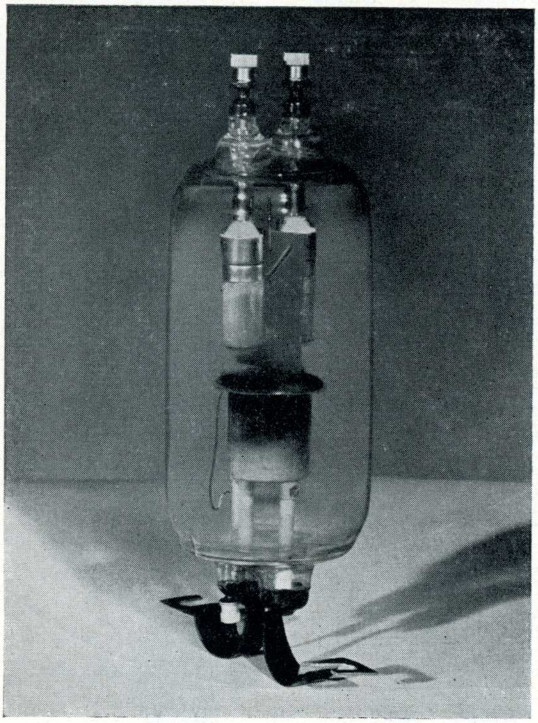
Peak inverse voltage	V_{invp}	max.	360 V
Output current (per anode)	I_a	max.	7.5 A ‡)
Peak anode current	I_{ap}	max.	45 A
Surge current	I_{surge}	max.	375 A §)
Temperature of mercury vapour	t_{Hg}	max.	30—80 °C
Anode resistance	R_t	min.	0.25 Ω

---

‡) Maximum averaging time (T_{av}) 5 sec.

§) Maximum duration 0.1 sec.

RECTIFYING TUBE TYPE 1849



69629

Fig. 87. The rectifying tube type 1849.

The 1849 is a directly heated, mercury vapour and inert gas-filled, double-anode rectifying tube specially designed for use in cinema rectifiers. It is also suitable for application in rectifiers such as are used for book-keeping machines and for feeding D.C. mains, and in battery chargers.

The special design, combined with a rigid construction ensure a long life. The maximum D.C. output current per tube is 25 A, and the maximum permissible peak inverse voltage amounts to 360 V.

The tube is provided with an auxiliary ignition electrode, a_h, which should be connected to an auxiliary D.C. source, as for example the Auxiliary Ignition Unit type 1289, a description of which is given on p. 106.

The conditions under which this tube should be used in cinema rectifiers are described on p. 54, and the commonly used circuit diagrams are represented in figs 48 to 52.

The maximum values of the D.C. output currents obtainable when using the 1849 tube can be read from the table on p. 114.

In industrial applications, the 1849 should be used under the conditions described on p. 29 under "Industrial Rectifiers". The circuit diagrams are given in figs 30, 34, 36 and 37, but since the 1849 is of the double-anode type, each pair of tubes represented in these diagrams must be replaced by one 1849 tube. The maximum D.C. output voltages and currents obtainable are given in the table on p. 114, the figures being derived from practical circuits.

Circuit diagrams for the use of the 1849 in battery chargers are represented in figs 8 and 9. The maximum number of Pb-cells which can be charged in series with this tube is 40.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.		
Filament voltage	V_f		1.9 V
Filament current	I_f		29 A
Heating-up time	T_h	min.	2 min*)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	10 V
Ignition voltage	V_{ign}	28 V†)

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 88)

Mounting position	vertical, base down
Net weight	600 g
Shipping weight	2400 g

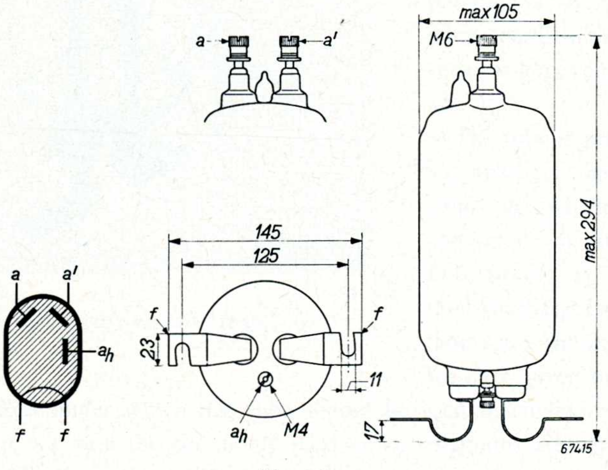


Fig. 88.

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*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 60 sec.

†) In order to obtain the low ignition voltage of 22 V, an auxiliary D.C. supply unit delivering at least 40 V, 10 mA should be connected to the auxiliary anode a_h, via a current-limiting resistor.

TYPICAL OPERATING CONDITIONS

Circuit	Transformer voltage V_{tr} (V_{rms})	Output voltage V_o (V)	D.C. output current I_o (A)
Fig. 30	115	85	25
Fig. 34	115	120	50
Fig. 36	105	120	75
Fig. 37	115	110	75

LIMITING VALUES (absolute maxima)

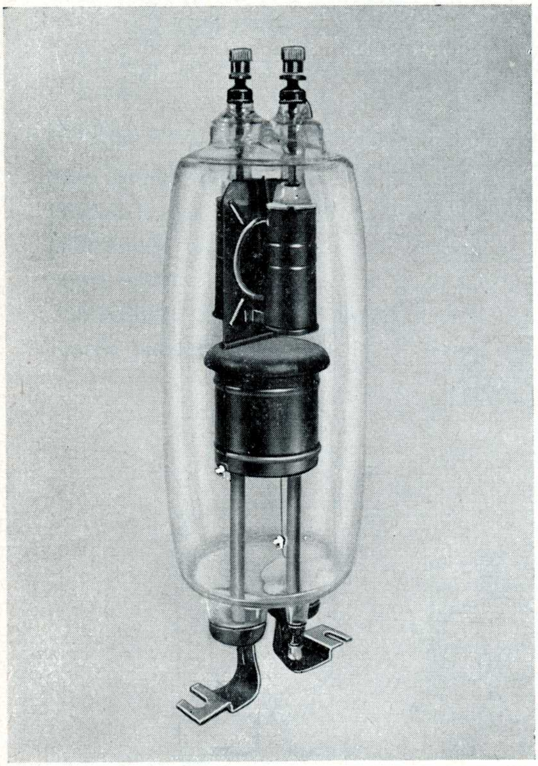
Peak inverse voltage	V_{invp}	max.	360	V
Output current (per anode)	I_a	max.	12.5	A ‡)
Peak anode current	I_{ap}	max.	75	A
Surge current	I_{surge}	max.	625	A §)
Temperature of mercury vapour	t_{Hg}	max.	30—80	°C
Anode resistance	R_t	min.	0.2	Ω

---

‡) Maximum averaging time (T_{av}) 15 sec.

§) Maximum duration 0.1 sec.

RECTIFYING TUBE TYPE 1859



70828

Fig. 89. The rectifying tube 1859.

The 1859 is a directly heated mercury vapour and inert gas-filled, double-anode rectifying tube for use in cinema rectifiers. It is also suitable for application in rectifiers, such as are used for bookkeeping machines, for feeding D.C. mains and in battery chargers.

The special design and rigid construction give the tube a long life. The maximum D.C. output current per tube is 50 A, the maximum permissible peak inverse voltage amounting to 360 V.

The tube is provided with an auxiliary ignition electrode, a_h, which should be connected to an auxiliary D.C. source, as for example the Auxiliary Ignition Unit type 1289, the description of which is given on p. 106.

The conditions under which this tube should be used in cinema rectifiers are described on p. 54, and the commonly used circuit diagrams are represented in figs 48 to 52. The maximum values of the D.C. output currents obtainable when using the 1859 tube can be read from the table on p. 114.

In industrial applications, the 1859 should be used under the conditions given on p. 114 under "Industrial Rectifiers". The circuit diagrams are shown in figs 30, 34, 36 and 37, but since the 1859 is of the double-anode type, each pair of tubes represented in these circuits must be replaced by one 1859 tube. The maximum D.C. output voltages and currents obtainable are given in the table on p. 114, the figures being derived from practical circuits.

Circuit diagrams for the use of the 1859 tube in battery chargers are represented in figs 8 and 9. The maximum number of Pb-cells which can be charged in series with this tube is 40.

TECHNICAL DATA

FILAMENT DATA

Heating	direct by A.C.	
Filament voltage	V_f	1.9 V
Filament current	I_f	60 A
Heating-up time	T_h	2 min*)

TYPICAL CHARACTERISTICS

Arc voltage	V_{arc}	12 V
Ignition voltage	V_{ign}	28 V†)

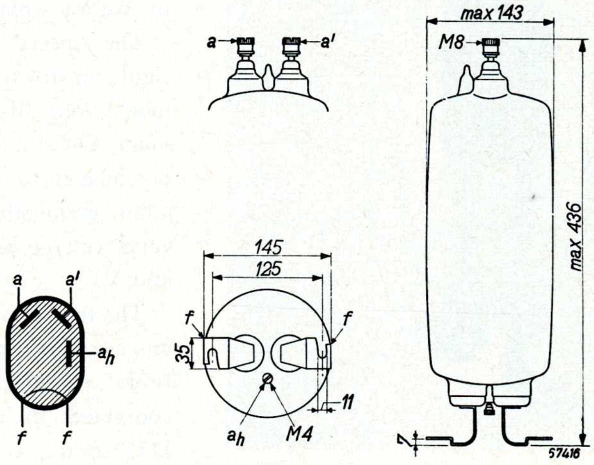


Fig. 90.

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 90)

Mounting position	vertical, base down
Net weight	1650 g
Shipping weight	3800 g

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*) The value given is the recommended minimum heating time. If urgently wanted, this value may be decreased to 60 sec.

†) In order to obtain the low ignition voltage of 28 V, an auxiliary D.C. supply unit delivering at least 40 V, 10 mA should be connected to the ignition electrode a_h, via a current-limiting resistor.

TYPICAL OPERATING CONDITIONS

Circuit	Transformer voltage V_{tr} (V_{rms})	Output voltage V_o (V)	D.C. output current I_o (A)
Fig. 30	115	85	50
Fig. 34	115	120	100
Fig. 36	105	120	150
Fig. 37	115	110	150

LIMITING VALUES (absolute maxima)

Peak inverse voltage	V_{invp}	max.	360 V
Output current (per anode)	I_a	max.	25 A ‡)
Peak anode current	I_{ap}	max.	150 A
Surge current	I_{surge}	max.	1250 A §)
Temperature of mercury vapour	t_{Hg}	max.	30—80 °C
Anode resistance	R_t	min.	0.1 Ω

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‡) Maximum averaging time (T_{av}) 20 sec.

§) Maximum duration 0.1 sec.

AUXILIARY EQUIPMENT

AUXILIARY IGNITION UNIT TYPE 1289

In order to facilitate the ignition of the 1173, 1174, 1176, 1177, 1838, 1849 and 1859 tubes, they have been provided with an auxiliary ignition electrode. This electrode should be connected, via a current-limiting resistor, to an auxiliary D.C. source delivering about 40 V, 10 mA power. For this purpose use can be made of the Auxiliary Ignition Unit type 1289, the circuit diagram of which is given in fig. 91.

It contains a small metal rectifier, *Sl*, and a simple *RC* filter. The unit is suitable for one, two or three tubes, the auxiliary ignition electrodes, a_h, being connected to the positive terminals and the cathodes to the negative terminal.

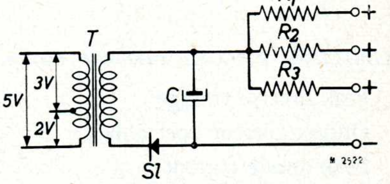


*Fig. 91. **Circuit diagram of the Auxiliary Ignition Unit type 1289.***

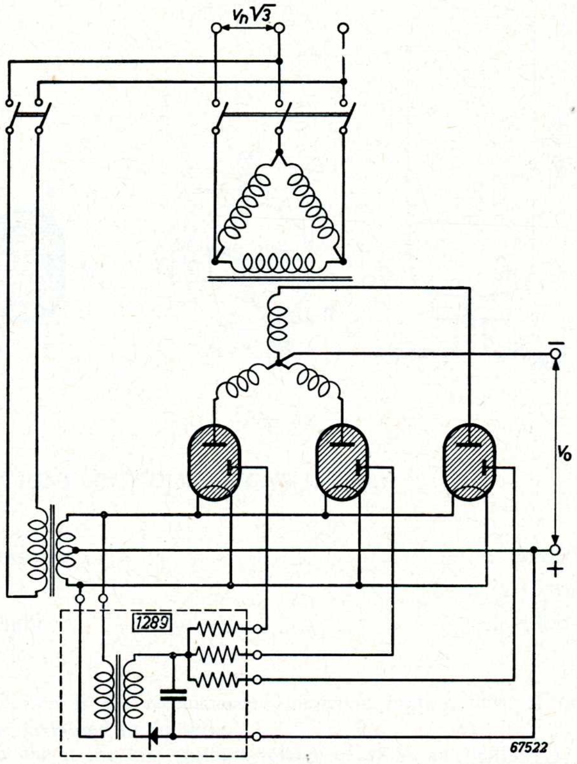


Fig. 92. Basic circuit diagram for a three-phase half-wave rectifying circuit using the Auxiliary Ignition Unit type 1289.

The primary of the built-in transformer can be connected with its 2 V tap to the filament supply voltage of one tube. A basic circuit diagram is given in fig. 92 for a three-phase half-wave rectifying circuit using three tubes with auxiliary ignition electrodes.

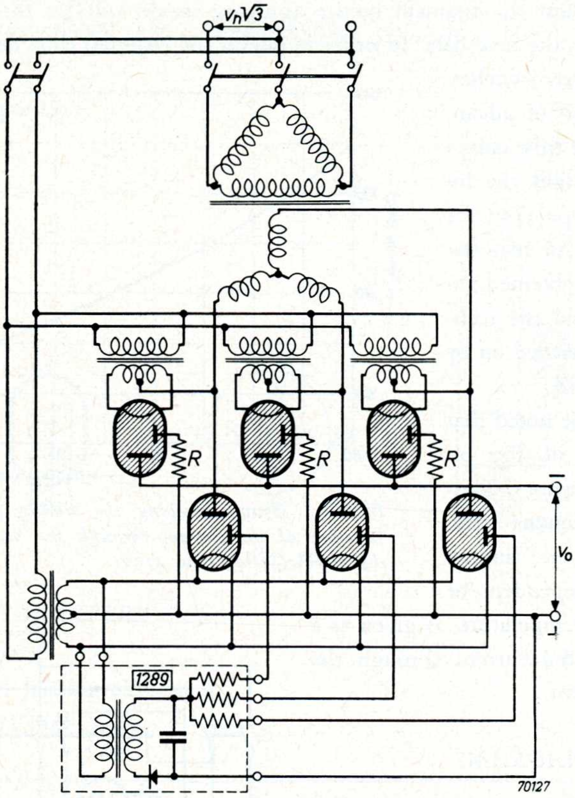


Fig. 93. ***Basic circuit diagram for a three-phase full-wave rectifying circuit using the Auxiliary Ignition Unit type 1289.***

According to this method, a three-phase full-wave (bridge) circuit would require 1 + 3 ignition units. It has, however, proved possible to simplify such a circuit considerably by using the D.C. output voltage of the rectifier for feeding the auxiliary ignition electrode. Instead of 1 + 3, only one ignition unit and three resistors for limiting the current to the auxiliary ignition electrodes are then required. The circuit diagram is represented in fig. 93. The resistors *R* must have such a value that the mean value of the current flowing to the auxiliary ignition electrodes is approx. 10 mA. Temporarily, the instantaneous value of the voltage supplied to the auxiliary ignition electrodes will become slightly negative, but this is not objectionable.

A similar circuit can be worked out for a two-phase full-wave and a four-phase full-wave circuit.

BIMETAL RELAY TYPE 4152

When starting up a rectifier equipped with gasfilled rectifying tubes, it is necessary to heat the filament before applying anode voltage, the time required being given in the tube data. In order to obtain the required time delay, use can be made of separate switches. It is, however, of advantage to use for time delays up to 2 minutes the bimetal relay type 4152 for this purpose, so that the time delay is obtained automatically and the rectifier can be swiched on by only one switch.

It should be noted that the contacts of the bimetal relay are not designed for continuous load. In fig. 94 the timing, which is independent of the ambient temperature, is given as a function of the current through the heating element.

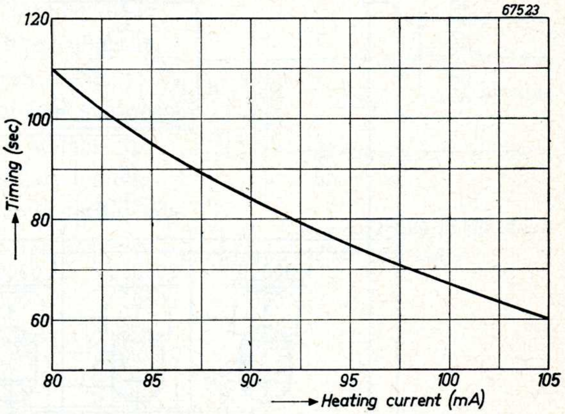


Fig. 94. Graph showing the timing in seconds as a function of the current through the heating element of the bimetal relay type 4152.

CIRCUIT DIAGRAMS

In fig. 95 an example is given of a rectifier using the bimetal relay type 4152.

With switch S^1 the filament transformer is switched on, whilst also current starts to flow through the coil *Rel* of the switch S^2, the resistor *R* and the heating element of the bimetal relay. After a certain interval of time, the bimetal relay will close, thereby short-circuiting the resistor *R* and the heating element, so that the current through *Rel* will reach such a value as

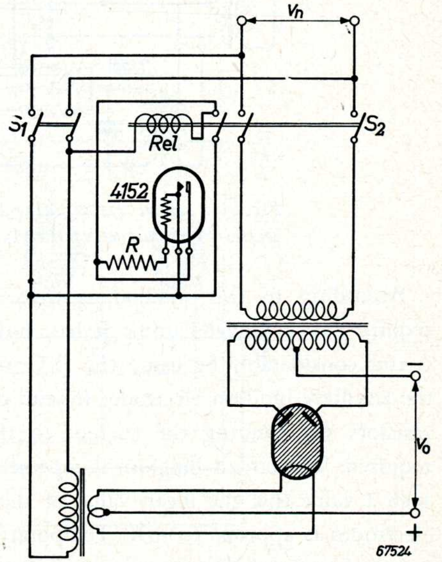


Fig. 95. Two-phase half-wave rectifying circuit using the bimetal relay type 4152.

to close switch S^2. The time interval can be adjusted to the correct value by choosing a suitable value for the resistors *R*. As soon as switch S^2 is closed, the bimetal relay is short-circuited and the coil *Rel* remains energized via a contact on S^2.

TECHNICAL DATA

BASE CONNECTIONS AND DIMENSIONS (in mm)

(see fig. 96)

Mounting position	vertical, base down
Base	A-type
Socket	40465

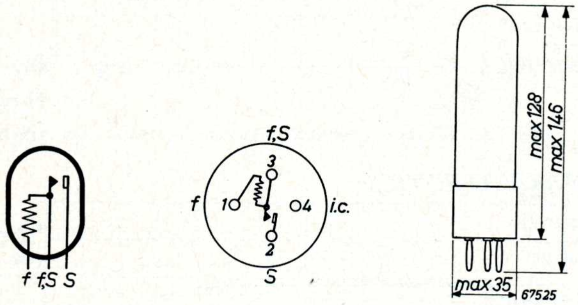


Fig. 96.

TYPICAL CHARACTERISTICS

Heating current	92 mA ± 13%
Resistance of heating element	340—372 Ω
Timing at 92 mA	60—100 sec.

Operating voltage	Max. value of switching-on current	Max. value of switching-off current
220 V D.C.	1.5 A	250 mA
220 V A.C.	1.5 A	250 mA
380 V A.C.	0.7 A	75 mA

BARRETTERS

Barretters can be used when the output current of a rectifier has to be kept constant within certain limits, independently of mains voltage fluctuations or variations in the load.

They are used, for example, in battery chargers, in order to compensate the decrease of the battery current resulting from the rise in battery voltage during the charging, and the influence of mains voltage fluctuations on the output current. Also when the number of battery cells is varied between given limits, the current will be kept practically constant.

Below, data are given for the barretters types 329 and 340, which can be used in combination with the rectifying tubes listed in this Bulletin, the r.m.s. current values being stabilized at 1.1 and 5.9 A respectively. For higher values of the output current of the rectifier, it is possible to connect two or more barretters of the same type in parallel.

BARRETTER TYPE 329

BASE CONNECTIONS AND DIMENSIONS (in mm)
(see fig. 97)

Mounting position	any
Base	H-type
Socket	40465

TYPICAL CHARACTERISTICS

Stabilized current	1.1 A
Working range	10—30 V

BARRETTER TYPE 340

BASE CONNECTIONS AND DIMENSIONS (in mm)
(see fig. 98)

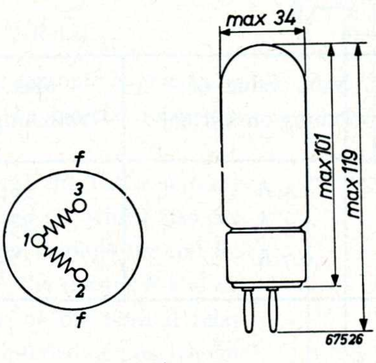


Fig. 97.

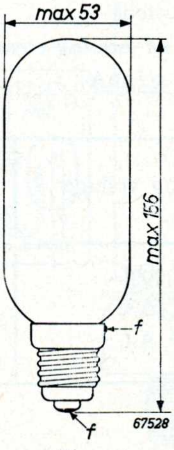


Fig. 98.

Mounting position	any
Base	Edison
Socket	E3 000 22

TYPICAL CHARACTERISTICS

Stabilized current	5.9 A
Working range	3—10 V

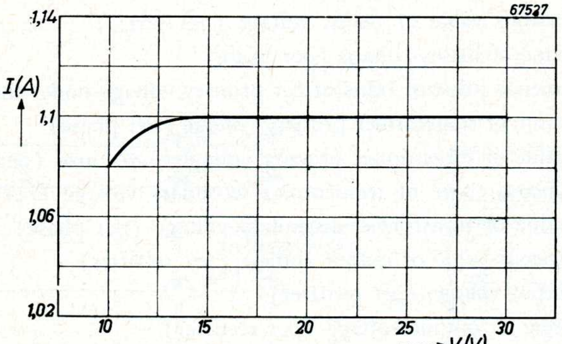


Fig. 99. Current/voltage characteristic of the 329 tube.

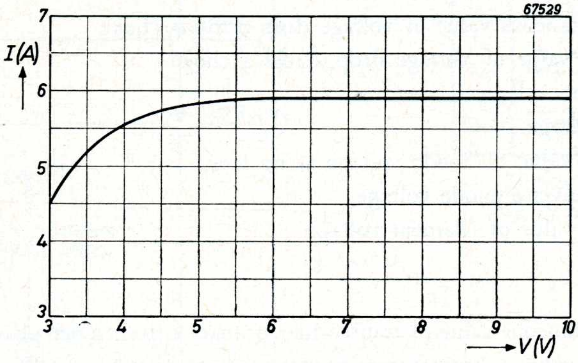


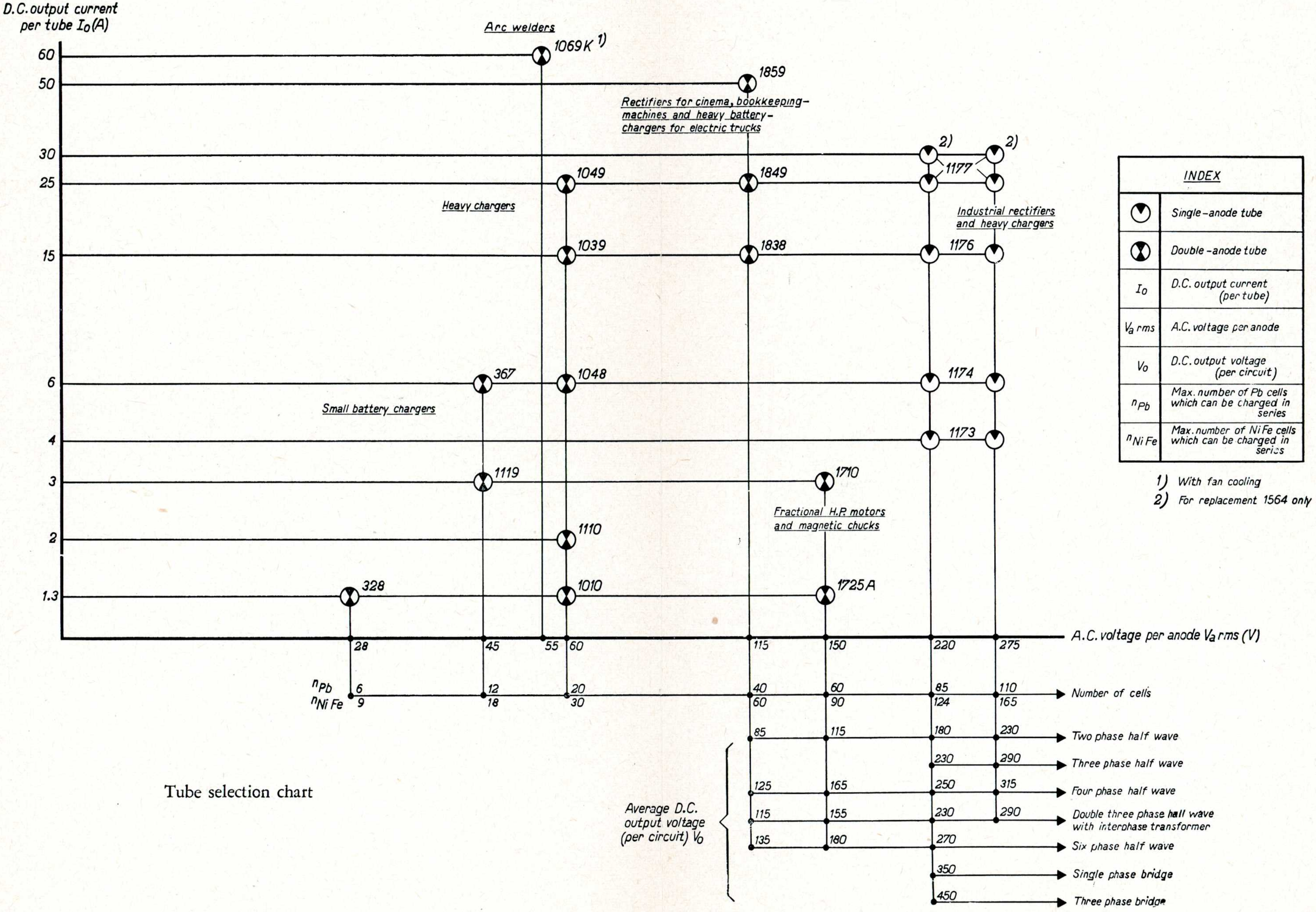
Fig. 100. Current/voltage characteristic of the 340 tube.

GLOSSARY OF SYMBOLS

Symbol	Definition
Voltages	
v_n	instantaneous value of mains voltage (per phase)
V_n	r.m.s value of mains voltage (per phase)
v_1'	instantaneous value of transformer primary voltage under load (per phase)
V_1'	r.m.s. value of transformer primary voltage (per phase)
V_1	r.m.s. value of transformer primary voltage under load (per phase)
v_{tr}	instantaneous value of transformer secondary voltage (per phase)
V_{tr}	r.m.s. value of transformer secondary voltage (per phase)
v_o	instantaneous value of output voltage (per rectifier)
V_o	D.C. output voltage (per rectifier)
$V_{o\,\mathrm{p}}$	peak value of output voltage (per rectifier)
V_b	nominal battery voltage; back e.m.f.
$V_{b\,\mathrm{max}}$	maximum battery voltage
V_{bc}	voltage per battery cell
v_L	instantaneous value of voltage drop across a choke
	r.m.s. value of voltage drop across a choke
V_{ign}	ignition voltage
V_{arc}	arc voltage
$V_{a\,\mathrm{rms}}$	r.m.s. value of anode voltage at no load
$V_{\mathrm{inv\,p}}$	peak inverse anode voltage
V_f	r.m.s. value of filament voltage
Currents	
i_1	instantaneous value of transformer primary current (per phase)
I_1	r.m.s. value of transformer primary current (per phase)
I_2	r.m.s. value of transformer secondary current (per phase)
i_o	instantaneous value of output current (per rectifier)
I_o	D.C. output current (per rectifier)
$I_{o\,\mathrm{p}}$	peak value of output current (per rectifier)
i_a	instantaneous value of anode current
I_a	D.C. anode current
$I_{a\,\mathrm{rms}}$	r.m.s. value of anode current
$I_{a\,\mathrm{p}}$	peak value of anode current
I_f	r.m.s. value of filament current
Impedances	
R_{tr}	equivalent resistance of transformer secondary (per phase)
R_t	total secondary circuit resistance (per phase)

Symbol	Definition
R_a	additional anode resistance
Z_a	total anode impedance
Z_a'	additional anode impedance
R_o	load resistance
Powers	
W_o	D.C. output power (per rectifier)
W_f	filament power
W_{arc}	arc losses
$(VA)_1$	apparent power in primary windings of transformer
$(VA)_2$	apparent power in secondary windings of transformer
$(VA)_t$	apparent power for the transformer
$(VA)_L$	apparent power loss in choke
W_{Ra}	power loss in additional anode resistor
Miscellaneous	
m_1	number of primary phases
m_2	number of secondary phases
μ	voltage ratio of transformer (V_{tr}/V_1)
k_1	proportionality factor
k_2	mains fluctuation safety factor
β	D.C./A.C. voltage ratio
γ	V_{tr}/V_o
δ	$V_{a\,\text{rms}}/V_{tr}$
σ	$V_{\text{inv}\,\text{p}}/V_{tr}$
τ	I_a/I_o
n_b	number of battery cells connected in series
f	form factor
f_p	peak factor
B	$\sqrt{1-\beta^2}-\beta \arccos \beta$ (see p. 13)
w_{ct}	weight of transformer core
w_{cL}	weight of choke core
η_v	efficiency of the tube
η_i	efficiency of the installation
T_h	pre-heating time of filament
T_{av}	averaging time
t	time
ν	frequency

TABLE XII



Tube selection chart

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