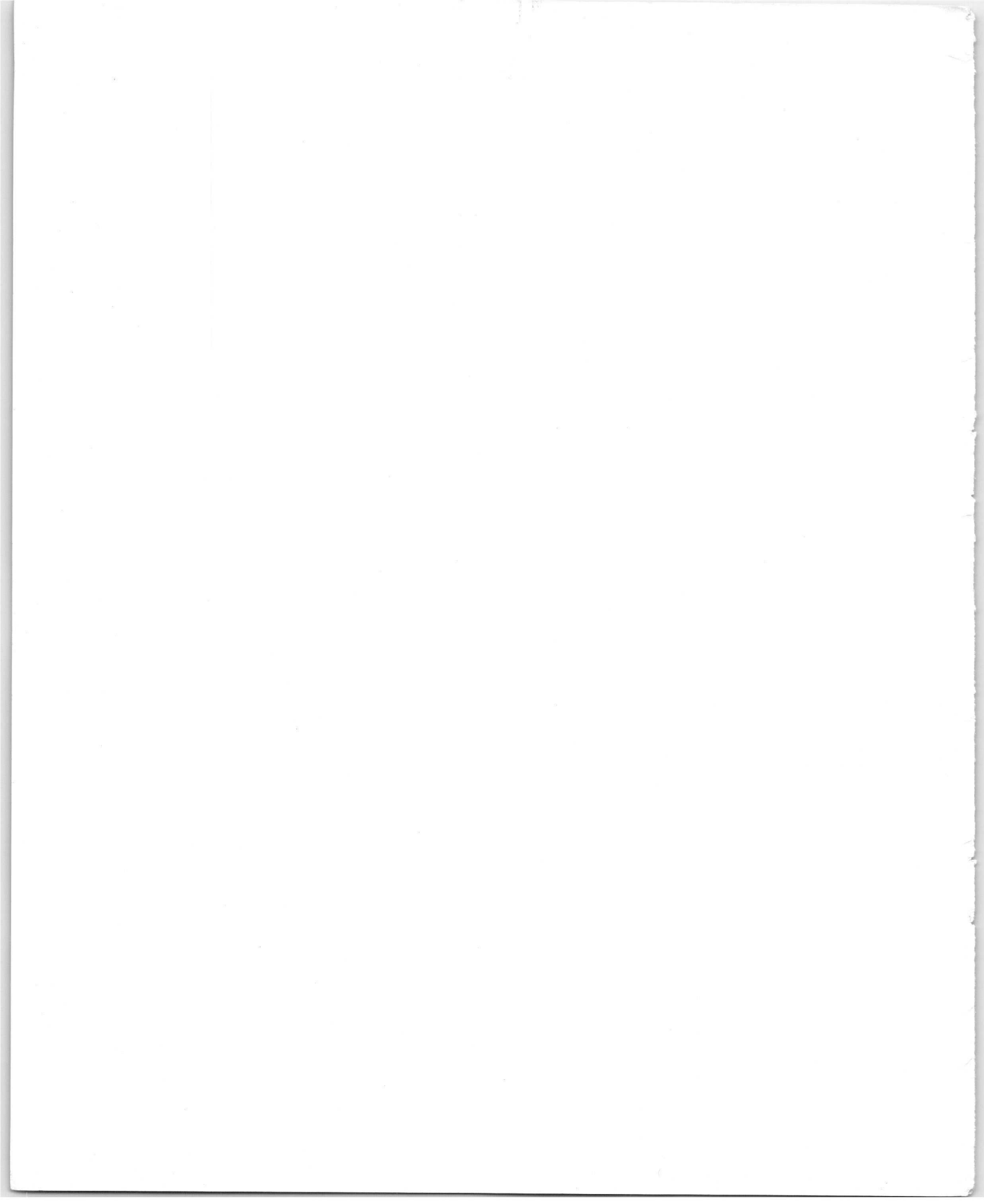


Thyratrons

FOR INDUSTRIAL CONTROL

Mullard

THYRATRONS FOR INDUSTRIAL CONTROL

Circuit Specifications

Comprehensive Control System for a DC Motor (Fig. 24, page 23)

$R_1 = 47k\Omega$	1W	$*P_1 = 20k\Omega$	5W
$R_2 = 470k\Omega$	0.5W	$P_2 = 10k\Omega$	1W
$R_3 = 470k\Omega$	0.5W	$C_1 = 2.0\mu F$	
$R_4 = 470k\Omega$	0.5W	$C_2 = 0.1\mu F$	
$R_5 = 4.7k\Omega$	0.5W	$C_3 = 0.47\mu F$	
$R_6 = 10k\Omega$	1W	$C_4 = 0.1\mu F$	
$*R_7 = 10k\Omega$	12W	$C_5 = 0.1\mu F$	
$*R_8 = 10\Omega$	12W	$C_6 = 0.1\mu F$	
$*R_9 = 100k\Omega$	0.5W	$C_7 = 4700pF$	
$R_{10} = 33k\Omega$	0.5W	$C_8 = 4700pF$	
$R_{11} = 33k\Omega$	0.5W	$V_1 = EB91$	
$*R_{12} = 100k\Omega$	0.5W	$V_2 = ECC81$	
$*R_{13} = 10\Omega$	12W	$V_3 = EB91$	
$R_{14} = 20k\Omega$	3W	$V_4 =$	} thyatron appropriate to motor rating
$*R_{15} = 560\Omega$	1W	$V_5 =$	
$R_{16} = 10k\Omega$	1W	$V_6 = GZ32$	
$R_{17} = 100\Omega$	0.5W	$NL_1 =$	"Metrosil", 5mA at 50V
$R_{18} = 100\Omega$	0.5W	$NL_2 =$	"Metrosil", 1mA at 230V

$T_1 =$ auxiliary transformer with secondary windings: 150-30-0-30-150 V, 10mA; and 6.3V, 2A.

$T_2 =$ mains transformer with secondary windings: 325-300-275-0-275-300-325 V; 5V, 2A for GZ32 heater; and an appropriate heater winding for V4 and V5.

$T_3 =$ Current transformer with two primary windings, rated for current in thyratrons, with the secondary designed to give 150-0-150 V, 50mA_(r.m.s.) at full rated primary current.

$R/2 =$ telephone relay with a coil resistance of 2k Ω .

* The values of these components will be affected by the rating of the motor and the size of thyatron employed. Guiding values are quoted.

R_{10} , R_{11} , C_5 , and C_6 should be $\pm 5\%$ tolerance components.

A similar circuit was published by A. L. Whiteley in "The Engineer", Vol. 186, 1948, p. 219, under the title "Electronic Control of Motors."

Single-Cycle Timer for a Small Spot Welder (Fig. 25, page 24)

The heater voltages shown (windings S2 and S4) are for the XG1-2500. If some other mercury vapour thyratron is used for V2 and V3, the appropriate heater voltage must be provided.

Peaking transformer T2

Primary	5000 turns, 47 SWG
Secondary	10,000 turns, 47 SWG
Bobbin*	1.6 × 6 × 20mm

Laminations 4, Mu-metal: as shown in Fig. 25(a)

The windings should finish at the neutral line side of the transformer.

Follow on transformer T3 Fig. 25(b)

Primary (1)	100 turns, 22 SWG
Grid Winding (2)	3000 turns, 47 SWG
D.C. Winding (3)	2000 turns, 47 SWG
Bobbin*	2.4 × 6 × 10mm

Laminations 6, Mu-metal: as shown in Fig 25(a)

*A larger bobbin may be used, but the lamination specification must not be varied. The laminations are stacked alternately, with the bobbin (whatever its dimensions) on one of the long sides of the rectangle.

Low-power Self-excited Inverter (Fig. 31, page 27)

Transformer

Primary:	2 × 1200 turns enam. copper 0.35mm diam.
Secondary WS1:	1300 turns enam. copper 0.32mm diam.
Secondary WS2:	2 × 300 turns enam. copper 0.1mm diam.
Secondary WS3:	80 turns enam. copper 0.7mm diam.
Laminations	as in Fig. 31(a).

Choke

Winding: 1200 turns of enam. copper 0.45 mm diam.; air gap 0.5 mm. Laminations as in Fig. 31(b).

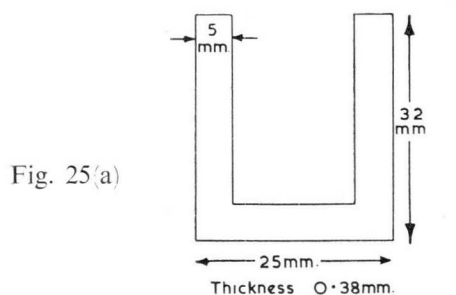


Fig. 25(a)

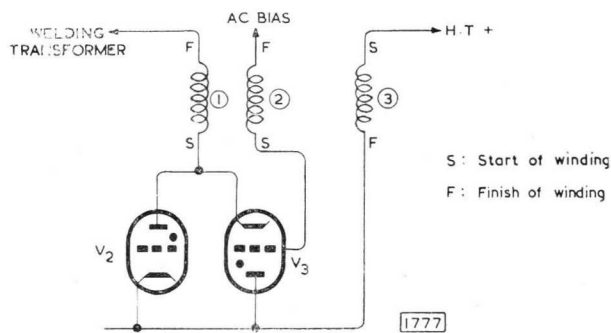


Fig. 25(b)

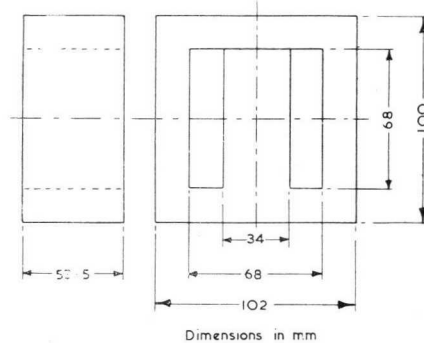


Fig. 31(a)

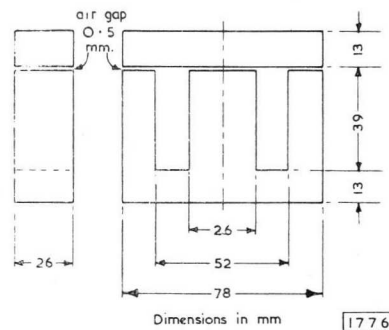


Fig. 31(b)

THYRATRONS

for industrial control



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patented feature.*

PUBLISHED BY THE TECHNICAL SERVICE DEPARTMENT FOR THE COMMUNICATIONS
AND INDUSTRIAL VALVE DEPARTMENT,

MULLARD LIMITED

CENTURY HOUSE, SHAFTESBURY AVENUE, LONDON, W.C.2

1954

FOREWORD

The increasing use in industry of electronic methods of measurement and control has led to the development of many thyatron and thyatron circuits. The thyatron is capable of controlling currents up to about 20 amperes at normal supply voltages. It is particularly suitable where precise control, rapid response, and a low loss of power in the control operation are necessary. Its many applications include motor and welder control, power regulation, the inversion of d.c. to a.c., relay operation, the control of a variety of industrial processes, and the regulation of lighting. Mullard produce suitable gasfilled or mercury vapour thyatrons for all these purposes.

This publication is intended to be a guide to users of thyatrons. A practical description of thyatron operation is followed by a discussion of valve ratings and their significance in circuit design. Full technical information is given for the Mullard range of thyatrons (with the exception of the hydrogen-filled types, which are intended primarily for use as pulse modulators). A separate section discusses practical applications and includes illustrative circuits and general design considerations.

Further study of thyatrons and their circuits is assisted by the bibliography. Practical advice on specific applications will gladly be given to industrialists and circuit designers by Mullard Ltd.

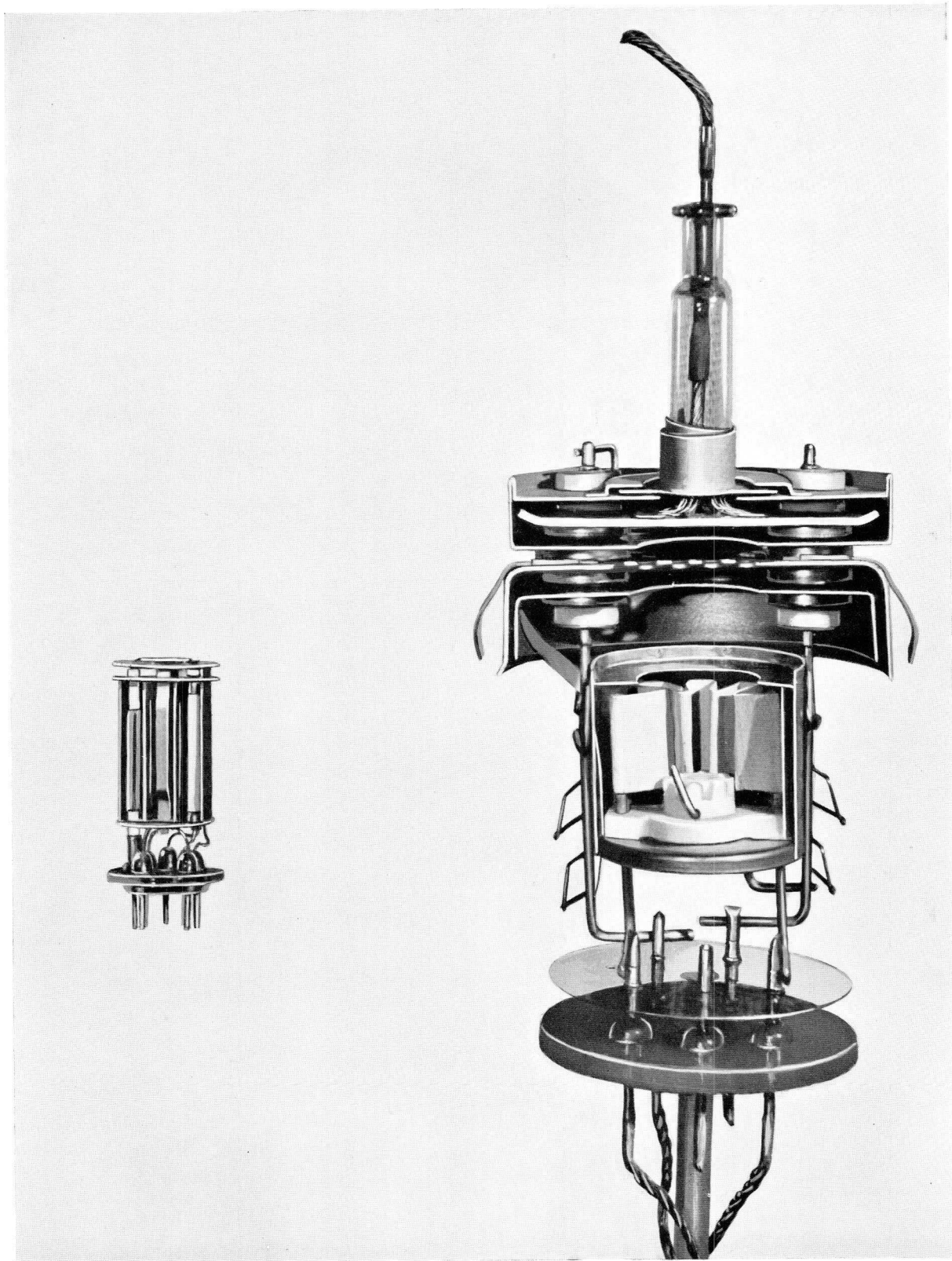


FIG. 1. CUT-AWAY VIEWS OF TWO TYPICAL THYRATRONS

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DEFINITIONS

Heating Time

The time required for a valve to attain minimum operating temperature with normal voltage applied to the heating element. For a mercury vapour valve this time is generally much longer than that required to bring the cathode to the normal operating temperature.

Anode Voltage Drop or Arc Voltage

The potential difference between anode and cathode during conduction.

Control Characteristic

A relation, usually depicted graphically, between the critical grid voltage and the anode voltage.

Control Ratio

The slope of the straight part of the control characteristic.

Critical Grid Voltage

The instantaneous value of grid voltage at which anode current commences to flow.

Critical Grid Current

The instantaneous value of grid current immediately before anode current commences to flow.

Commutation Factor

The product of the rate of anode current decay ($A/\mu\text{sec}$) and the rate of the initial inverse anode voltage rise ($V/\mu\text{sec}$) immediately following the current decay. These values should, in practice, be taken as the average rate of current decay over the last 10 μsecs of current conduction, and the average rate of inverse voltage rise over the first 200V.

Deionisation Time

The time between the cessation of anode current and the instant when the grid regains control.

Ionisation Time

The time required under specified conditions for the anode current to rise to 90 per cent of its rated peak value, the time being measured from the instant of application of critical grid voltage.

Maximum Averaging Time

The longest period of time over which it is permissible to compute the maximum average value of the characteristic under consideration.

Condensed Mercury Temperature

The temperature of the external surface of that part of the valve envelope at which the mercury is seen to condense during normal operation of the valve.

GENERAL DESCRIPTION AND OPERATING PRINCIPLES

MODE OF OPERATION

The thyatron is basically a three-electrode valve with a thermionic cathode, an anode, and a control electrode or grid. It contains either a gas (which is usually one of the rare atmospheric gases or a mixture of two of them), or mercury vapour which is in equilibrium with liquid mercury.

When a positive potential is applied to the anode the valve will not conduct until the grid is raised to or above a critical voltage. Electrons from the cathode will then have sufficient energy to ionise the gas and establish an arc discharge between anode and cathode. The valve is now conducting normally and is said to be *struck*. The presence of the ionised gas makes the potential difference between anode and cathode (usually referred to as the *arc voltage* or *anode voltage drop*), virtually independent of the anode current and approximately equal to the ionisation potential of the gas.

Provided the limits of electron emission and gaseous conduction are not exceeded, the current through the valve will be limited only by the impedance of the external circuit, and will not be space-charge limited as in a high vacuum valve. As soon as conduction is established the influence of the grid is neutralised by the ionised gas, and the arc can only be extinguished by reducing the anode voltage below the arc voltage. After the cessation of current through the valve there is a finite time before the grid regains control and once again prevents conduction. This is called the *deionisation time*.

To summarise, a thyatron behaves as a uni-directional switch which is "closed" by the grid circuit and "opened" by the anode circuit.

CONSTRUCTION

The construction of two typical thyatrons is shown in Fig. 1. The larger valve is the Mullard XR1-6400, with an average cathode current rating of 6.4 amperes. The smaller valve, rated for an average cathode current of 100 milliamperes, is the Mullard EN91.

Thyatron envelopes are usually of glass, which provides good insulation and a robust and economic construction. The larger thyatrons usually have directly-heated cathodes with efficient heat shields to reduce thermal loss. In the smaller types a box structure is used, serving as an electrostatic screen and also as a heat shield for the indirectly-heated cathode.

GRIDS AND GRID CONTROL

Within the working range of a thyatron there is, for each value of anode voltage, a definite value of grid voltage at which the valve will start to conduct. This is known as the *critical grid voltage*. At a given anode voltage the valve will always conduct when the grid voltage is more positive than the critical value.

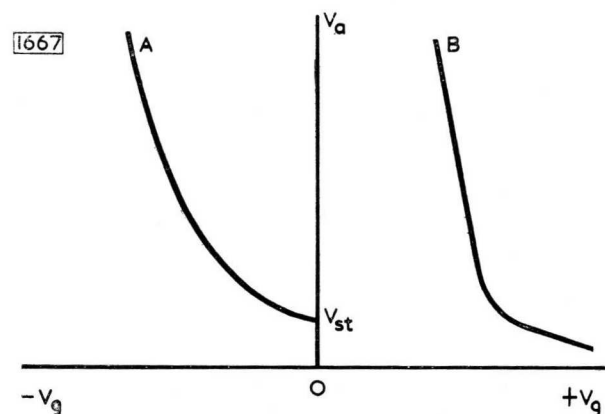


FIG. 2

A curve showing the relationship between the anode voltage and the critical grid voltage is known as the *control characteristic*.

Control Characteristics

Two typical curves are reproduced in Fig. 2. Curve A is for a valve having a negative control characteristic; that is to say, the critical grid voltage is negative with respect to the cathode. Curve B is for a valve having a positive control characteristic,

the critical grid voltage being positive with respect to the cathode.

Industrial thyratrons for control applications usually have a negative control characteristic. Such thyratrons require a negative grid bias when it is desired that the tube shall be non-conducting. This disadvantage is far outweighed by the fact that the valves do not, ideally, pass any grid current before conduction. The grid control voltage can therefore be provided by a high impedance source such as a voltage amplifying pentode of high mutual conductance. Only thyratrons with negative control characteristics are considered in this publication.

From curve A in Fig. 2 it will be seen that when the control grid is at cathode potential, the thyatron will *strike* (i.e. become conductive) at an anode voltage V_{st} . This voltage is an important characteristic since it represents the minimum anode voltage at which the thyatron retains its negative control characteristic. If it is desired to operate a thyatron at an anode voltage below V_{st} , conduction must be initiated by producing a low-current arc between the control grid and the cathode. With these conditions, often termed *positive firing*, it is necessary to feed the control grid from a source of lower impedance.

For any particular type of thyatron there will inevitably be small variations in critical grid characteristics, both from valve to valve and during the life of individual valves. These are due to dimensional variations in the electrode system, and to changes in valve temperature and cathode emission during operation. To indicate the extent of these variations, valve manufacturers usually quote a spread of critical grid voltage for each type of thyatron. The circuit designer must ensure that the particular grid circuit can accommodate any critical grid voltage within this band. It follows that, in general, the grid signal voltage must be large in comparison with the critical grid voltage. Since, however, the great majority of thyratrons have similar grid characteristics, standard control circuits can be designed for use with different types of thyatron.

Triode and Tetrode Thyratrons

Although the majority of thyatron applications require only one control electrode, many thyratrons are provided with a second electrode or shield grid which partially screens the control grid. The most important function of the second grid is to reduce the capacitance between the first grid and the anode, and

thus to reduce the extent to which the voltage of the first grid will follow any sudden change in the anode voltage. This obviously reduces the risk of random striking. Often the second grid serves also as a thermal screen for the first grid. If the temperature of the first grid is allowed to rise unduly it will emit electrons which will result in a spurious signal across the grid resistor, with a possible loss of control.

Many thyratrons incorporate a shield grid which is connected internally to the cathode. The valve is then nominally a triode. When, however, the shield grid connection is brought out to a separate base pin, the control characteristics can be modified by applying different potentials to this grid. A family of control

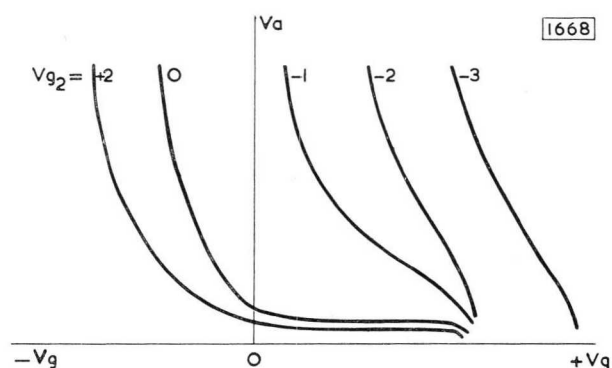


FIG. 3

characteristics, with the shield grid voltage as parameter, is given in Fig. 3. They show that by connecting the shield grid directly to the cathode, normal triode operation is obtained. If other potentials are applied to the shield grid, the control grid characteristic is changed. In fact the thyatron can be given a positive control characteristic if desired. An alternative mode of operation is to use the shield grid as a normal control electrode.

Grid Control

The normal method of striking a thyatron is to reduce the negative grid bias to the critical grid voltage value. If a d.c. voltage V_a is applied to the anode, the critical grid voltage $V_{g(crit)}$ can be represented by a straight line as indicated in Fig. 4. If the grid voltage is raised at the instant t from its hold-off bias value V_g to a value above $V_{g(crit)}$, the valve will strike. The anode voltage will then fall to the arc voltage, V_{arc} , and an output voltage, $V_a - V_{arc}$, will be available. To regain control the grid voltage must be made more negative than the critical value and the anode voltage must be reduced below the arc voltage.

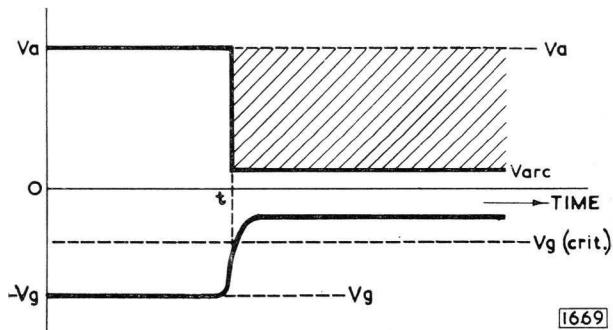


FIG. 4

When the anode of a thyatron is fed with a sinusoidal alternating voltage, the critical grid voltage $V_{g(crit)}$ will vary with the instantaneous value of V_a .

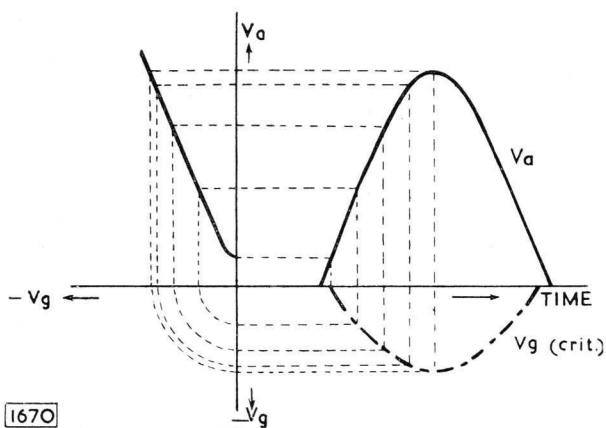


FIG. 5

This variation can be plotted from the control characteristic as shown in Fig. 5. If now a steady negative direct bias V_g is applied to the grid, the valve can be struck by neutralising the grid bias as indicated in Fig. 6. In this case, however, a time $t_1 - t$ must elapse before

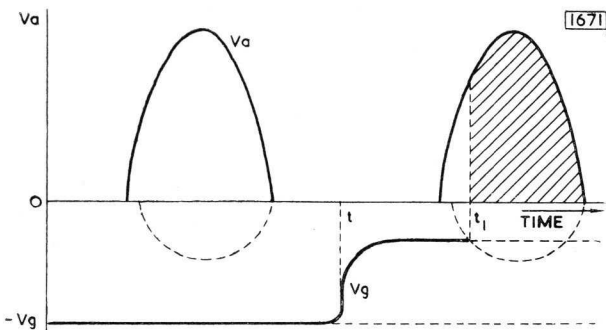


FIG. 6

the valve strikes, the duration of this delay depending on the instant at which the grid voltage was increased and the value to which it was raised. At the end of the positive half-cycle of V_a the anode voltage will be less than the arc voltage and the valve will automatically extinguish. With a single valve there is no conduction during negative half-cycles of the supply.

In many control applications thyratrons are fed from an alternating supply but are arranged to give a variable output voltage (either direct or alternating) by altering the time during which the thyratrons conduct in each half-cycle. This can be achieved by varying the instant at which each thyatron strikes.

Fig. 7 shows the basic connection for a bi-phase

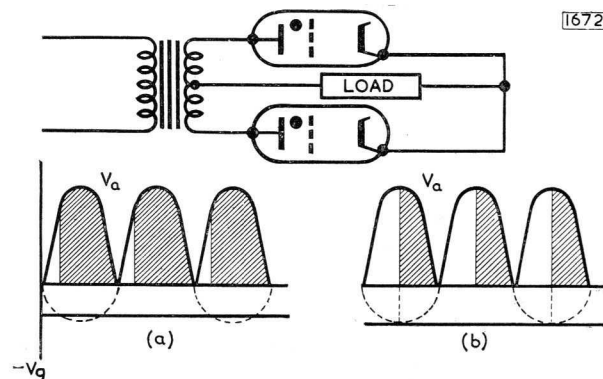


FIG. 7

rectifier employing two thyratrons. At (a) the valves are made to strike early in each half-cycle and a large unidirectional output is obtained. At (b) striking is delayed and the output is smaller. The arrangement in Fig. 8 is similar, but the valves are connected back-to-back to give an alternating output.

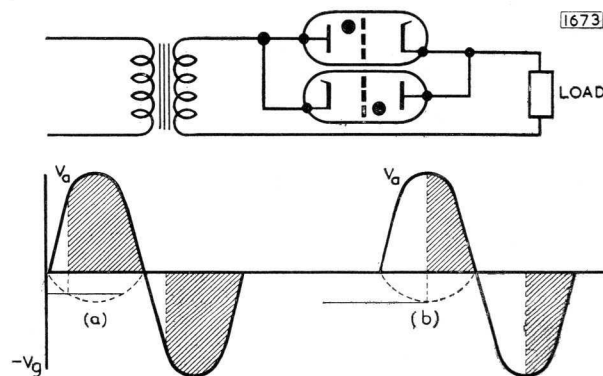


FIG. 8

As already explained, the control characteristics of a particular type of thyatron vary both from valve to valve and also for any one valve during its life. Allowances for this must be made in the design of the grid circuit. If consistent striking is to be achieved, the striking signal must intercept the critical grid characteristic at a steep angle to the time scale.

Methods of Grid Control

The graphs reproduced in Fig. 9 show how the duration of the conducting periods can be varied by applying a variable direct bias to the grid. It will be seen that this method gives control over only the first quarter of a cycle, and for the reasons given above may lead to inconsistency of the striking angle.

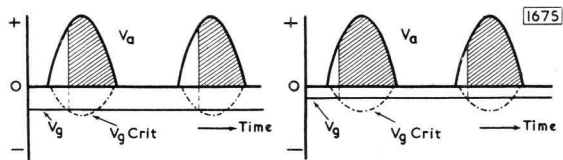


FIG. 9

It is therefore suitable only for "on-off" applications where the thyatron is employed merely as a simple relay.

Two methods of control illustrated in Figs. 10 and 11 use an alternating grid voltage to intercept the critical grid characteristic. Obviously, the larger the amplitude of the alternating grid voltage the steeper is the angle of interception and the "stiffer" the control.

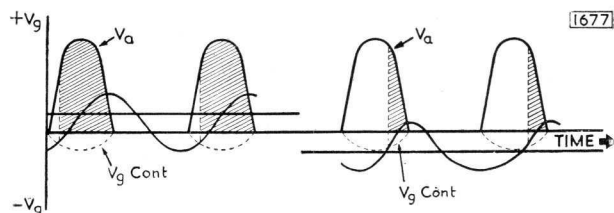


FIG. 10

In Fig. 10 the alternating grid voltage has a permanent phase shift with respect to the alternating anode voltage—usually 90° —and is in series with an adjustable direct bias. By changing the direct bias the point at which the grid voltage curve intercepts the critical grid characteristic is changed, thus altering the striking angle. This is sometimes called *vertical shift* control. If the range of adjustment of the direct

bias is equal to the peak-to-peak value of the alternating grid voltage, control can be exercised over the full 180° of the positive half-cycle of V_a . In the *horizontal shift* method of control illustrated in Fig. 11, the direct grid bias is maintained constant, the striking

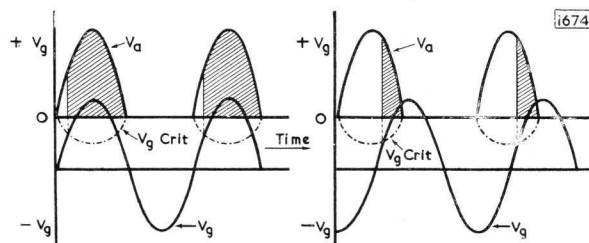


FIG. 11

angle being varied by adjusting the phase shift of the alternating grid voltage with respect to the alternating anode voltage over the range 0 to 180° .

Several methods of obtaining the phase shift required for the vertical and horizontal shift systems are available. The simplest, perhaps, which uses an R.C. phase-shifting network, is shown in Fig. 12. An output equal to $\frac{V}{2}$ is available between the points X and Y, and the phase of this voltage can be varied over 180° by adjusting the value of R. This can be explained by reference to the vector diagram in which OA is the output vector.

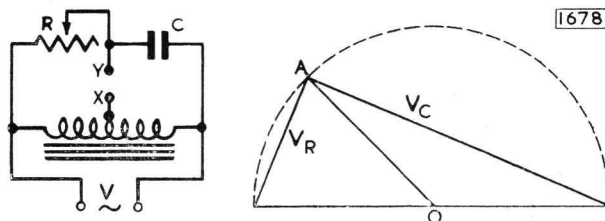


FIG. 12

For a vertical shift system where a constant phase shift of 90° is required, the value of R is constant and equal to $\frac{1}{\omega C}$. The variable direct bias is applied between the point X and the cathode of the thyatron, point Y being connected to the grid.

For manually-operated horizontal shift control the resistor R would be a potentiometer. In a servo system R could be simulated by a high-vacuum valve. A common variant of this arrangement is the use of a

fixed value of R , and the replacement of C by an inductor whose incremental permeability is controlled by a winding carrying a direct current.

Both the vertical shift and the horizontal shift methods of grid control are widely used, but they have the disadvantage that if a very stiff control is required, and the unit does not incorporate feedback, the alternating grid voltage must be large. A better solution is to feed the grid from a pulse source in which the phase of the pulses is variable. If the pulses have a steep leading edge a very stiff control can be obtained with pulses of quite small amplitude, as indicated in Fig. 13. Pulse control has the added advantage that it does not produce positive grid current when the anode potential is negative (*see page 15*). The pulse source most commonly used is a peaking transformer fed from a phase-shifting network.

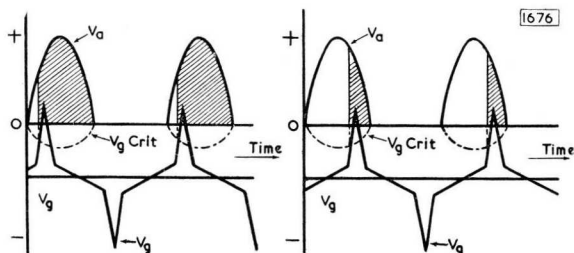


FIG. 13

METHODS OF EXTINCTION

A thyatron can be extinguished only by reducing the anode voltage below the arc voltage. This can be done either by opening the anode-cathode circuit or by short-circuiting the valve, and both methods can be achieved by means of a relay-operated system.

There are often objections to using mechanical contacts. Circuits in which the anode voltage is automatically reduced by electrical means, as in the simple relaxation oscillator circuit shown in Fig. 14, are preferred. When the thyatron is struck the capacitor C discharges through the load R_L . Provided that R is large, the current through it will not sustain valve conduction, and the thyatron will be extinguished. The capacitor C will then recharge to the voltage V in readiness for another discharge.

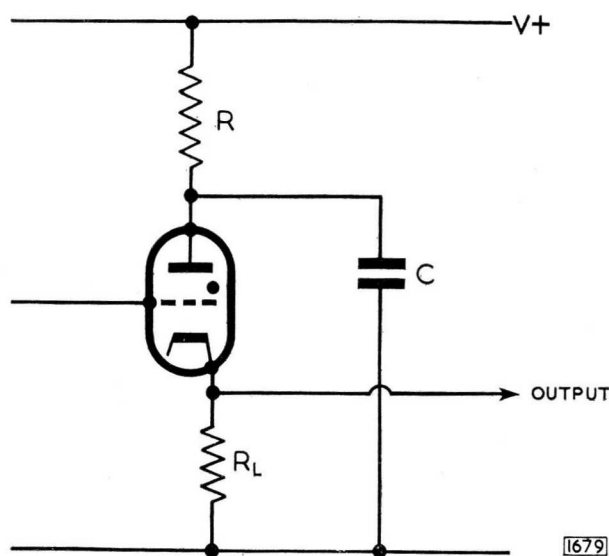


FIG. 14

Usually, however, the anode of the thyatron is fed from an alternating supply and the valve is therefore automatically extinguished at the end of each positive half-cycle. The grid may then re-strike the valve if required. The maximum time delay in the response of such a system using a bi-phase circuit is the period of half a cycle.

COMPARISON OF GAS-FILLED AND MERCURY VAPOUR THYATRONS

Temperature Dependence

Gas-filled and mercury vapour thyatrons differ mainly in respect of their range of operating temperatures, mercury vapour types being more temperature-dependent.

If the condensed mercury temperature is too low the valve will not carry its rated current, but if the condensed mercury temperature exceeds the rated limiting value the valve will not hold off its rated peak voltage. Mercury vapour thyatrons can only be used at full ratings within an ambient temperature range of about 15° to 50°C . Gas-filled thyatrons are usually rated for operation within an ambient temperature range of -55° to $+70^{\circ}\text{C}$. In addition, the slight temperature-dependence of rare gas thyatrons means that their heating-up time is conveniently short.

Mounting

Gas-filled thyratrons may be mounted in any position between horizontal and vertical with the base downward, and are therefore suitable for use in mobile equipment. Mercury thyratrons, on the other hand, may be mounted in a vertical position only.

Ionisation and Deionisation Time

The ionisation and deionisation times of mercury vapour thyratrons are normally longer than those

of gas-filled types. The latter may, therefore, be operated at higher frequencies, but they may have to be protected from high commutation factors leading to gas clean-up, i.e., the absorption of gas into the electrodes. This subject is dealt with more fully under *Gas Filling and Clean-Up* on page 18. Gas clean-up is usually more severe at the higher operating frequencies.

Mercury vapour thyratrons have a reservoir of mercury and therefore do not suffer from clean-up.

RATINGS AND DESIGN CONSIDERATIONS

Comprehensive data for the range of Mullard thyratrons, including ratings (limiting values) and electrical and mechanical characteristics, are given in the final section of this publication. In the present section the significance of the data, the reasons for the various operating limits, and other factors affecting circuit design, are considered.

CHOICE OF VALVE TYPE

The particular features of the two general types of thyatron are indicated in the following table:

TABLE I

	MERCURY	GAS-FILLED
Type of equipment	Static	Static or mobile
Approximate ambient temperature range	15°C to 50°C	-55°C to +70°C
Operating frequency	Low frequencies only	Up to approximately 5 kc/s
Heating-up time	Long	Short
Circuit characteristics	Simple circuit design	Circuit must not cause gas clean-up

ANODE VOLTAGE RATING

Maximum peak voltage ratings, both forward and inverse, are quoted for each type. They include any surges which may occur. If these ratings are exceeded, uncontrolled striking may take place.

In some applications it may be necessary to operate a thyatron at an anode voltage which is *lower* than the maximum strike voltage indicated by the control

characteristic. In these circumstances the grid circuit must allow sufficient positive grid current to flow to ensure that the discharge is transferred to the anode. Recommendations for specific applications where this mode of operation is necessary may be obtained on application to Mullard Ltd.

CATHODE CURRENT RATING

It is essential that the maximum peak and average current ratings of the thyatron are never exceeded. The maximum average current must be calculated for the published maximum averaging time T . The value obtained must not exceed the published limiting value. For any shorter period t the following relationship must be satisfied:

$$i_{pk} \leq I_{av} \cdot \frac{T}{t}$$

For continuous sine wave operation Figs. 15 and 16 may be used to indicate the ratio between the peak and average cathode current. Confirmation by actual measurement should, however, be made.

Maximum Peak Cathode Current

The peak cathode current, which is most conveniently measured with an oscilloscope, is limited by the peak emission from the cathode and the pressure of the conducting gas or vapour. Any attempt to exceed the quoted value will cause the arc voltage to rise and will reduce the life of the valve.

For certain thyratrons a second, lower limit to the peak cathode current rating is imposed for operation at frequencies below 25 c/s. This is to prevent damage to the cathode, which may occur if a high peak current is drawn for relatively long periods.

Maximum Average Cathode Current

The average cathode current, as measured by a d.c. moving coil meter, determines the valve dissipation due to load current as indicated below. If v and i are instantaneous values of the arc voltage and

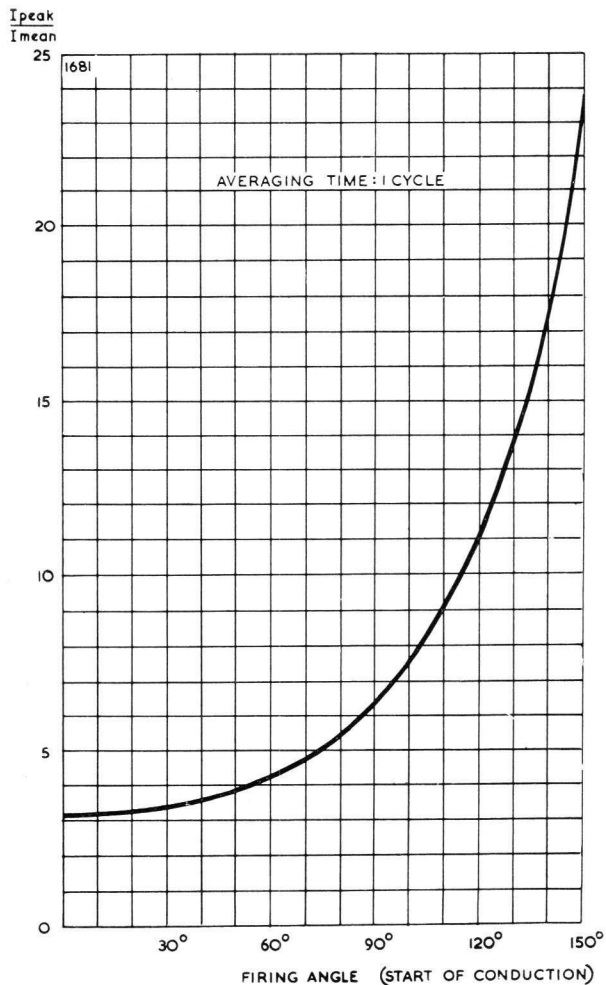


FIG. 15

anode current of a thyatron, then the mean power dissipated is:

$$P = \frac{1}{t} \int_0^t v \cdot i \cdot dt$$

However, V_{arc} is substantially constant and is independent of anode current, so that:

$$P = \frac{V_{arc}}{t} \int_0^t i \cdot dt = V_{arc} \times I_{av}$$

where I_{av} is the average anode current.

It is clear, therefore, that if a thyatron is operated above its maximum average current rating, excessive heating of the valve will occur, resulting in reduced life.

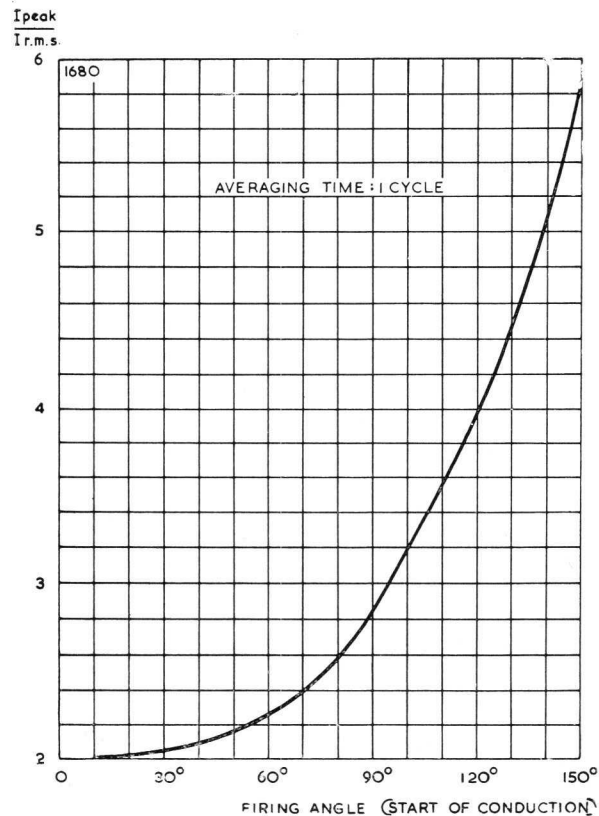


FIG. 16

Surge Current Rating

This is the value of the surge current which may occur a few times during the life of a valve without causing permanent damage. It is quoted in the published data for the benefit of the designers of the protective gear. In no circumstances must it be used as a design parameter for normal operation.

MAXIMUM NEGATIVE CONTROL GRID VOLTAGE

Two values of maximum negative control grid voltage are specified in the published data, one referring to conditions before conduction and the other to the conducting period.

The pre-conduction figure is the maximum negative voltage which can be applied to the grid without causing breakdown between cathode and grid. The maximum specified for the period of anode-cathode conduction is for applications in which the grid signal tends to hold the grid negative during conduction, e.g. pulse firing. This limitation prevents excessive grid bombardment. (See page 15).

MAXIMUM CONTROL GRID CURRENT

One reason for setting maximum permissible values for the control grid current is to reduce the risk of gas clean-up and electrode sputtering. This aspect is dealt with more fully on page 18. In addition, when positive grid current is drawn with the anode more positive than -10 volts, it is necessary to limit the grid current in order to keep the grid dissipation to a reasonable level. Normally the specified limits can be met with ease.

CONTROL GRID RESISTOR

Both a maximum value and a recommended minimum value of the control grid resistor are quoted in thyatron data.

Minimum Value

The minimum value for the control grid resistor is determined by the need to keep the grid current below a safe figure. In addition, there are certain cases, e.g. pulse firing, when the control grid signal tends to hold the grid circuit negative during conduction, and it is essential that in these circumstances the actual grid should be more positive than -10 volts (see page 11). The grid voltage is a function of the grid resistor. In the grid ion-current graph of the valve, the ion current is shown for a number of different values of average anode current. From these curves (by interpolation if necessary) the ion-current appropriate to the particular application can be found. It is then necessary to choose a grid resistor such that when this current flows through it the resultant voltage across it compensates for the grid signal voltage. It will be observed that a higher minimum value of grid resistor is required for lower values of average anode current. However, if the instantaneous value of anode current is very low, this restriction does not apply. In general, the grid should be more positive than -10 volts for all values of anode current greater than 10% of the rated maximum average anode current.

As an example of the use of the grid ion-current characteristic, an application of the thyatron Type XR1-3200 (in which the average cathode current is 2.4 amperes) will be considered. It will be assumed that pulse firing is employed, and that for the major part of the anode conduction period the point A in Fig. 17 is held at -60 volts with respect to the cathode. However, the control grid, point B,

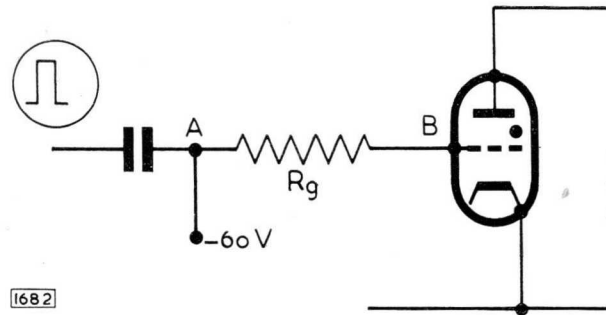


FIG. 17

must be maintained within the -10 volt limit, say at -8 volts. From the grid ion-current characteristic of the XR1-3200, Fig. 18, it is seen that a grid ion-current of -53 mA flows when the average anode current is 2.4 amperes and the grid voltage is -8 volts. Thus a total of $-60 - (-8) = -52$ volts must be dropped across R_g when a current of -53 mA flows through it. The minimum value for R_g is given by:

$$R_{g(\min)} = \frac{-52}{-53 \times 10^{-3}} \approx 1 \text{ k}\Omega.$$

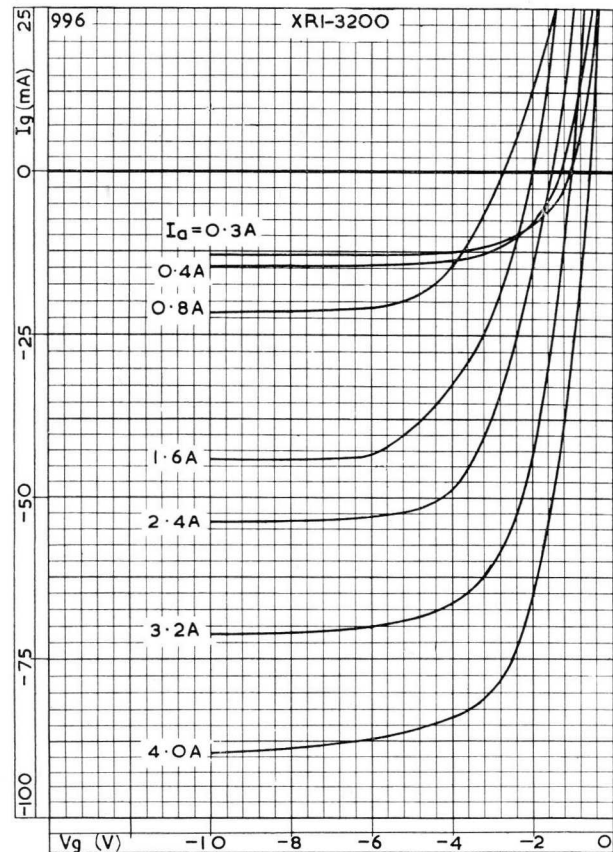


FIG. 18

Maximum Value

At first sight it might be considered that a very large value of grid resistor should be used with a thyatron in order to prevent any load falling on the source of the grid signal, and also to reduce grid conduction currents. However, owing to the effects of grid emission, leakage current, and grid-anode capacitance, a limit must be set to the maximum value.

In thyatrons there is usually a slight amount of emissive material on the control grid. When the anode is positive, electrons will flow from the control grid to the anode, and the corresponding grid current will produce a voltage drop across the grid resistor, making the grid more positive than is desired. This voltage drop tends to strike the valve. The effect increases with higher values of grid resistor. Similarly, the anode-grid capacitance will cause an anode-grid current to flow and will lead the anode voltage. This current will also generate an unwanted voltage across the grid resistor. Here again, a low value of grid resistor will reduce this unwanted grid signal.

The maximum values of grid resistor quoted for Mullard thyatrons are chosen so that the spurious signal produced by the above effects is negligible and is accommodated within the critical voltage spread.

It will be noticed that for the larger thyatrons a maximum grid resistor of the order of 100 k Ω is quoted. However, in certain small thyatrons, such as the EN91, both the interelectrode capacitances and the grid emission currents are so small that a maximum control grid resistor of 10 M Ω may be specified.

When the application demands the use of such a high value, care must be taken to ensure that the thyatron base and holder are kept clean and dry in order to minimise leakage currents between the anode and the control grid pins. Similarly, when a thyatron is fed with an alternating anode voltage and has a very high value of control grid resistor, the circuit capacitance between control grid and anode must be kept low. This may be achieved by connecting the control grid resistor directly to the grid terminal of the holder, and (in the case of a tetrode thyatron) by connecting the shield grid to the cathode at the holder.

When thyatrons are operated at anode voltages

below the striking voltage a limit to the maximum grid circuit resistance may be imposed by the need to ensure sufficient positive grid current to cause reliable initiation of the arc.

HEATER SUPPLY

The voltage of the heater supply should be kept within the rated limits specified in the valve data, to give consistent performance and to ensure good life.

If the supply voltage is too high, the temperature of the cathode, and thus the rate of evaporation of emissive material, will be excessive. Some of this material will be deposited upon the grid, and, as the grid temperature will also be high due to heat radiation from the cathode, excessive grid emission may occur, with its attendant problem of loss of grid control.

If, on the other hand, the heater voltage is too low, the cathode temperature will be low and emission will be reduced. This will result in an increase of the arc voltage, and in cathode sputtering which will shorten the life of the valve. It is therefore very important to adjust the heater voltage to the correct value. When checking this voltage, particularly in the larger valves, the measurement should be made at the valve pins rather than at the socket terminals. The heater voltage should be set to within $\pm 2.5\%$ of the nominal value. The valve will, however, accommodate temporary mains fluctuations of up to $\pm 6\%$.

In directly-heated valves there is a tendency for the part of the cathode which instantaneously has the maximum potential difference with respect to the anode, to be overloaded. If maximum valve life is desired, this effect should be eliminated by arranging that the filament supply voltage is 90° out of phase with the anode supply.

HEATING TIME

It is essential that the cathode shall have reached its full operating temperature, and is therefore capable of its rated emission, before cathode current is drawn. This condition is reached in the time specified in the valve data as the *minimum cathode heating time*.

For gas-filled thyatrons this is the only condition which must be met, since the gas pressure is substantially constant over the permissible range of ambient temperature. With a mercury vapour thyatron, however, it is also essential that the condensed mercury vapour temperature reaches the minimum

value specified in the valve data before cathode current is drawn. This temperature determines the pressure, and hence the current-carrying capacity of the mercury vapour. If an attempt is made to draw the maximum rated peak cathode current at reduced mercury temperature, the arc voltage rises, resulting in bombardment of the cathode and reduction of valve life.

The time taken to reach a given condensed mercury temperature from the instant of switching on the heater supply can be ascertained from the appropriate heating and cooling curves, which are reproduced in the section on thyatron data. If, for example, the specified minimum condensed mercury temperature is 40°C and the ambient temperature is 18°C , the condensed mercury temperature must be raised by $40^{\circ}\text{C} - 18^{\circ}\text{C} = 22^{\circ}\text{C}$ before drawing cathode current.

The term "ambient temperature" is rather indefinite when applied to conditions in the neighbourhood of an electronic valve, and it is therefore preferable to work entirely in terms of condensed mercury temperature and to measure this temperature under operating conditions. The temperature-measuring device must be one having a low thermal capacity, e.g. a fine wire thermocouple; and it should be attached to the valve in such a way as to cause the minimum interference with normal heat dissipation.

If a mercury vapour thyatron is to be operated at a peak current below the rated maximum, it is permissible to run the valve at a somewhat reduced condensed mercury temperature. Information as to the reduction permissible for Mullard thyatrons may be obtained on application.

It is usually unsatisfactory to rely upon an operator to observe the necessary time delay between switching on the heater supply and allowing cathode current to be drawn from the thyatron. Some form of automatic delay should be employed. For short delays an electronic timing circuit can be used. Some notes on suitable thyatron timers will be found on page 27.

The delay device can operate in either of two ways. It can be used to close the anode circuit of the thyatron at the expiration of the required delay period; but this may necessitate the use of a heavy-duty switch. The alternative method is to connect all supplies to the thyatron simultaneously, but with an over-riding negative grid bias voltage which prevents conduction. The delay circuit eventually removes this bias and allows the thyatron to operate.

IONISATION AND DEIONISATION TIMES

Maximum Frequency Limitation

When the voltage at the grid reaches the critical value and the thyatron starts to conduct, the anode voltage does not drop instantaneously from the supply voltage to the arc voltage. The time required to reach the arc voltage is termed the *ionisation time*, and depends upon the grid signal as well as upon the geometry of the valve and the nature of the gas filling.

Similarly, when the anode voltage drops below the arc voltage, the positive ions are not instantaneously neutralised. These positive ions form a sheath around the grid which prevents the grid from controlling the initiation of the arc. After a certain time, called *deionisation time*, the ion density will have decreased to a sufficiently low value for the grid to regain control. The deionisation time, like the ionisation time, is a function of the electrode potentials, the valve dimensions, and the nature of the gas filling. Generally speaking, high negative voltages on both grid and anode assist rapid deionisation, but any advantages so gained must be balanced against possible electrode sputtering and gas clean-up.

The deionisation time imposes a limit upon the maximum frequency at which a thyatron may be operated. If the non-conducting periods are shorter than the deionisation time the grid is unable to regain control and the valve will function as an uncontrolled rectifier. In general, mercury vapour thyatrons are limited by deionisation time to a maximum operating frequency of 500 c/s, while xenon-filled thyatrons lose control at frequencies of the order of 5 kc/s. However, for certain valves a considerably lower limit is specified to guard against the incidence of gas clean-up and sputtering.

In view of the great dependence of ionisation and deionisation times on circuit conditions and electrode potentials, any purely theoretical calculations which make use of these times should be treated with some caution.

CONDITIONS FOR LONG LIFE

The electrode structure and glass envelope of a thyatron have an almost infinite expectation of life. There are, however, two potentially expendable components in a thyatron—the cathode, and (where mercury vapour is not used) the gas filling.

The Cathode

Thyratrons, whether mercury vapour or gas filled, invariably have oxide-coated cathodes. If cathodes of this type are not bombarded by swiftly-moving positive ions, their lives are extremely long. It is essential, therefore, never to permit the arc voltage to exceed the published value. A high arc voltage will occur if the peak cathode current is too high, if the tolerances on cathode and heater voltages are not maintained within the specified limits, or if an attempt is made to draw current before the cathode has reached its correct operating temperature. With a mercury vapour valve it is also necessary to ensure that the condensed mercury temperature is within the limits set by the manufacturer.

Gas Filling and Clean-up

If at any time a thyratron is used in such a way that a high voltage exists between any two electrodes in the presence of an active or residual ion population, the thyratron will be damaged. Normally, only positive ions need be considered in this connection. If a high voltage exists between two electrodes these ions will be accelerated towards the negative electrode, embedding themselves in the electrode surface. The gas pressure is thus reduced. In addition, their impact will scar the electrode and sputter the surface material into the valve structure.

In gas-filled valves the amount of gas originally present is limited. If most of it is cleaned up in the manner described, the thyratron will become ineffective. It is therefore necessary to ensure that the circuit and operating conditions do not cause excessive gas clean-up.

So far as the main anode-cathode circuit is concerned, gas clean-up is most likely to occur at the time of extinction, when an inverse voltage often appears across the valve. The amount of gas clean-up under these conditions will be slight if the *commutation factor* specified for the particular valve is not exceeded. The commutation factor is defined as the product of *the rate of decrease of anode current in amperes per microsecond* (measured over the 10 microseconds immediately preceding current extinction), and *the rate of increase of inverse voltage in volts per microsecond* (measured over the first 200 volts).

At normal supply frequencies, circuits in which the inverse voltage is applied sinusoidally will not impose a high commutation factor. As an example, a single-phase thyratron circuit with a sinusoidal supply

feeding a *purely resistive load* may be considered. If the peak anode current is 80 amperes and the peak inverse voltage 1500 volts, the commutation factor at 5 kc/s will be of the order of 120.

In some applications, however, one thyratron is fully conductive until another takes over the load. At that instant a large inverse voltage is applied to the anode of the first thyratron. This condition arises in inverter circuits and in three-phase thyratron circuits feeding inductive loads. It is likely to impose a high commutation factor.

If the commutation factor for a particular application is excessive, it can be reduced by means of a *snubbing circuit*. A typical arrangement is shown in

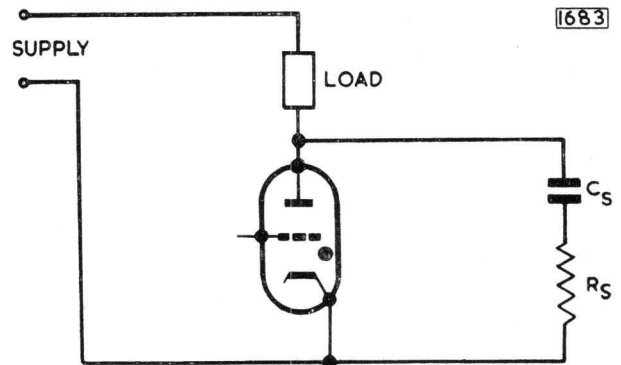


FIG. 19

Fig. 19. It consists of the capacitor C_S and resistor R_S in series, connected in parallel with the thyratron. In conjunction with the impedance of the load, the capacitor C_S prevents any rapid changes of voltage from being impressed on the valve; it also tends to compensate for any rapid decrease of load current. The resistor R_S is necessary to prevent the flow of excessive peak cathode current when the capacitor discharges into the thyratron.

Protection against a high commutation factor is of great importance at high operating frequencies, since if slight gas clean-up occurs, its cumulative effect is proportional to the frequency. It is for this reason that for certain small thyratrons an upper limit of operating frequency has been specified instead of a limiting value for the commutation factor.

Gas clean-up can also occur with certain forms of grid control (e.g. vertical shift control) in which there is grid-to-cathode conduction at times when the anode is at a negative potential, i.e. after the main discharge has been extinguished. For this reason the data sheets for Mullard thyratrons specify a maximum

value for the positive grid current which may safely be drawn while the anode is more negative than -10 volts. Similarly, if, during anode-to-cathode conduction, the grid is more negative than -10 volts, it will be bombarded by positive ions. The value of grid resistor must therefore be sufficiently high to keep the grid voltage within the published limits.

Mercury vapour thyratrons do not suffer from gas clean-up, but, under conditions of rapidly increasing negative voltage in the presence of positive ions, these ions will be accelerated towards the negative electrode. Since they are of large mass, they may damage the electrode by impact. For this reason mercury vapour thyratrons are often limited to a maximum operating frequency of 150 c/s, although the frequency limitation which would have been set by consideration of deionisation time alone is of the order of 500 c/s.

It may be safely claimed that the care taken in the design and manufacture of modern thyratrons has resulted in valves of this class having long lives. However, if extremely long life is the prime consideration in a particular application, it is a wise policy to under-run the thyatron by, say, 20% in respect of both current and voltage ratings. This reduces the thermal stresses on the valve structure and diminishes the possibility of grid emission. It also minimises the risk of damage caused by any misuse of the equipment, such as operation at a supply voltage outside the limit set by heater voltage tolerance or the operation of mercury vapour thyratrons at an excessively low ambient temperature.

The life of a thyatron in any particular application is governed mainly by two sets of factors. The first comprises the magnitudes of the voltages applied to the electrodes and of the current carried by the arc. The second comprises the nature and timing of these voltages and currents, which are usually determined by the type of load. It is therefore difficult to predict valve life for a given application without having full knowledge of all the operating conditions.

MEASURING TECHNIQUES

In the design of thyatron control circuits it is of great assistance if an oscilloscope with a d.c. amplifier is available. Direct access to the deflector plates and facilities for displaying two sets of curves simultaneously are desirable. With such equipment, accurate information can be obtained about the behaviour of the grid circuit in relation to the voltages

at the anode. This information is essential in the design of reliable circuits. Care must be taken to ensure that the stray capacitances of the oscilloscope are small, particularly when measurements are being made on a high-resistance grid circuit.

Measurement of Commutation Factor

In order to measure the commutation factor obtaining in a particular circuit it is necessary to examine the anode voltage and anode current over a period of approximately 30 microseconds about the instant of commutation. It is therefore essential to use a timebase with a sweep of that order, and to arrange that it can be synchronised to trigger at the required instant; and it is customary to obtain the triggering signal from the supply line voltage, feeding it to the oscilloscope via a suitable delay device or simple phase-shifting network (*see* Fig. 20).

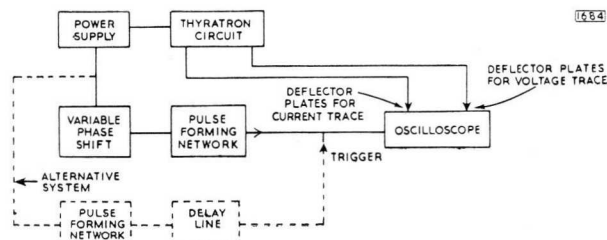


FIG. 20

Normally, the signal for the voltage trace will require attenuation by a potentiometer chain such as R_1 , R_2 (Fig. 21). If C_2 is the input capacitance to the oscilloscope, its effect should be balanced by C_1 ,

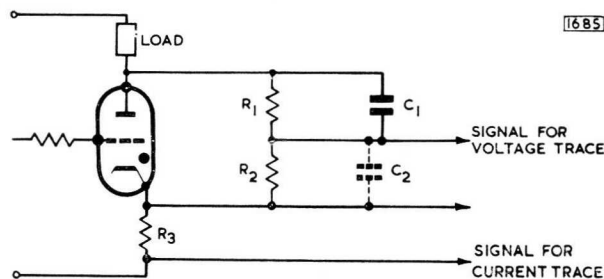


FIG. 21

which should be so chosen that $C_1 \times R_1 = C_2 \times R_2$. The thyatron current waveform can be obtained from the small resistor R_3 . The oscilloscope should have an accurately calibrated time scale so that the rates of change of current and voltage can be ascertained.

APPLICATIONS

The field of application of the thyatron is too wide for complete classification, but it may be said that thyratrons can be used whenever it is desired to control currents up to some tens of amperes at voltages up to about 2 kilovolts. The thyatron is not the only device suitable for such applications, but when the control source impedance is high and the operating delays may be less than one microsecond, the thyatron usually offers the only practicable solution.

Applications fall into two main categories: first, direct power control in heavy industry, where thyratrons with current ratings above 0.5 amperes are used for such purposes as motor and welding control; and second, light industrial applications such as process timing control and the operation of electromagnetic devices from high impedance or low current signal sources such as photocells and light metallic contacts.

Some of the principal applications are dealt with in the following pages. The circuit diagrams given in this section are only for illustration and general guidance. They are not intended to be directly suitable for every specific application.

MOTOR CONTROL

The increased complexity of modern manufacturing processes produces a need for continuously variable motor speeds, and for drives whose speed can be determined, partially or wholly, by some other process. Thyratrons are being used in increasing numbers to provide such control.

The specific forms of control are based on three fundamental methods of use:

- (1) The conversion of an alternating voltage into a direct and variable voltage.
- (2) The control of an alternating supply by conduction for only a certain part of each half-cycle.
- (3) The conversion of a direct voltage into an alternating voltage of variable frequency (inversion).

Control of A.C. Machines

For synchronous machines, thyatron control of the field excitation can be used to determine important characteristics. With alternators, for example, thyatron control of the excitation can form the final stage of an electronic voltage regulator. Similarly, with synchronous motors operating on variable load, thyratrons can be used to ensure automatically the optimum values of pull-out load and power factor.

With a.c. motors in general, speed control is possible by feeding the machines from a variable frequency source. This can be generated by a thyatron inverter. Moreover, by thyatron control of the inverter power supply, both a variable frequency and a variable voltage can be obtained. Notes on inverters will be found on page 26.

When it is desired to vary the r.m.s. value of the voltage supplied to a motor, two thyratrons may be connected back-to-back, or alternatively a thyatron can be used with a series-connected transformer to form a variable impedance. Further information on these applications is given on page 25.

Control of D.C. Motors

Thyatron control of d.c. motors provides a ready means of increasing the versatility of individual drives by introducing continuously variable speed control and control of the torque and power characteristics. Normally, a separately-excited shunt motor is used, and thyratrons are employed to provide a variable rectified supply, derived from the a.c. supply mains, to the armature, to the field, or to both, according to the characteristics required. Fig. 22 shows the torque and power characteristics which can be obtained with either armature or field control. Up to full rated speed the voltage applied to the field is kept constant, and that to the armature is controlled to give constant armature current and therefore constant torque and rising output power as speed increases. Above the nominal speed, the armature voltage is maintained at a constant value, and the voltage applied to the field is

controlled to ensure constant power and a torque characteristic which falls hyperbolically with increase of speed.

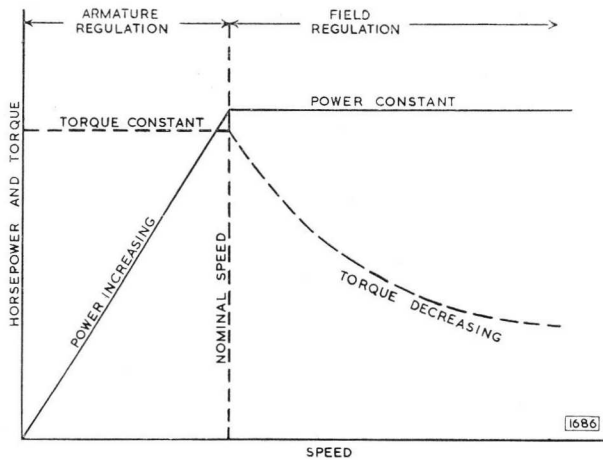


FIG. 22

One of the great attractions of this form of control is the ease with which deviations from ideal characteristics can be compensated, or any required characteristic can be achieved.

Armature Current Limitation

In any control system for d.c. motors the armature current must be limited in order to avoid excessive starting current and to protect the motor and control gear from overload. In electronic controllers this can be achieved by the use of a current transformer whose primary is in series with a thyatron. The voltage in the secondary, which is proportional to the armature current of the motor, is rectified and compared with a reference voltage. The difference between the two voltages is amplified and fed to the grid circuit of the thyatron so that the armature voltage is automatically reduced if the armature current exceeds a predetermined value.

Armature Drop Compensation

The speed of a d.c. motor operating with constant excitation is not proportional to the applied armature voltage V , but to $V - IR$ when IR is the voltage drop in the armature. Although IR may be small and even negligible at high speeds, it can be comparable with V at low speeds. Thus to obtain a fairly linear voltage/speed characteristic over a wide speed range, it is necessary to compensate for the IR drop.

An additional secondary winding on the transformer used for armature current limitation will provide a voltage proportional to the armature current. This

voltage can be connected so that the voltage supplied to the armature by the thyratrons is increased by an amount equal to IR . In an alternative method, which, however, does not differ in principle, the current transformers may be replaced by resistors.

Constant Operating Speed

If a constant operating speed is required a further measure of compensation is necessary, since the armature compensation leaves the system subject to supply voltage variations. By comparing the armature voltage with a reference voltage, and feeding back the difference voltage in the appropriate sense to the thyatron control grid, the armature speed can be kept extremely constant.

In the methods described above, it is assumed that the effect of armature reaction on the main field is negligible. This may not be so if very constant speeds are required. A small tacho-generator can then be used, the output voltage of which is compared with a reference voltage and the difference fed back to the control circuit.

Table II indicates which Mullard thyratrons are suitable for armature control of d.c. fractional H.P. motors. The thyatron rating should be checked against the particular circuit conditions. It should also be noted that when armature control is applied to a d.c. motor, the r.m.s. current in the armature windings will be higher than when operating on a smooth d.c. supply. Care must therefore be taken to ensure that the permissible copper losses for the motor are not exceeded. For a d.c. motor which is not specifically designed for this mode of operation, it may be necessary to reduce the rating of the motor.

Control Circuit for D.C. Fractional H.P. Motor with Single-phase Supply

A simple and inexpensive circuit for manually controlling a d.c. fractional H.P. motor, working on a 230 volt single-phase supply, is shown in Fig. 23. No

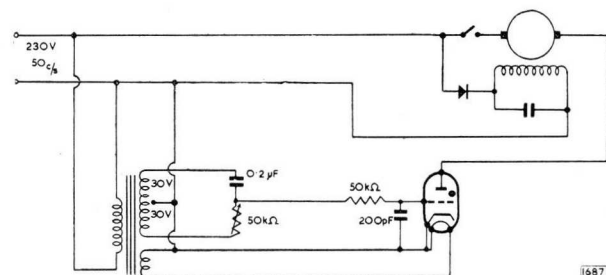


FIG. 23

TABLE II

MULLARD THYRATRONS SUITABLE FOR ARMATURE CONTROL OF D.C. FRACTIONAL H.P. MOTORS

MOTOR RATING (H.P.)	TYPE OF THYRATRON					
	110-volt Motor Half-wave Rectification		220-volt Motor Full-wave Rectification		220-volt Motor Three-phase Rectification	
	Mercury	Gas-filled	Mercury	Gas-filled	Mercury	Gas-filled
1/16	XG1-2500	XR1-3200	XG5-500	EN32	—	—
1/8	XG1-2500	XR1-3200	XG5-500	XR1-3200	XG5-500	EN32
1/4	XGQ2-6400	XR1-3200	XG1-2500	XR1-3200	XG5-500	XR1-3200
1/3	XGQ2-6400	XR1-6400	XG1-2500	XR1-3200	XG1-2500	XR1-3200
1/2	XGQ2-6400	XR1-6400	XG1-2500	XR1-3200	XG1-2500	XR1-3200
3/4	—	—	XG1-2500	XR1-3200	XG1-2500	XR1-3200
1	—	—	XG1-2500	XR1-3200	XG1-2500	XR1-3200

input transformer is required. The circuit provides armature control only, and the field excitation is obtained by half-wave rectification. Field control could be introduced if required.

Variable phase or "horizontal" grid control of the thyatron is employed, a 50 k Ω potentiometer being used as the control element. The 200 pF capacitor connected between the grid and cathode of the thyatron prevents random striking caused by transient voltages induced in the mains supply or in the control circuit by associated equipment. Choice of thyatron, field current rectifier, and smoothing circuit, will depend upon the size of the motor and the particular application. Automatic control of the heating-up time of the thyatron is not indicated in the diagram, but must be included in practical circuits.

Comprehensive Control System for a D.C. Motor, incorporating IR Drop Compensation and Armature Current Limitation

The circuit diagram Fig. 24 shows a simple but comprehensive motor controller, the armature being

connected to terminals A and L, and the field coil across F and L. Constant field excitation is obtained from V6. The armature supply voltage is varied by the thytrons V4 and V5, the control grid signal being a variable d.c. voltage with a superimposed a.c. voltage delayed 90° with respect to the appropriate anode voltage.

The speed of the motor is varied by the potentiometer P₁. "IR drop" compensation and armature current limitation are determined by the preset potentiometer and resistor, P₂ and R₁₆ respectively. All these actions are combined in the double triode V2. The left hand section V2A controls the speed and IR drop compensation, whilst the right hand section V2B is used for armature current limitation.

The armature voltage is used as a measure of the speed of the motor. It is compared with the fraction of the field voltage determined by the setting of the potentiometer P₁. If the speed falls, the armature voltage falls below the reference voltage, and negative

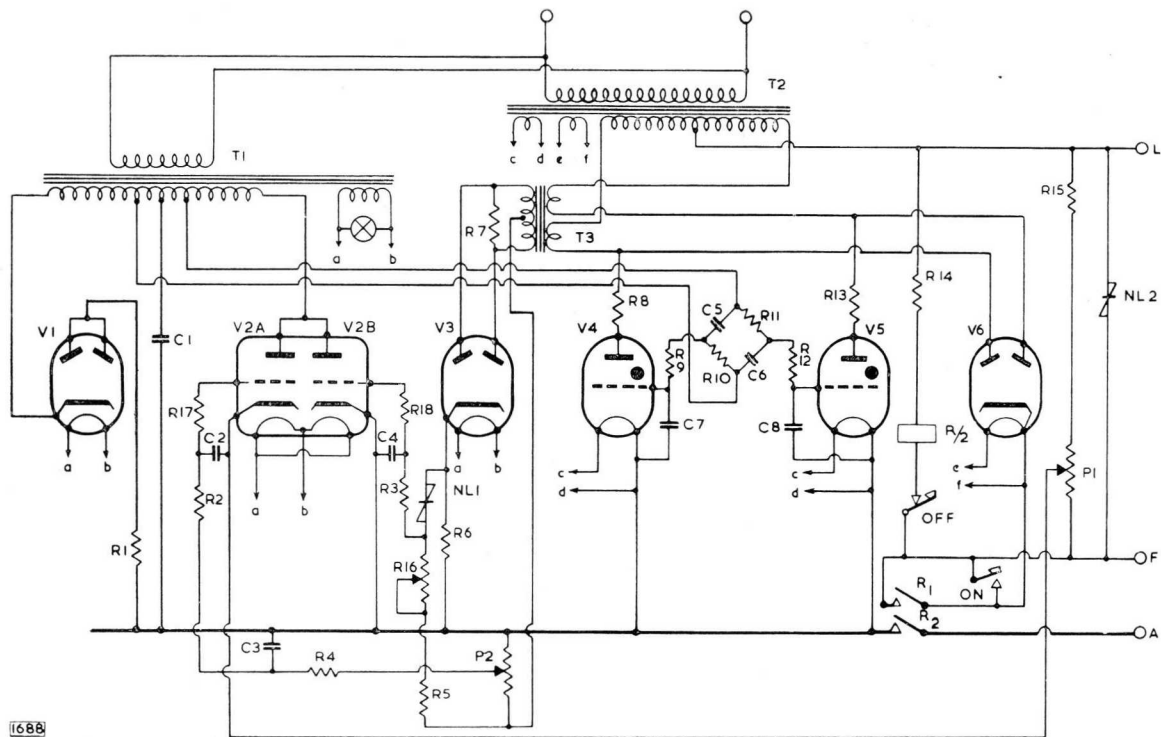


FIG. 24

bias will then be applied to V2A and the striking of V4 and V5 will be advanced to restore the armature voltage. The reverse will apply for an increase in speed. By changing the setting of P₁ the speed of the motor can be varied over a wide range.

The armature voltage drop compensation is added to the speed control by connecting the grid of V2A to the slider of the potentiometer P₂. This is adjusted to give a linear speed characteristic at low speeds, the compensation remaining operative over the entire speed range. A delay circuit C₃ R₄, prevents instability due to too rapid compensation.

Armature current limitation is obtained by a current transformer T₃ and a rectifier V3 which produce a voltage proportional to the d.c. line current. At normal values of current V2B is held non-conducting, but if the limit is exceeded it will conduct and the thyatron striking will be delayed, so decreasing the applied armature voltage.

It will be seen that the primaries of the current transformers also carry the field current. This, with the relay R/2, ensures that the field is established before the armature voltage can be applied. The thyratrons will be cut off until V2B is biased back.

This control system will give a substantially flat speed/torque characteristic over a range of speed

variation of about 10 : 1. Provided the field is not saturated, the variation of speed due to mains fluctuations of $\pm 10\%$ will not exceed $\pm 2\%$. For small motors, V6 can be a vacuum diode such as a Mullard type GZ32. For larger equipments a gas-filled rectifier should be used.

RESISTANCE WELDING CONTROL

In many applications the full benefit of resistance welding can be realised only if the welding current and its duration can be accurately controlled over a current scale ranging from nearly zero to the maximum current obtainable from the equipment, and a time scale covering from 10 milli-seconds to several seconds. Exact repetition of welding conditions is also of great importance. Electro-mechanical timing and control methods are restricted to long minimum-time intervals, and they tend to be unsatisfactory when used in highly inductive circuits. Electronic methods, however, permit accurate control of current and duration over a wide range.

The supply to the welding electrodes can be directly controlled by two thyratrons connected back-to-back. For very large welders, thyratrons may be used to control the firing of ignitrons or other mercury-pool devices.

C1, R1 and R2, giving approximately the same phase delay as the loaded welding transformer. The values shown correspond to a delay of 35° . When SW1 is closed V1 will strike when the supply voltage reaches a positive value of $\sqrt{2} \times 230 \sin 35^\circ$ volts. As a positive d.c. potential is applied to the anode of V1, it will continue conducting until SW1 is opened.

Each time SW1 is closed V1 strikes and a positive pulse is developed by its cathode circuit to strike V2 which continues conducting for approximately half a cycle. When the current in V2 ceases, the peaking transformer in series with the welding transformer primary applies a positive pulse to the grid of V3. This thyatron conducts for another half cycle, giving a total welding time of one cycle. The bias for each valve is produced by a 14 V a.c. voltage in antiphase with the respective anode voltage, giving a negative bias across either C2 or C3 due to positive grid current.

Switch SW2 permits two different resistors to be connected in series with the thyratrons to give a coarse heat control.

The thyatron used in this circuit should be chosen in accordance with the maximum current which may be drawn from the supply by the welding transformer.

REGULATION OF D.C. POWER SUPPLIES

Thyratrons can be used as grid-controlled rectifiers. For a fixed input voltage the rectified output can be varied by delaying or advancing the instant of grid striking, and control of output can thus be achieved without the use of large regulating transformers. The smoothing circuit requirements will be more stringent if control over a wide range is necessary. A reference is included in the bibliography.

The grid control circuit may be coupled to the output so that a stabilised supply is obtained. The response time of the system will be limited in general to half a cycle of the supply voltage. However, the normal mains variation of $\pm 10\%$ can be reduced to a mean voltage stability of $\pm 1\%$ within the limit of the response time. When this limitation is not important the thyatron stabilised supply has the advantage of greater efficiency and fewer components.

Where such stabilisation is insufficient a second stage can be added, consisting of a conventional hard valve voltage stabiliser, as shown in Fig. 26. This stage will only have to deal with the voltage variations due to rapid fluctuations in the load. Accordingly,

the average duty of the series valves will be considerably decreased by the effective reduction of the mains variation by the thyratrons. The hard valves

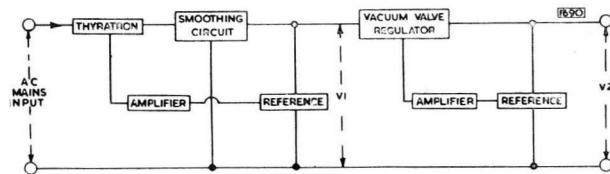


FIG. 26

can then be selected on their peak current rating, and not, as is usual, on the permissible anode dissipation. Thus the number of valves required for a given output will be reduced. The thyratrons replace the normal rectifiers, and the only addition is the thyatron grid control circuit.

REGULATION OF A.C. POWER SUPPLIES

Thyratrons can be used to control alternating supplies by simple on-off switching, or by variation of the r.m.s. voltage applied to a load. The basic circuits are shown in Figs. 27 and 28 respectively. In Fig. 27

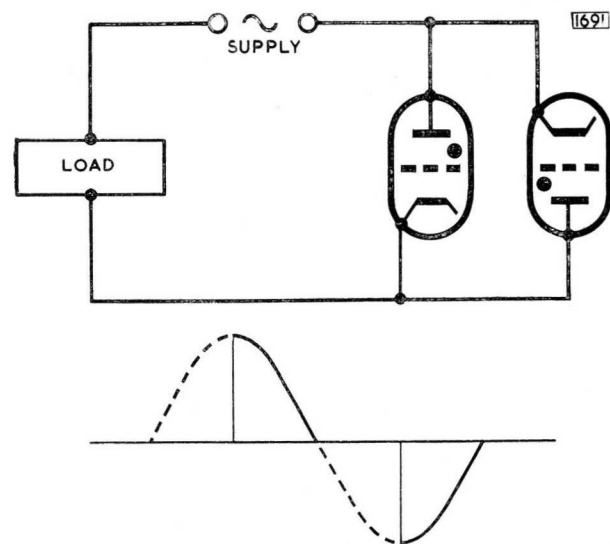


FIG. 27

two thyratrons are connected back-to-back in series with the load. If the control grid circuits are adjusted for full conduction, a waveform which is almost identical to the supply waveform will be applied directly to the load. The load circuit can be interrupted by biasing the thyratrons back to cut-off. Variation of the r.m.s. voltage applied to the load is obtained by adjusting the bias. For 90° striking the waveform applied to the load is as shown. Any intermediate

waveform (and hence r.m.s. voltage) can be obtained by suitable adjustment of the bias.

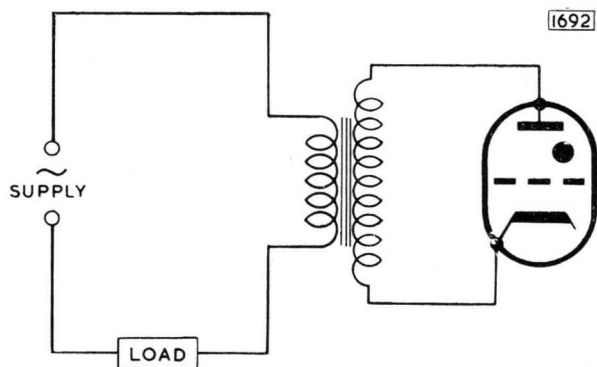


FIG. 28

Fig. 28 shows an alternative method of control. The load is connected to the mains in series with the primary winding of a step-up transformer. The secondary winding is connected to a thyatron, or two wired back-to-back. If the arrangement is biased to cut-off, only the comparatively small magnetising current of the transformer will flow through the load. If, however, the thyatron circuit is made to conduct, the voltage across the transformer primary will be equal to the arc voltage of the thyatron divided by the turns ratio of the transformer; thus the greater part of the supply voltage will be applied to the load. By delaying the striking of the thyatron, the time for which the greater part of the supply voltage is applied to the load is decreased; therefore the r.m.s. voltage applied to the load also decreases. With a suitable choice of transformer ratio the thyatron can be operated near its full current and voltage ratings, thus a high valve utilisation factor is obtained.

An On-Off Switch for A.C. Circuits

The circuit diagram reproduced in Fig. 29 is that of an electronic on-off switch using two thyratrons connected back-to-back, the switching operation being initiated by a very light mechanical switch. This arrangement is particularly useful where the load has to be switched repeatedly at short intervals with consequent excessive wear of switch contacts. The circuit uses Mullard mercury-vapour thyratrons Type XGQ2-6400, which are rated for a maximum average current of 6.4 amperes, so that a current of approximately 13 amperes (r.m.s.) can be controlled. The circuit values are, however, suitable for the majority of Mullard thyratrons.

With the switch open, both thyratrons are prevented from striking by a negative bias of approximately 20 volts obtained from the metal rectifiers. When the switch is closed, the grid of each thyatron is connected to the mid-point of a 3.3—10—10—3.3 k Ω potentiometer across the valves. Thus, during a given half-cycle one thyatron will conduct, and the arc voltage will appear across the other during most of the half-cycle. The two thyratrons will conduct alternately in successive half-cycles.

THYRATRON INVERTERS

Static alternating current generators of medium power, capable of operating at either constant or variable frequency, have many applications. For example:

1. Generation of alternating current at normal supply frequency to enable a.c. mains-operated equipment to be used where only a d.c. supply is available.
2. Production of variable frequency power for speed control of a.c. motors.
3. Low frequency power generation for vibrators.
4. Generation of power for induction heating.

These and other requirements for power outputs up to about 40 kW can be met by using thyratrons in multi-phase inverters. The principle of the single phase parallel inverter can be explained by reference to Fig. 30, which shows the basic circuit of the so-called constant voltage inverter.

A variable frequency oscillator may be used to trigger the thyratrons alternately through the grid transformer. When thyatron V_1 is conducting, a voltage applied to the grid of the second thyatron V_2 will cause this valve to strike. There is a rapid fall

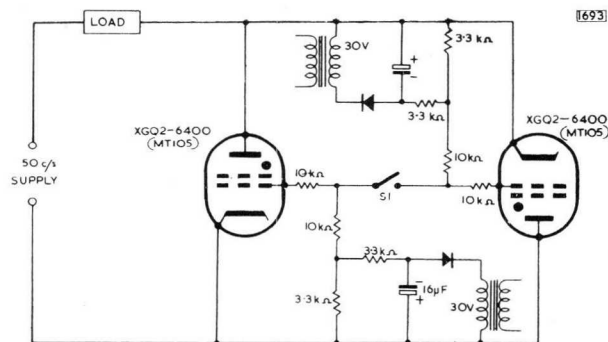


FIG. 29

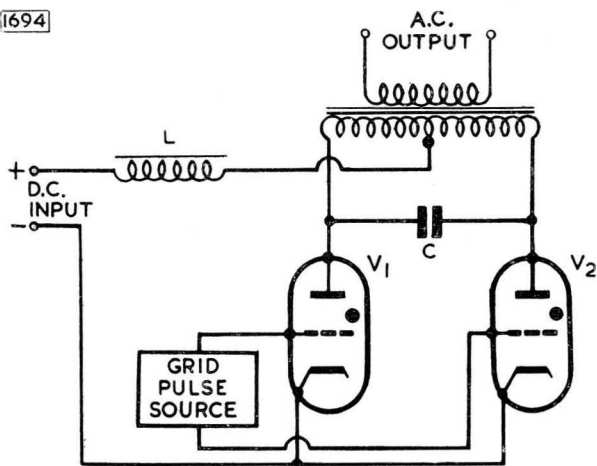


FIG. 30

in the anode potential of V_2 to a value equal to the arc voltage. In a mercury vapour thyatron this voltage is about 12 volts. The fall of potential is transmitted to the anode of V_1 by means of the commutating condenser C . The anode potential of V_1 at V_{arc} (since the valve is already struck) will be forced below this value and the valve will extinguish. The anode voltage must remain below V_{arc} long enough for the valve to deionise. The voltage across V_1 then rises at a rate determined by the circuit constants. Before the next trigger pulse is applied to V_1 its anode potential must be above the striking voltage (about 40 to 50 volts) for the inverter to operate. This switching of the thyratrons causes alternating pulses of current to flow in the transformer primary, and an alternating voltage is induced in the secondary winding. The frequency is determined by the trigger repetition rate.

The circuit is externally excited by the grid pulse oscillator, but it is possible, particularly in constant-load, constant-frequency applications, to supply the control grid circuit from the output, and thus to make the circuit self-exciting. In general, however, the externally excited inverter is preferable by reason of its greater stability.

Low-power Self-excited Inverter

The circuit of a low-power, self-excited inverter using a pair of EN91 thyratrons, is given in Fig. 31. It is intended for operation from 220-volt d.c. mains, and it gives a useful 50 c/s output of about 24 watts at

220 volts. It operates in the manner described above, except that self-excitation is obtained from the winding WS2 via the phase-shifting network R_5, C_2 .

To allow the cathodes of the thyratrons to heat up, operation of the anode circuit is delayed for 10 seconds by relay R/1. During this period the heaters are fed from the d.c. input via the dropping resistor R2. R/1 is a thermal relay which, after the 10-second delay, switches on the main circuit of the inverter. The voltage induced in the winding WS3 then energises relay S/1 which disconnects the heaters and R/1 from the d.c. mains and connects them to WS2.

This circuit will operate at 100 c/s if R_5 is reduced and the value of C_1 is changed from $0.75 \mu\text{F}$ to $0.3 \mu\text{F}$. The action of the device is also reversible, so that by feeding the transformer from a 220-volt 50 c/s supply a d.c. output of 0.2 ampere at 180 volts can be obtained. This inverter was designed for operation at low d.c. and a.c. voltages and therefore does not give optimum efficiency.

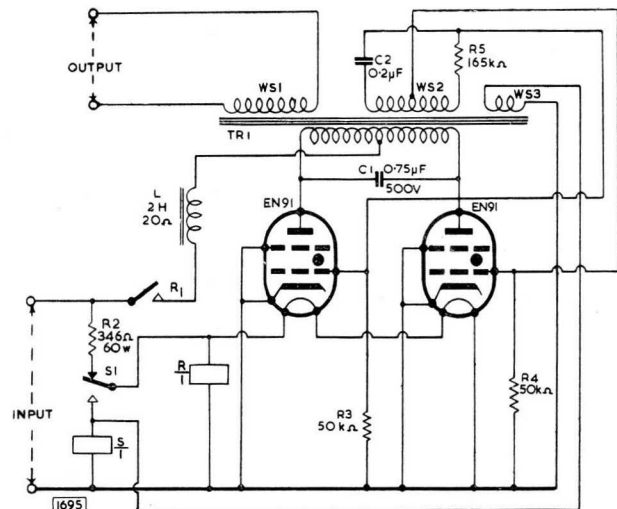


FIG. 31

TIMING CIRCUITS

Small thyratrons such as the Mullard types EN91 and EN32 may be operated with high impedance grid circuits, and are therefore suitable for use in timing circuits where this is of primary importance. They can also operate quite large relays or contactors directly.

Typical examples of such use are resistance welding, punch pressing, and pre-set heat cycle control.

A basic circuit for many such systems is shown in Fig. 32. With the switch in position A, the thyatron grid is biased to -100 volts and the valve cannot conduct. If the switch is thrown to position B, the capacitor C will start to discharge through resistor R, and the grid will become less negative at a rate determined by the time constant RC. When the critical grid voltage is reached the valve will strike and will initiate action in the anode circuit.

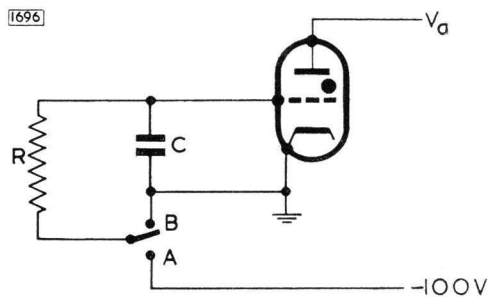


FIG. 32

The greater the time constant RC, the longer will be the measured time interval. In general, a limit is set by the maximum published value of control grid resistor and by the physical dimensions of the capacitor.

In order to minimise the effect of the spread of valve characteristics it is necessary to charge the capacitor to a voltage which is large in comparison with the critical grid voltage. For accurate timing the capacitor and resistor must be stable in value, and the capacitor must have a small loss angle (electrolytic capacitors are unsuitable).

It is obvious that the thyatron fires on a relatively flat portion of the exponential voltage/time characteristic, thus changes in valve characteristics will produce relatively large changes in the measured time interval. Where extreme accuracy is required the RC network should be charged to a negative voltage as before, but discharged by connecting it to some positive potential and not to the cathode line. This will ensure that firing occurs on a steeper portion of the exponential discharge curve.

Fig. 33 shows a simple a.c.-operated timer in which a relay operates at a predetermined time after switch SW1 is closed. While the switch is open C1 is charged to the peak value of the secondary voltage via R2, R3 and via the control-grid-to-cathode diode action during

the half-cycles when the grid is positive with respect to the cathode. Closing switch SW1 completes the anode circuit, and the voltage across C1 appears as a negative bias on the control grid. Conduction will start after an interval determined by the values of RV1 and C1. As the thyatron supplies pulses and not a steady direct current, the capacitor C2 is required to prevent relay chatter. An additional resistor R4, in series with the relay coil, may be needed to limit the average anode current.

In designing this circuit care must be taken to ensure that the maximum permissible pre-conduction grid voltage of the thyatron is not exceeded. This imposes a voltage limit between points A and B of 70 volts r.m.s. for thyatron type EN91 and 180 volts r.m.s. for type EN32. Where a higher supply voltage

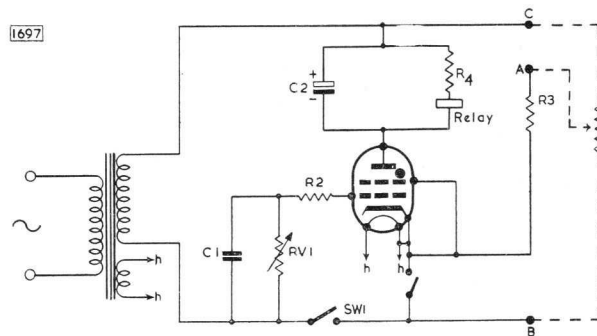


FIG. 33

than this is required, point A can be potentiometer connected (dotted lines) instead of directly connected to point C.

The following are typical values for the circuit components: $R2=10$ k Ω , $C2=4$ μ F (electrolytic), $R3=33$ k Ω . C1 and RV1 are chosen in accordance with the desired time interval.

Two or more circuits of this type may be connected in cascade either to provide longer time intervals or to control a timed programme of operation.

LIGHTING CONTROL

Smooth control of incandescent lamps, from full illumination to zero, can be obtained with a simple thyatron circuit. Controllers of this type may be interconnected so that single lamps or complete banks can be controlled from one small potentiometer.

In the case of fluorescent lighting, the striking voltage of the lamp is influenced by its loading during the previous half-cycle, and, in a comprehensive

controller, a simple "ringing" circuit is usually employed to strike the lamps. Thyratrons determine the point in each half-cycle at which the circuit rings, and they also carry the subsequent lamp current.

ELECTRIC FURNACE CONTROL

In this application, thyratrons may either be used as simple on-off switches, or they can be arranged to give continuously variable heat input. The thyratrons are usually controlled from a temperature-dependent element so that the oven temperature is maintained at a pre-determined level.

CONTROL OF VIBRATORS

There is a considerable demand for controlled vibrating equipment, both for electromagnetic conveyors and for programmed mixing. Thyratrons can provide both switching and continuous control.

FIRING OF MERCURY POOL RECTIFIERS

For accurate firing of ignitrons and grid-controlled mercury-pool rectifiers it is necessary to feed the igniting or control electrode with a large current signal which has a steep leading edge. Thyratrons are very suitable for this purpose, and they also present a high input impedance to the signal source. This is particularly important in a feedback system with fine control.

For ignition duty the peak-to-mean current ratio is considerably higher than for other applications. For certain thyratrons, therefore, e.g. XG1-2500, a special ignitron firing rating is quoted. Designers who wish to use other types of thyatron for this service, where the published ratings are likely to be exceeded, should consult the valve manufacturer.

THYRATRONS AS UNCONTROLLED RECTIFIERS

The thyatron is essentially a rectifier with the conduction period in each positive half-cycle controlled by the potentials applied to the grid. It can, however, be used to provide *uncontrolled* rectification by means of simple passive grid circuits which allow conduction over most of the positive half-cycle. The high inverse-to-forward impedance ratio inherent in gas-filled valves should be retained.

At low supply voltages the control grid may be connected to the anode via a resistor of suitable value as in Fig. 34. This method must not be used where the peak inverse voltage exceeds the rated maximum permissible grid-to-cathode voltage. To obtain a low

strike voltage the value of the resistor should be as small as possible, but the maximum grid current rating should not be exceeded.

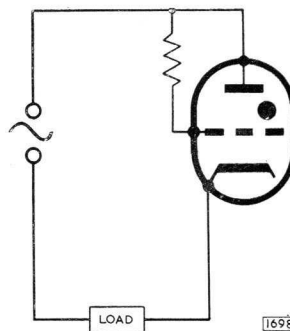


FIG. 34

At high supply voltages a high value of strike voltage, say 200 volts, may not be objectionable, and the control grid may be connected directly to the cathode.

For operation at medium voltages the control grid should be connected to a potentiometer between anode and cathode as shown in Fig. 35. To limit the inverse

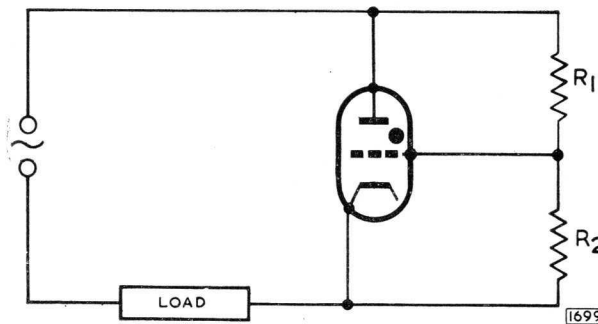


FIG. 35

current the total resistance $R1 + R2$ should be large. The maximum value of $R1$ is determined by the grid current required to strike the valve at a low anode voltage. The ratio $R1/R2$ is set by the maximum permissible grid-to-cathode pre-conduction voltage. The values of $R1$ and $R2$ are thus dependent on the type of rectifier circuit, the supply voltage, and the characteristics of the thyatron.

Table III shows suitable $R1/R2$ ratios for different valves and for different values of transformer secondary voltage. The table applies to the circuits given in Table IV. For the single phase bridge system the $R1/R2$ ratios relate to twice the transformer voltage quoted in Table III.

Table III is based on a maximum $R2$ value of 100 k Ω . Lower values can be used, but the ratio

TABLE III
GRID CIRCUIT RESISTANCE RATIOS FOR UNCONTROLLED RECTIFIER CIRCUITS

Transformer voltage per leg, kV r.m.s.	Minimum R1/R2 Ratio for Valve Type*		
	XG5-500	XG1-2500	XR1-3200 XR1-6400
0.1	—	—	0.2
0.2	0.2	0.2	1.6
0.3	0.9	0.9	3.0
0.4	1.6	1.6	4.3
0.5	2.3	2.3	5.7
1.0	5.7	—	—
1.5	9.2	—	—

* The use of $\pm 10\%$ resistors is allowed for.

TABLE IV
CHARACTERISTICS OF RECTIFICATION SYSTEMS

Type of Circuit	Single-phase full wave	Single-phase bridge	Three-phase half wave	Three-phase full wave	Three-phase double Y with reactor	Hexaphase half wave
No. of Valves	2	4	3	6	6	6
V_{dc}	$0.9 \times V_s$	$0.9 \times V_s$	$1.17 \times V_s$	$2.34 \times V_s$	$1.17 \times V_s$	$1.35 \times V_s$
Peak inverse voltage	$2.83 \times V_s$	$1.41 \times V_s$	$2.83 \times V_s$	$2.45 \times V_s$	$2.83 \times V_s$	$2.83 \times V_s$
Peak valve current	$1 \times I_{dc}$	$1 \times I_{dc}$	$1 \times I_{dc}$	$1 \times I_{dc}$	$0.51 \times I_{dc}$	$1 \times I_{dc}$
Average valve current	$0.51 \times I_{dc}$	$0.51 \times I_{dc}$	$0.33 \times I_{dc}$	$0.33 \times I_{dc}$	$0.167 \times I_{dc}$	$0.167 \times I_{dc}$
Ripple factor	0.667	0.667	0.25	0.057	0.057	0.057
Major ripple frequency	$2 \times f$	$2 \times f$	$3 \times f$	$6 \times f$	$6 \times f$	$6 \times f$

V_{dc} = mean d.c. output voltage.
 I_{dc} = mean d.c. output current.

V_s = r.m.s. voltage per transformer leg.
 f = supply frequency.

R1/R2 must not be decreased. The ratios quoted permit the use of resistors with a tolerance of $\pm 10\%$.

In Tables III and IV all voltages have been quoted in terms of the transformer r.m.s. voltage instead of the more usual d.c. output voltage—which is dependent on load current. Errors may occur if the peak inverse voltage per valve is determined from the measured d.c. output voltage. Table IV assumes no

regulation or other voltage losses in transformer or valves.

For sine wave operation the resistor R1 can be replaced by a capacitor, with an improvement in the inverse voltage characteristics of the system. However, any transient voltages which appear during the negative half-cycle may give rise to excessive grid-to-cathode voltages.

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TECHNICAL DATA FOR MULLARD THYRATRONS

The final section of this publication contains full technical data for the Mullard ranges of mercury vapour and gas-filled thyratrons. The data should be read in conjunction with the following general recommendations.

Installation

Mercury vapour thyratrons should always be mounted vertically with the cathode connections at the lower end. When a mercury vapour thyatron is first installed, and before it is put into service, it should be run for at least half an hour at its normal heater or filament voltage but without any electrode voltages applied, in order to vaporise any mercury which may have been deposited on the electrode assembly during transit. This precaution should also be taken before putting into service a mercury vapour valve which has been out of use for any considerable time.

Gas-filled thyratrons have much less rigid limitations of mounting position. The smaller types may be operated in any position.

Limiting Values

It is important that these limits are never exceeded. Such variations as mains fluctuations, component tolerances, and switching surges must be taken into consideration in arriving at actual valve operating conditions.

Filament Supply

The heater or filament voltage of a thyatron should be maintained within $\pm 2.5\%$ of its specified value. The valve will, however, accommodate temporary mains fluctuations up to $\pm 6\%$. The filament transformer for directly-heated types should be centre-tapped.

Current Ratings

For each rating of maximum average current, a maximum averaging time is quoted. This is to ensure that an anode current greater than the maximum permissible average value is not drawn for a time long enough to produce an excessive temperature within the valve. The maximum peak anode current is

determined by the available safe cathode emission, whereas the average current is limited by its heating effects. For periods less than the maximum averaging time it is permissible to draw average currents greater than the maximum rated value. In this case it should be understood that this maximum value must not be exceeded over *any* period equal to the maximum averaging time. When different values of peak current are quoted for different frequencies of operation, this must be taken into consideration.

The surge (fault protection) current rating indicates the maximum value of transients, resulting from a sudden overload or short circuit, which the valve will pass for a period not exceeding 0.1 seconds without immediate destruction. Several overloads of this nature will, however, appreciably reduce the life of the valve.

Use of Control Characteristics

The control characteristic is shown by upper and lower boundary curves within which all valves may be expected to remain during life. The control characteristic of a particular valve may move within these boundaries, although, as a rule, these limits should be considered as extreme cases. This should be taken into consideration when designing grid excitation circuits for thyratrons.

Effects of Positive Ion Current

When a thyatron is conducting, a positive ion current of magnitude proportional to the cathode current is generated. This current will, in general, flow to the electrode which is at the most negative potential during conduction. In order to prevent damage to the valve it is necessary to ensure that the voltage of this electrode is more positive than -10 V during this phase. This precaution will prevent: an increase in electrode emission due to excessive electrode dissipation; sputtering of electrode material; changes in the control characteristics caused by shift in contact potential; and, in inert gas-filled valves, a rapid gas clean-up.

In circuits where the control grid is held negative during anode conduction, a suitable choice of resistor in series with the grid will maintain an effective grid bias more positive than -10 V. The correct value of resistor may be determined from the grid ion current characteristic. If the instantaneous value of anode current is low then the restriction on grid bias does not apply. In general, the grid should be more positive than -10 V for all values of anode current greater than 10 per cent of the rated maximum average current.

In circuits where the anode potential changes from a positive to a negative value and the control grid is at a positive potential, thereby drawing cathode current, a small positive ion current flows to the anode. In such a case the inclusion of a high value of anode resistor is precluded by circuit requirements and the anode will usually reach a high negative potential. It is therefore essential to limit the magnitude of the positive ion current by severely restricting the current flowing from cathode to grid. This may be effected by using the maximum permitted series grid resistor and (or alternatively) keeping the positive grid voltage swing as low as possible.

In circuits where the anode potential changes very rapidly from a positive to a high negative value, as with inductive loads fed from polyphase supplies, there will be residual positive ions which will be drawn towards the anode with considerable energy. In an inert gas-filled valve this would result in excessive gas clean-up, therefore it is necessary to observe the limitations imposed by the appropriate commutation factor.

Valve Temperature Limitations

To ensure that the requisite valve heating time has elapsed before electron current is drawn from the cathode, it is necessary for the heater or filament to be run for the appropriate time which may be

determined from the heating and cooling characteristics. This precaution ensures that the cathode is at the correct temperature for electron emission and also that the gas pressure, in mercury vapour valves, is within the required limits. In applications where the ambient temperature is unduly low, some means of auxiliary heating may be required to assist in attaining the requisite minimum condensed mercury temperature.

It is necessary to provide adequate ventilation round the valve so that the maximum ambient or condensed mercury temperature is never exceeded. This avoids the danger of arc-back or loss of grid control.

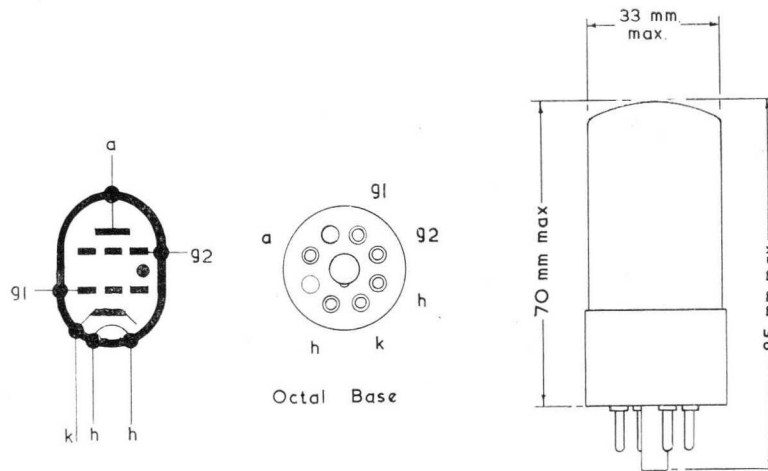
When it is necessary to check the condensed mercury temperature of mercury vapour thyratrons the following procedure should be adopted. A temperature indicator of low thermal capacity, such as a fine-wire thermocouple, should be attached to the valve at the mercury condensation point by means of the minimum amount of suitable adhesive or cement. Care should be taken to ensure that other conditions of operation, such as load current, ambient temperature of the air outside the equipment, and ventilation, remain unchanged during the measurement.

Power Supply Frequency Limitations

In general, when thyratrons are operated at frequencies below 25 c/s, a lower maximum peak anode current is applicable. This is necessary to ensure that cathode fatigue does not occur.

The maximum frequency at which a thyatron will operate satisfactorily is dependent upon the deionisation time and therefore upon the conditions of operation. At higher frequencies the valve will fail to operate because of arc-back and loss of grid control. At high frequencies the commutation factor should be kept as low as possible in order to ensure satisfactory life.

EN32



PRELIMINARY DATA

The EN32 is a tetrode thyratron with an inert gas filling and an indirectly-heated cathode, mounted on an international octal base. With the recommended connection of the shield grid to the cathode the valve has a negative control characteristic. The small control-grid current allows a high value grid resistor to be used, so that the EN32 can be controlled from a high impedance signal source such as a photocell. The valve is suitable for use in relay circuits, regulated power supplies, and general industrial applications.

The Services type number is CV2253.

CHARACTERISTICS

Electrical

Heater voltage	6.3	V
Heater current at 6.3 V	0.95	A
Control ratio		
g_2 to k and $R_{g1}=0 \Omega$	275	
g_1 to k and $R_{g2}=0 \Omega$	370	
Arc voltage	10	V

Mechanical

Type of cooling	Convection
Mounting position	Any

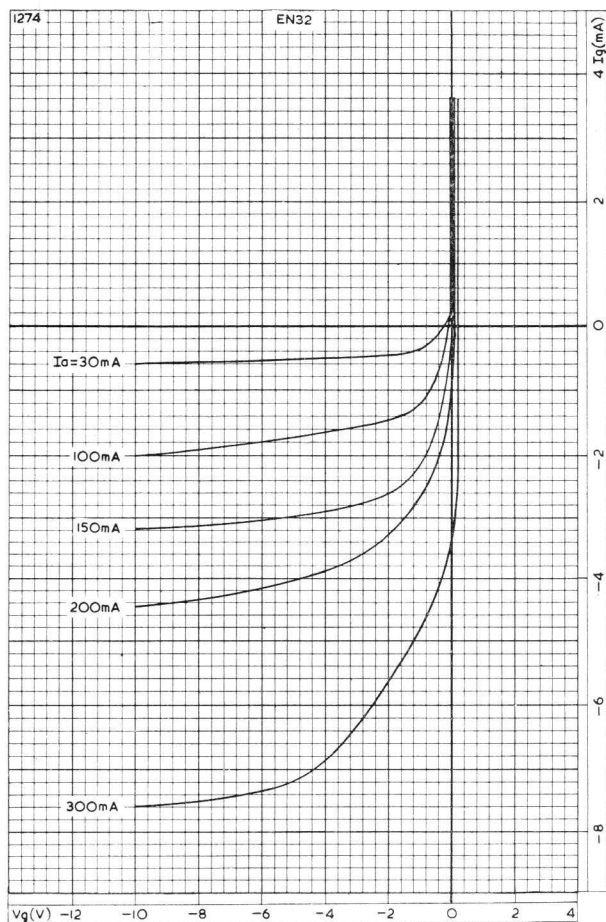
LIMITING VALUES (absolute ratings, not design centre)

Max. peak inverse anode voltage	1.3	kV
Max. peak forward anode voltage	650	V
Max. peak cathode current	2.0	A
Max. average cathode current (max. averaging time 15 secs.)	300	mA
Max. surge (fault protection) current (with max. duration of 0.1 sec.)	10	A
Max. negative control-grid voltage before conduction	250	V
Max. negative control-grid voltage during conduction	10	V
Max. average positive control-grid current for anode voltage more positive than -10 V (averaging time one cycle)	20	mA
Max. peak positive control-grid current for anode voltage more negative than -10 V	1.0	mA
Max. control-grid resistor ($I_a=200$ mA)	10	M Ω
Max. negative shield-grid voltage before conduction	100	V
Max. negative shield-grid voltage during conduction	10	V

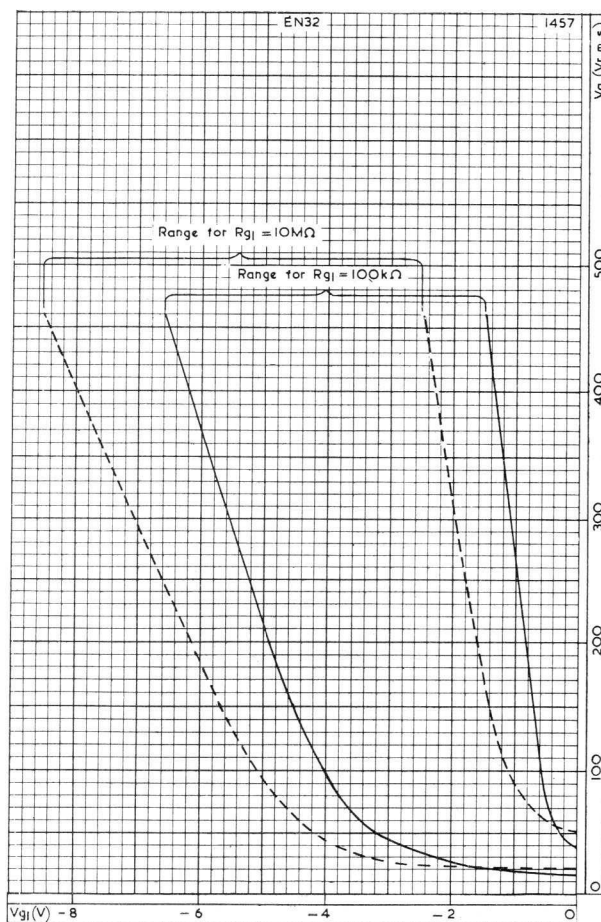
LIMITING VALUES (continued)

Max. average positive shield-grid current for anode voltage more positive than -10 V (averaging time one cycle)	20	mA
Max. peak heater-cathode voltage with heater positive	25	V
Max. peak heater-cathode voltage with heater negative	100	V
Min. valve heating time	15	secs.
Ambient temperature limits	-75 to $+90$	$^{\circ}$ C

Where circuit conditions permit, the shield-grid should be connected directly to the cathode.



GRID ION CURRENT CHARACTERISTICS



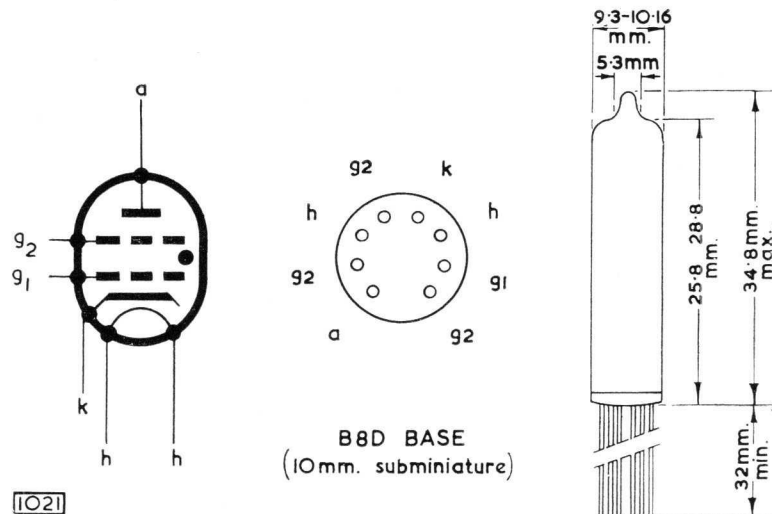
CONTROL CHARACTERISTIC

CONTROL CHARACTERISTIC

The curves indicate the spread in characteristics due to:

- (a) Variations in characteristics due to changes in heater voltage.
- (b) Variations in characteristics during life.
- (c) Variations in grid resistor.

EN70



The EN70 is a subminiature tetrode thyratron with an inert gas filling. It is in all-glass construction with flying leads which are designed to be soldered directly into circuits. Its small size makes it particularly useful where the available space is severely limited.

With the recommended connection of the shield grid to the cathode the valve has a negative control characteristic. The valve can be used with a high value of grid resistor, and it is very suitable for relay applications.

The Services type number is CV474.

Direct soldered connections to the leads of this valve must be at least 5 mm. from the seal and any bending of the valve leads must be at least 1.5 mm. from the seal.

LIMITING VALUES (absolute ratings, not design centre)

Max. peak inverse anode voltage	500	V
Max. peak forward anode voltage	500	V
Max. peak cathode current	100	mA
Max. average cathode current (max. averaging time 15 secs.)	20	mA
Max. negative control-grid voltage before conduction	200	V
Max. negative control-grid voltage during conduction	10	V
Max. average positive control-grid current for anode voltage more positive than -10 V (averaging time one cycle)	700	μ A
Max. peak positive control-grid current for anode voltage more positive than -10 V	2.0	mA
Max. peak positive control-grid current for anode voltage more negative than -10 V	30	μ A

CHARACTERISTICS

Electrical

Heater voltage	6.3	V
Heater current at 6.3 V		
Average	0.15	A
Maximum	0.165	A
Anode to control-grid capacitance	0.08	pF
Input capacitance	1.1	pF
Output capacitance	1.2	pF
Ionisation time (approx.)	0.5	μ sec
Arc voltage	11	V
Critical grid current at $V_a=350$ V _{r.m.s.}	0.2	μ A

Mechanical

Type of cooling	Convection
Mounting position	Any
Max. net weight	{ 0.1 oz. 3.0 g

LIMITING VALUES (continued)

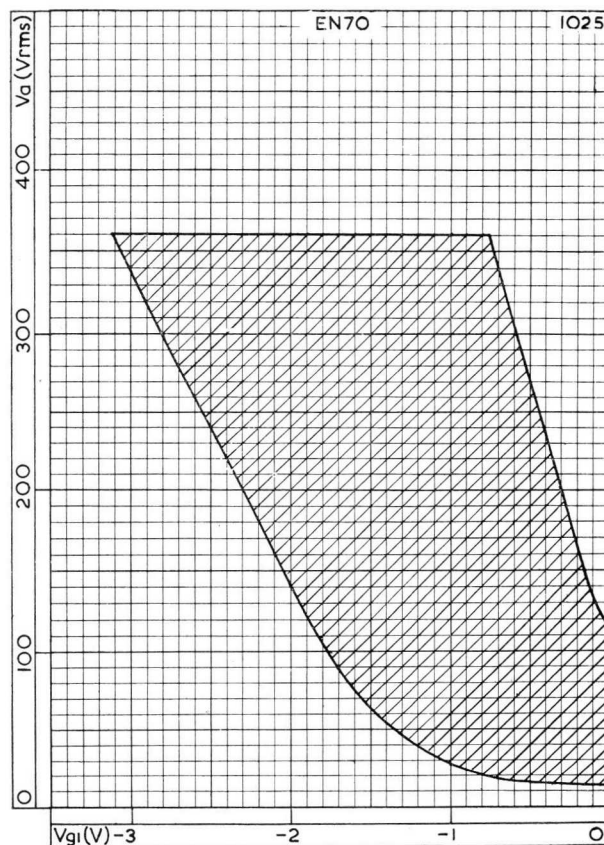
Max. control-grid resistor	10	M Ω
Recommended min. control-grid resistor	100	k Ω
<i>It is not desirable that the control-grid should be positive when the anode is more negative than -10 V, but where this condition is unavoidable the control-grid resistor may need to be greater than the recommended minimum value.</i>		
Max. negative shield-grid voltage before conduction	100	V
Max. negative shield-grid voltage during conduction	5.0	V
Max. average positive shield-grid current for anode voltage more positive than -10 V (averaging time one cycle)	700	μ A
Max. shield-grid resistor	1.0	M Ω
Max. peak heater-cathode voltage with heater positive	25	V
Max. peak heater-cathode voltage with heater negative	100	V
Min. valve heating time	10	secs.
Ambient temperature limits	-55 to +70	$^{\circ}$ C
Max. operating frequency	100	c/s

Where circuit conditions permit, the shield-grid should be connected directly to the cathode.

TYPICAL OPERATING CONDITIONS

Heater voltage	6.3	V
R.M.S. anode voltage	150	V
Shield-grid voltage	0	V
R.M.S. control-grid voltage (180 $^{\circ}$ out of phase with anode voltage)	5.0	V
*Peak control-grid signal voltage	5.0	V
Control-grid circuit resistance	1.0	M Ω
Anode circuit resistance	3.75	k Ω

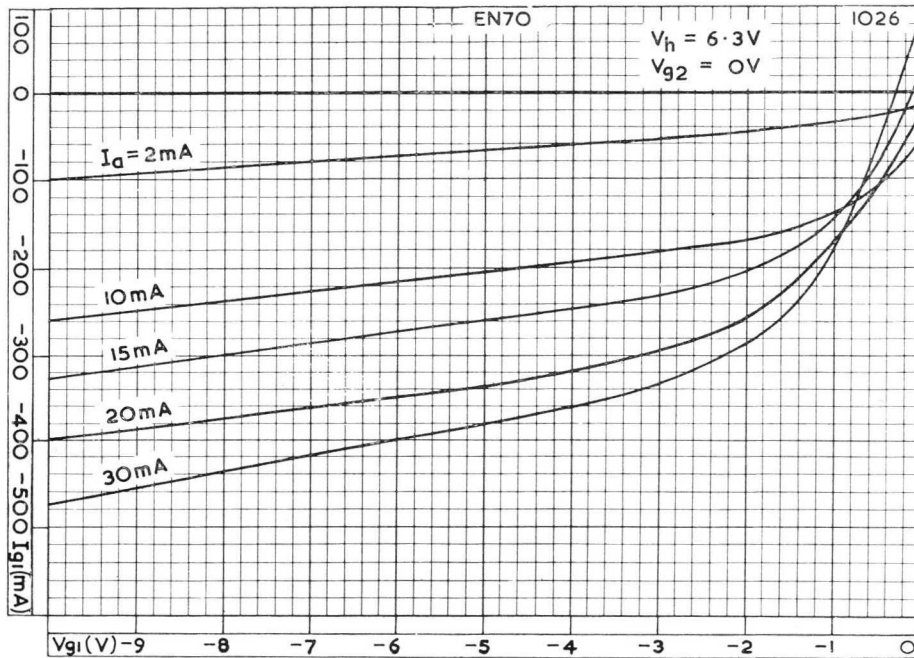
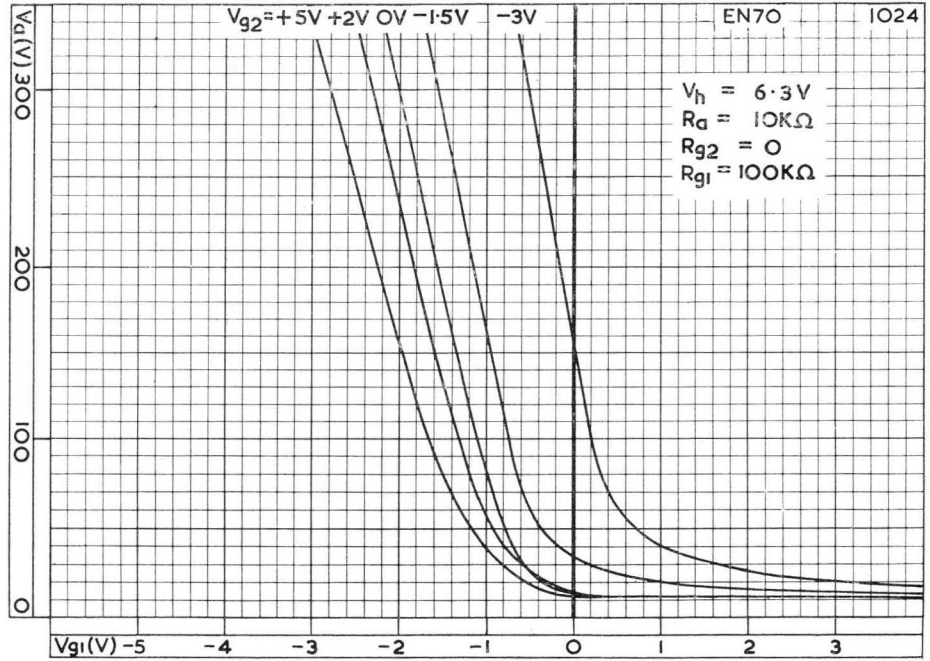
*The frequency of the signal is high compared with 50 c/s.



CONTROL CHARACTERISTIC

EN70

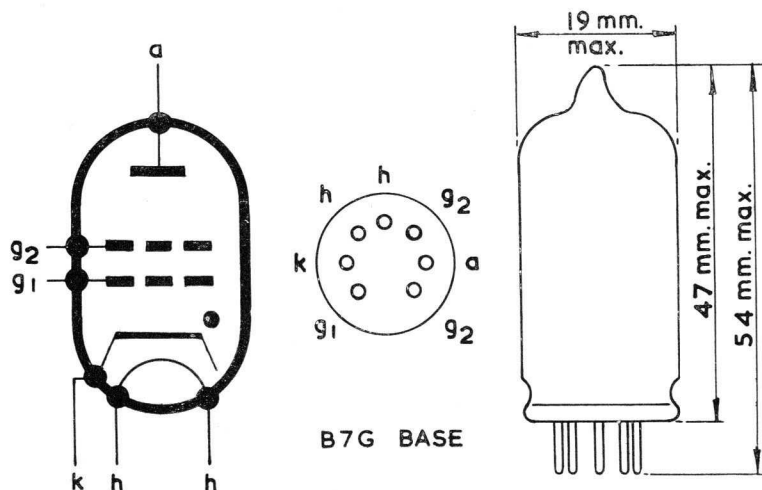
SPREAD OF CONTROL CHARACTERISTIC WITH SHIELD-GRID VOLTAGE AS PARAMETER



GRID ION CURRENT CHARACTERISTIC

EN91

(2D21)



The EN91 is a tetrode thyratron with an inert gas filling and an indirectly-heated cathode. The control and shield grids are brought out to separate pins on the B7G all-glass base. The valve has a negative control characteristic and a high control ratio which is independent of temperature over a wide range.

The low inter-electrode capacitances provide a substantial degree of immunity from line voltage surges. The small grid current allows a high value of grid circuit resistance to be used. This results in a high circuit sensitivity, so that the valve can be operated directly from a high vacuum photocell. The EN91 is primarily intended for use in relay or grid-controlled rectifier circuits.

The Services type number is CV797.

CHARACTERISTICS

Electrical

Heater voltage	6.3	V
Heater current at 6.3 V		
Average	0.60	A
Maximum	0.66	A
Anode to control-grid capacitance	0.03	pF
Control-grid to cathode and shield-grid capacitance	2.5	pF
Deionisation time (approx.)		
(a) $V_{g1} = -100$ V, $I_a = 100$ mA	35	μ sec
(b) $V_{g1} = -10$ V, $I_a = 100$ mA	75	μ sec
Ionisation time (approx.)	0.5	μ sec
Arc voltage	8	V
Critical grid current at $V_a = 460$ V r.m.s.	0.5	μ A

Mechanical

Type of cooling	Convection
Mounting position	Any

Max. net weight	}	0.5	oz.
		14	g

LIMITING VALUES (absolute ratings, not design centre)

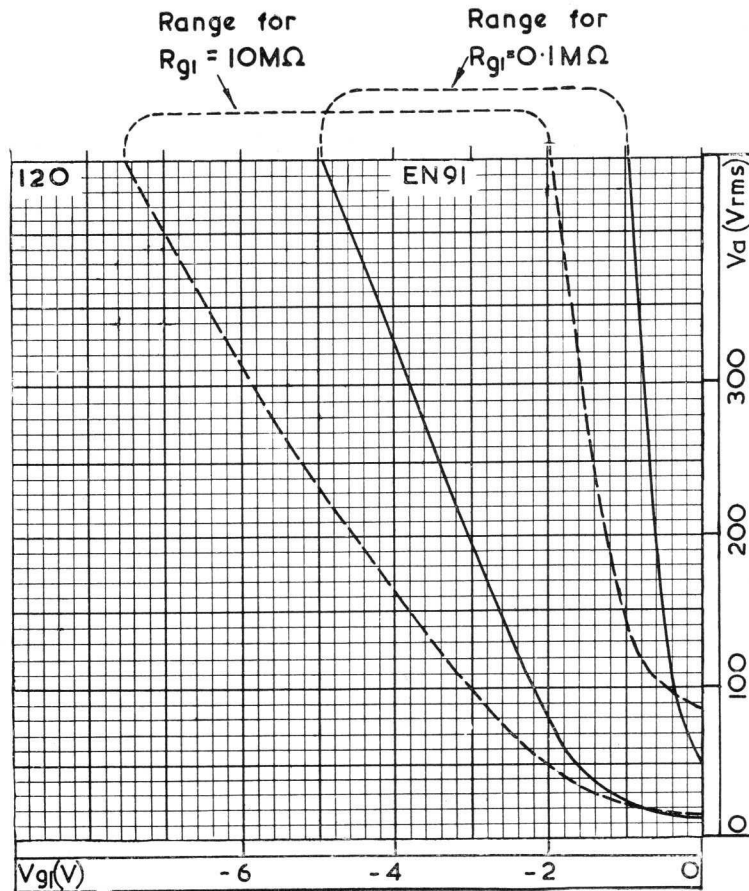
Max. peak inverse anode voltage	1.3	kV
Max. peak forward anode voltage	650	V
Max. peak cathode current	500	mA
Max. average cathode current (max. averaging time 30 secs.)	100	mA
Max. surge (fault protection) current (with max. duration of 0.1 sec.)	10	A
Max. negative control-grid voltage before conduction	100	V
Max. negative control-grid voltage during conduction	10	V
Max. average positive control-grid current for anode voltage more positive than -10 V (averaging time one cycle)	10	mA
Max. peak positive control-grid current for anode voltage more positive than -10 V	50	mA
Max. peak positive control-grid current for anode voltage more negative than -10 V	30	μ A

EN91

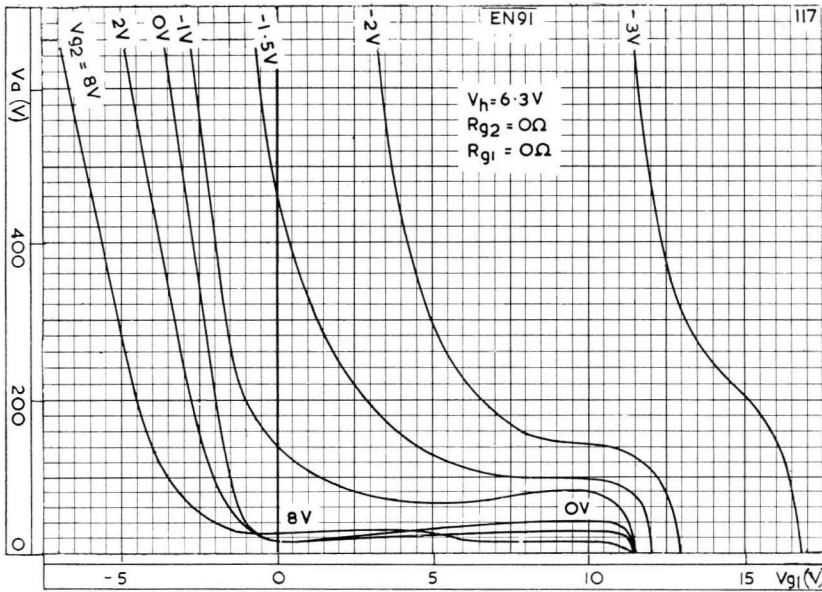
LIMITING VALUES (continued)

Max. control-grid resistor	10	M Ω
Recommended min. control-grid resistor	100	k Ω
<i>It is not desirable that the control-grid should be positive when the anode is more negative than -10 V, but where this condition is unavoidable the control-grid resistor may need to be greater than the recommended minimum value.</i>		
Max. negative shield-grid voltage before conduction	100	V
Max. negative shield-grid voltage during conduction	10	V
Max. average positive shield-grid current for anode voltage more positive than -10 V (averaging time one cycle)	10	mA
Max. shield-grid resistor	1.0	M Ω
Max. peak heater-cathode voltage with heater positive	25	V
Max. peak heater-cathode voltage with heater negative	100	V
Min. valve heating time	10	secs.
Ambient temperature limits	-75 to +90	$^{\circ}$ C
Max. operating frequency	500	c/s

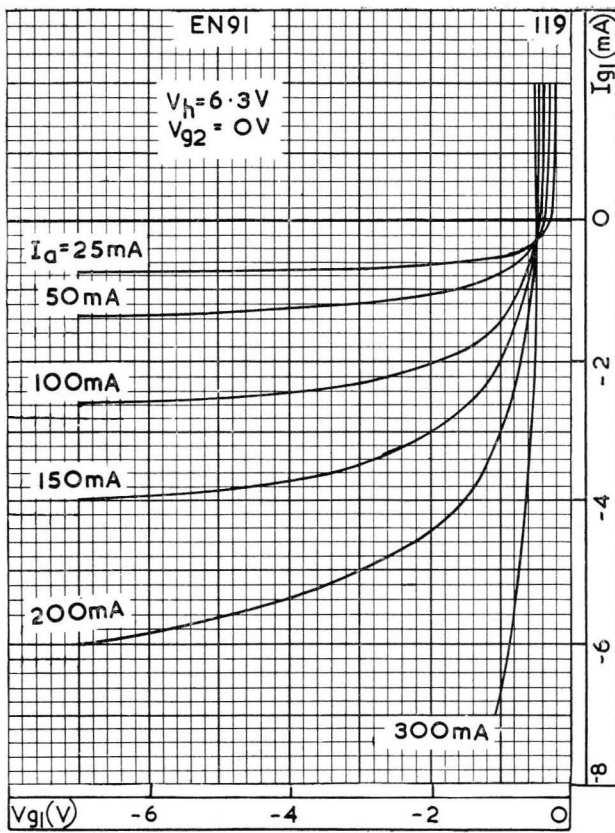
Where circuit conditions permit, the shield-grid should be connected directly to the cathode.



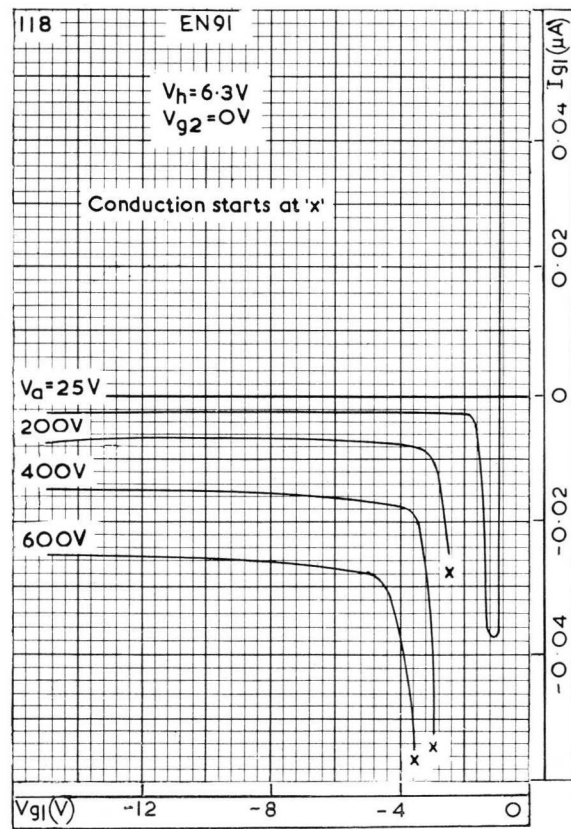
OPERATING RANGE OF
CRITICAL GRID VOLTAGE



SPREAD OF CONTROL CHARACTERISTIC WITH SHIELD-GRID VOLTAGE AS PARAMETER



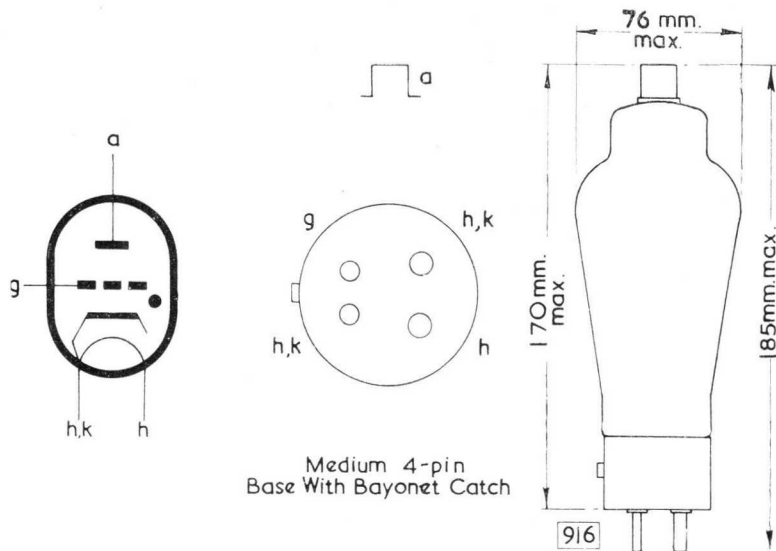
CONTROL-GRID CURRENT PLOTTED AGAINST CONTROL-GRID VOLTAGE DURING CONDUCTION



CONTROL-GRID CURRENT PLOTTED AGAINST CONTROL-GRID VOLTAGE BEFORE CONDUCTION

XGI-2500

(MT57)



The XGI-2500 is a triode thyatron with a mercury vapour filling and an indirectly-heated cathode, mounted on a medium four-pin base. The valve has a negative control characteristic, and it is designed for a maximum average cathode current of 2.5 amperes, with maximum peak values of 15 amperes at frequencies exceeding 25 c/s and 5 amperes at lower frequencies. Special ratings for ignitron firing service are given. The effect of anode voltage surges is minimised by the low value of anode-to-grid capacitance.

Relatively little power is required in the grid circuit, and the valve is suitable for motor control, ignitron firing, relay operation, and other industrial applications.

Max. net weight $\left\{ \begin{array}{l} 6.0 \text{ oz.} \\ 170 \text{ g} \end{array} \right.$

CHARACTERISTICS

Electrical

Heater voltage	5.0	V
Heater current at 5.0 V		
Average	4.5	A
Maximum	4.8	A
Anode to control-grid capacitance	4.0	pF
Control-grid to cathode capacitance	8.0	pF
Deionisation time (approx.)	1000	μsec
Ionisation time (approx.)	10	μsec
Arc voltage	16	V
Critical grid current at $V_a=1.0 \text{ kV}$	<20	μA

Mechanical

Type of cooling	Convection
Equilibrium condensed-mercury temperature rise above ambient	
At full load (approx.)	42 °C
At no load (approx.)	33 °C
Mounting position	Vertical, base down

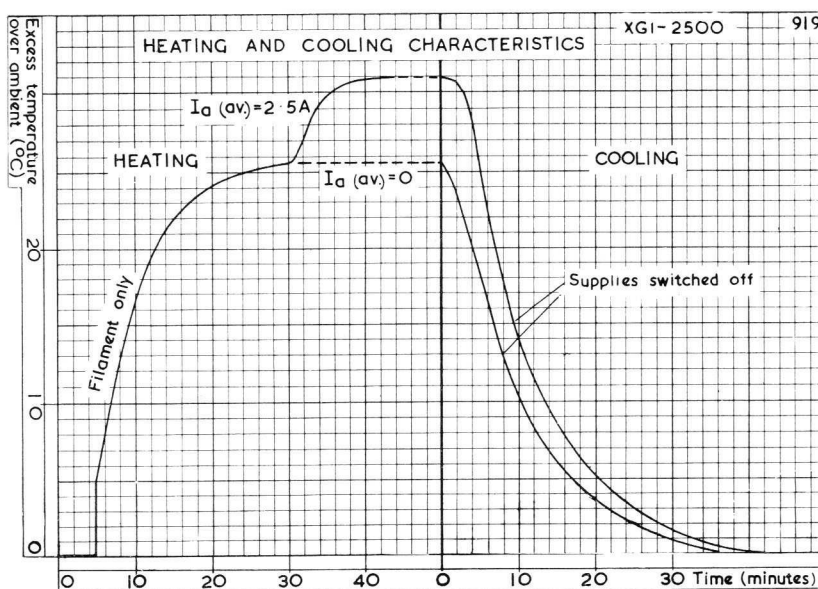
LIMITING VALUES (absolute ratings, not design centre)

Max. peak inverse anode voltage (condensed mercury temperature 40 to 75°C)	1.5	kV
Max. peak inverse anode voltage (condensed mercury temperature 40 to 80°C)	1.0	kV
Max. peak forward anode voltage (condensed mercury temperature 40 to 75°C)	1.0	kV
Max. peak forward anode voltage (condensed mercury temperature 40 to 80°C)	1.0	kV

Max. condensed mercury temperature rating for intermediate anode voltages may be determined by linear interpolation.

LIMITING VALUES (continued)

Max. peak cathode current (25 c/s and above)	15	A
Max. peak cathode current (below 25 c/s)	5.0	A
Max. peak cathode current (ignitron firing service)	40	A
Max. average cathode current (max. averaging time 15 secs.)	2.5	A
Max. average cathode current (ignitron firing service)	1.0	A
Max. surge (fault protection) current (with max. duration of 0.1 sec.)	200	A
Max. negative control-grid voltage before conduction	500	V
Max. negative control-grid voltage during conduction	10	V
Max. average positive control-grid current for anode voltage more positive than -10 V (averaging time 15 secs.)	250	mA
Max. peak positive control-grid current for anode voltage more positive than -10 V	1.0	A
Max. peak positive control-grid current for anode voltage more negative than -10 V	100	mA
Max. control-grid resistor	100	k Ω
Recommended min. control-grid resistor	10	k Ω
Min. valve heating time—see heating and cooling characteristic below		
Max. power supply frequency	150	c/s



Time required for **cathode** to reach operating temperature=5 minutes.

TYPICAL EXAMPLE OF THE APPLICATION OF HEATING AND COOLING CHARACTERISTICS

The minimum permissible condensed mercury temperature for XGI-2500 is 40°C and, assuming an ambient temperature of 15°C, it is necessary

therefore to wait until the excess mercury temperature has risen by 25° before applying the h.t. supplies.

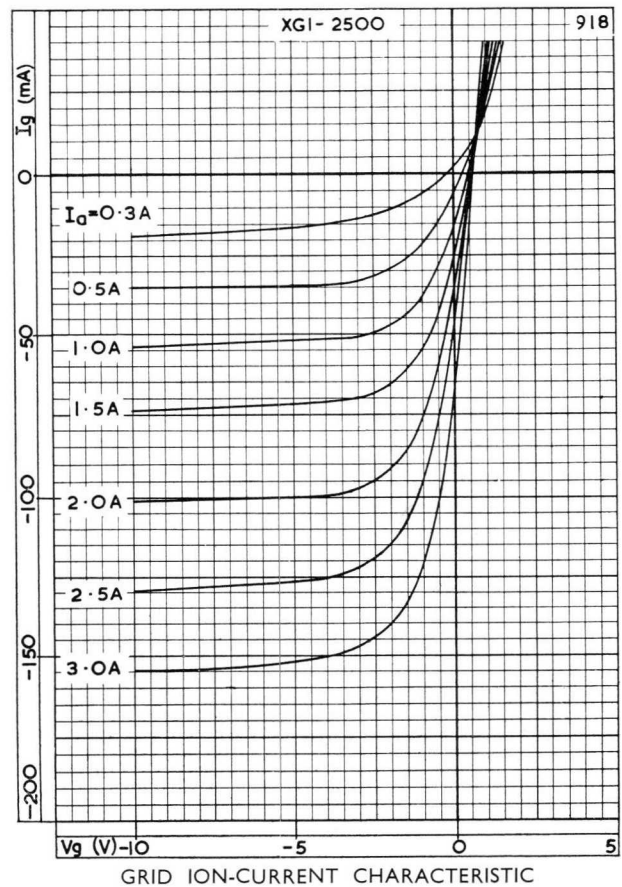
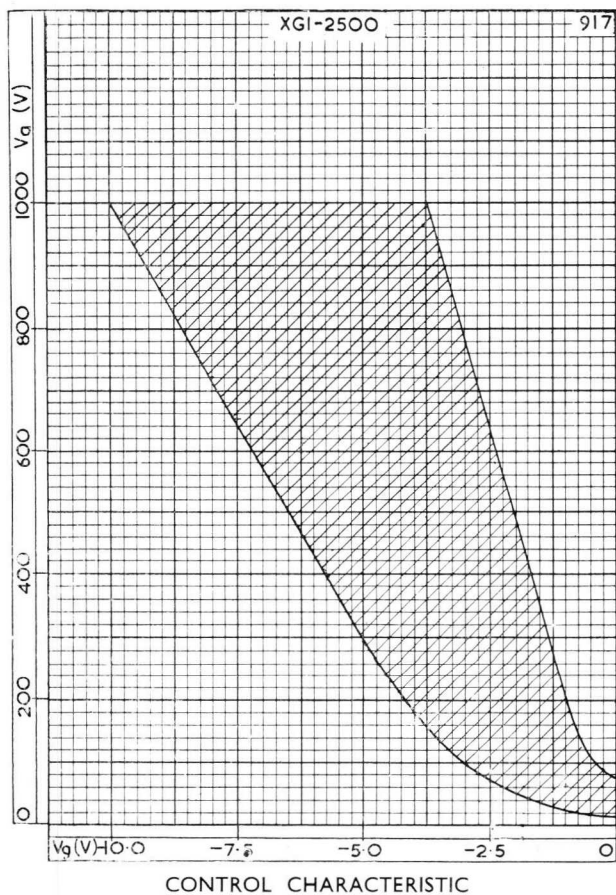
From the heating characteristic it will be seen that this entails a delay of at least 24 mins. After applying the h.t. the valve is operated at a mean anode current

of 2.5 A for a time sufficient for the condensed mercury temperature to reach equilibrium conditions. If, now, both h.t. and filament supplies are switched off for a period of 20 mins. it is observed from the cooling characteristic that the excess temperature at the end of this period will be 5.3° .

Upon switching on the filament again the heating-up time indicated on the heating characteristic for an excess temperature of 5.3° (i.e. 5 mins.) may be deducted from the total heating up time of 24 mins. originally required for an excess temperature of 25° to give a reheating time of 19 mins. before applying the h.t. supplies again.

In each case the time required for re-heating exceeds the minimum *cathode* heating time of 5 minutes.

When the normal operation of the valve is at a lower peak current than the maximum rating, it may be permissible to reduce considerably the preliminary valve heating time. If such a reduction is proposed, however, reference should first be made to Mullard Ltd.



CONTROL CHARACTERISTIC

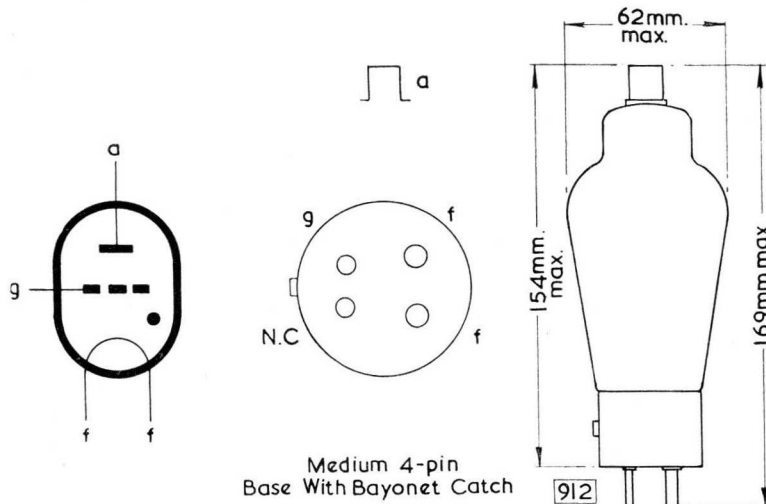
The shaded area between the curves indicates the spread in characteristics due to:—

- (a) Initial differences between individual valves.
- (b) Variations in characteristics during life.
- (c) Variations in characteristics due to changes in heater voltage.
- (d) The effects of circuit loading.

The effects of different values of series grid resistor have been ignored.

XG5-500

(MT17)



Medium 4-pin
Base With Bayonet Catch

The XG5-500 is a triode thyatron with mercury vapour filling and a directly-heated cathode, mounted on a medium four-pin base.

The valve has a negative control characteristic. The maximum average cathode current rating is 500 mA, with maximum peak values of 2.0 amperes at frequencies greater than 25 c/s and 1.0 ampere at lower frequencies. The low value of anode-to-grid capacitance reduces the risk of anode voltage surges affecting the grid circuit. The valve is designed primarily for use in industrial control circuits.

CHARACTERISTICS

Electrical

Filament voltage	2.5	V
Filament current at 2.5 V		
Average	5.0	A
Maximum	5.4	A
Anode to control-grid capacitance	4.0	pF
Control-grid to cathode capacitance	8.0	pF
Deionisation time (approx.)	1000	μ sec
Ionisation time (approx.)	10	μ sec
Arc voltage	16	V
Critical grid current at $V_a=2.5$ kV	<20	μ A

Mechanical

Type of cooling	Convection
Equilibrium condensed-mercury temperature rise above ambient	
At full load (approx.)	28 °C
At no load (approx.)	20 °C

Mounting position	Vertical, base down						
Max. net weight	<table border="0"> <tr> <td>{</td> <td>4.0</td> <td>oz.</td> </tr> <tr> <td>{</td> <td>114</td> <td>g</td> </tr> </table>	{	4.0	oz.	{	114	g
{	4.0	oz.					
{	114	g					

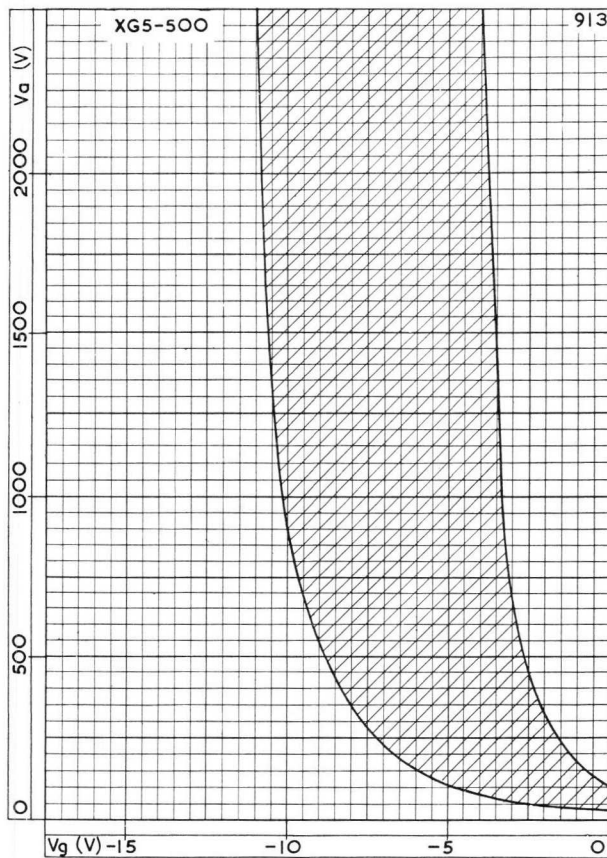
LIMITING VALUES (absolute ratings, not design centre)

Max. peak inverse anode voltage	5.0	kV
Max. peak forward anode voltage	2.5	kV
Max. peak cathode current (25 c/s and above)	2.0	A
Max. peak cathode current (below 25 c/s)	1.0	A
Max. average cathode current (max. averaging time 15 secs.)	500	mA
Max. surge current (with max. duration of 0.1 sec.)	40	A
Max. negative control-grid voltage before conduction	500	V
Max. negative control-grid voltage during conduction	10	V

XG5-500

LIMITING VALUES (continued)

Max. average positive control-grid current for anode voltage more positive than -10 V (averaging time 15 secs.)	50	mA
Max. peak positive control-grid current for anode voltage more positive than -10 V	250	mA
Max. peak positive control-grid current for anode voltage more negative than -10 V	50	mA
Max. control-grid resistor	100	k Ω
Recommended min. control-grid resistor	10	k Ω
Min. valve heating time—see heating and cooling characteristic on page 49.		
Condensed mercury temperature limits	+35 to +70	$^{\circ}$ C
Max. power supply frequency	150	c/s

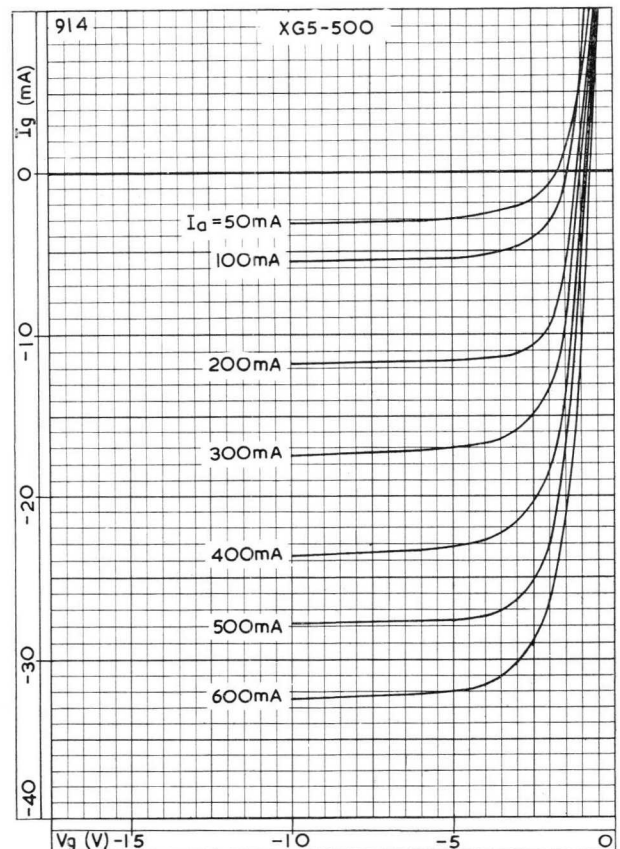


CONTROL CHARACTERISTIC

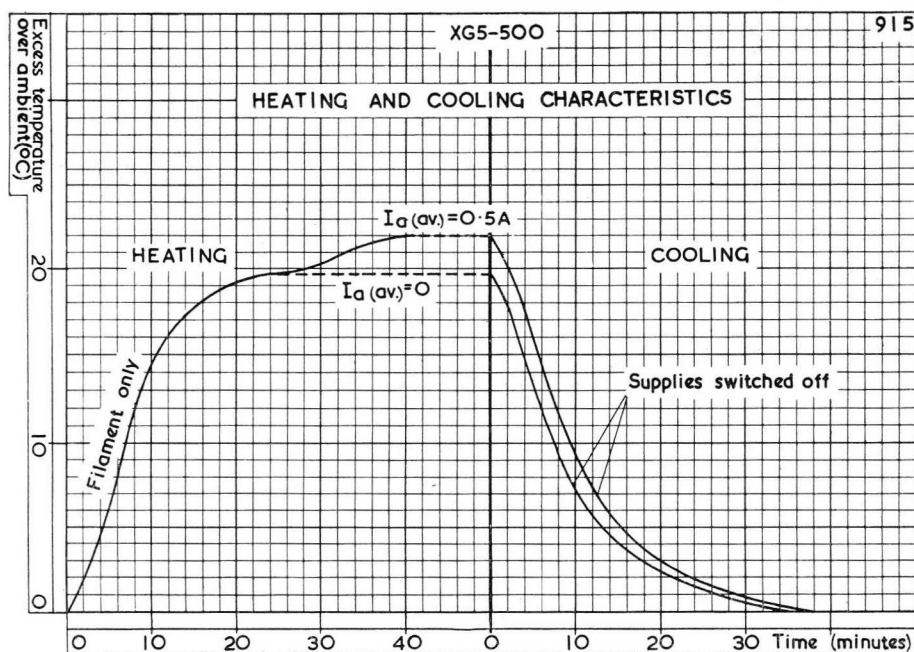
The shaded area between the curves indicates the spread in characteristics due to:—

- (a) Initial differences between individual valves.
- (b) Variations in characteristics during life.
- (c) Variations in characteristics due to changes in heater voltage.
- (d) The effects of circuit loading.

The effects of different values of series grid resistor have been ignored.



GRID ION CURRENT CHARACTERISTIC



HEATING AND COOLING CHARACTERISTICS

Time required for **cathode** to reach operating temperature = 5 seconds.

TYPICAL EXAMPLE OF THE APPLICATION OF HEATING AND COOLING CHARACTERISTICS

The minimum permissible condensed mercury temperature for XG5-500 is 35°C and, assuming an ambient temperature of 20°C, it is necessary therefore, to wait until the excess mercury temperature has risen by 15° before applying the h.t. supplies.

From the heating characteristic it will be seen that this entails a delay of at least 11 mins. After applying the h.t. the valve is operated at a mean anode current of 500 mA for a time sufficient for the condensed mercury temperature to reach equilibrium conditions. If, now, both h.t. and filament supplies are switched off for a period of 15 mins. it is observed from the cooling characteristic that the excess temperature at the end of this period will be 5.2°.

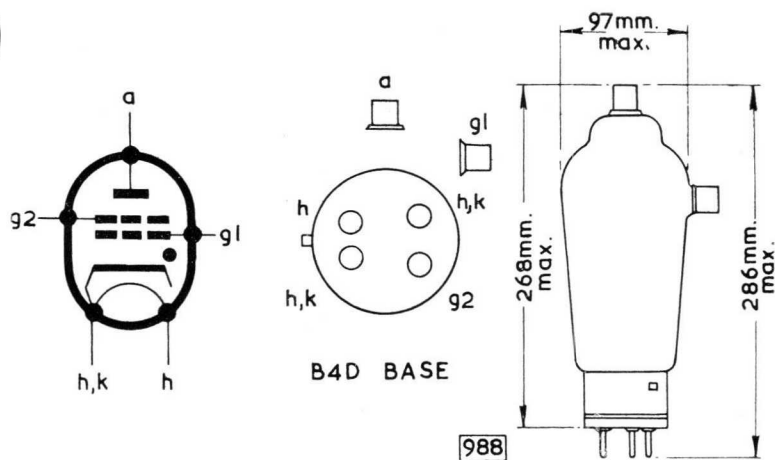
Upon switching on the filament again the heating-up time indicated on the heating characteristic for an excess temperature of 5.2° (i.e. 4.5 mins.) may be deducted from the total heating-up time of 11 mins. originally required for an excess temperature of 15° to give a reheating time of 6.5 mins. before applying the h.t. supplies again.

In each case the time required for re-heating exceeds the minimum *cathode* heating time of 5 seconds.

When the normal operation of the valve is at a lower peak current than the maximum rating, it may be permissible to reduce considerably the preliminary valve heating time. If such a reduction is proposed, however, reference should first be made to Mullard Ltd.

XGQ2-6400

(MT105)



The XGQ2-6400 is a tetrode thyatron with a mercury vapour filling and an indirectly-heated cathode, mounted on a B4D four-pin "super-jumbo" base. It has a negative control characteristic. The maximum average cathode current is 6.4 amperes, with maximum peak ratings of 40 amperes. The shield grid is brought out to a separate pin. It should normally be connected to the cathode via a resistor of 10 k Ω .

The valve is suitable for motor control and other industrial applications.

CHARACTERISTICS

Electrical

Heater voltage	5.0	V
Average heater current at 5.0 V	10	A
Anode to control-grid capacitance	2.0	pF
Deionisation time (approx.)	1000	μ sec
Ionisation time (approx.)	10	μ sec
Arc voltage	16	V

Mechanical

Type of cooling	Convection	
Mounting position	Vertical, base down	
Max. net weight	17	oz.
	500	g

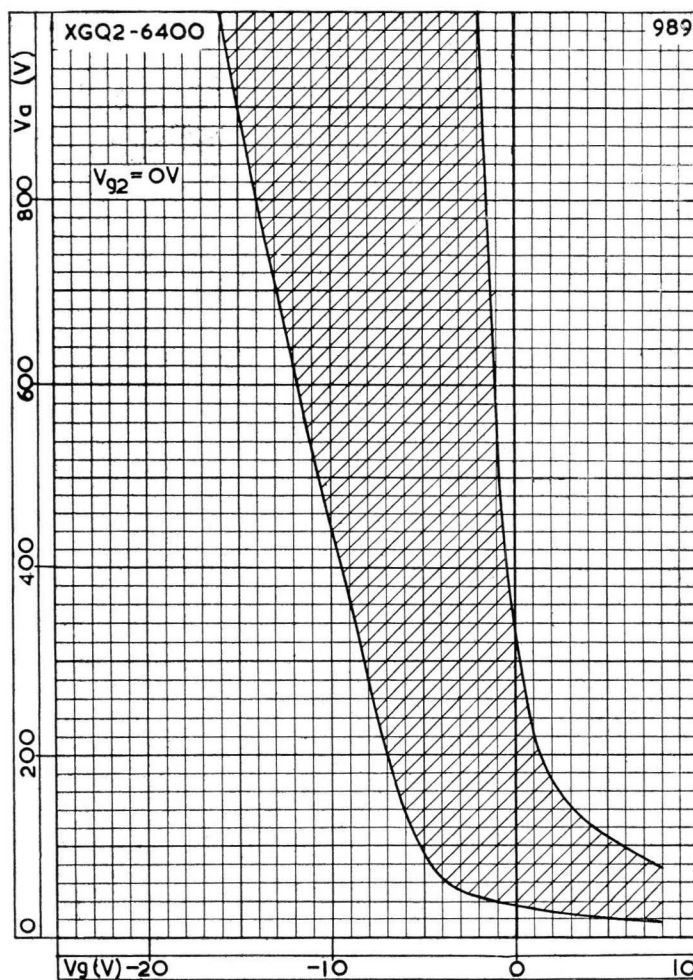
LIMITING VALUES (absolute ratings, not design centre)

Max. peak inverse anode voltage	2.5	kV
Max. peak forward anode voltage	2.5	kV
Max. peak cathode current (25 c/s and above)	40	A
Max. peak cathode current (below 25 c/s)	12.8	A
Max. average cathode current (max. averaging time 15 secs.)	6.4	A
Max. surge (fault protection) current (with max. duration of 0.1 sec.)	400	A
Max. negative control-grid voltage before conduction	1.0	kV
Max. negative control-grid voltage during conduction	10	V
Max. average positive control-grid current for anode voltage more positive than -10 V (averaging time 15 secs.)	250	mA
Max. peak positive control-grid current for anode voltage more positive than -10 V	1.0	A

LIMITING VALUES (continued)

XGQ2-6400

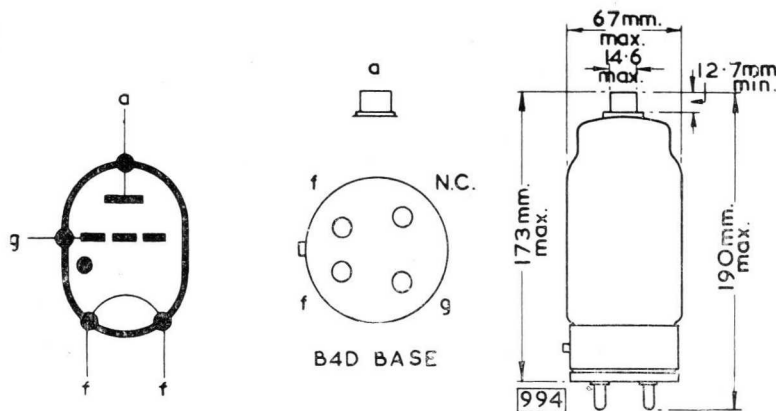
Max. control-grid resistor	100	k Ω
Recommended min. control-grid resistor	10	k Ω
Max. negative shield-grid voltage before conduction	500	V
Max. negative shield-grid voltage during conduction	10	
Max. average positive shield-grid current for anode voltage more positive than -10 V (averaging time 15 secs.)	500	mA
Max. peak positive shield-grid current for anode voltage more positive than -10 V	2.0	A
Max. shield-grid resistor	10	k Ω
Min. valve heating time	5	minutes
Condensed mercury temperature limits	+40 to +80	$^{\circ}\text{C}$



CONTROL CHARACTERISTIC

XRI-3200

(MT5544)



The XRI-3200 is a triode thyatron with an inert gas filling and a directly-heated cathode, mounted on a B4D four-pin "super-jumbo" base.

The valve is designed for an average cathode current of 3.2 amperes, with a maximum peak value of 40 amperes. The maximum peak inverse and forward anode voltages are both 1.5 kV. The valve has a negative control characteristic, and it is suitable for use in motor control and inverter circuits and for ignitron firing and other industrial applications.

The Services type number is CV2210.

Max. net weight $\left\{ \begin{array}{l} 11 \text{ oz.} \\ 300 \text{ g} \end{array} \right.$

CHARACTERISTICS

Electrical

Filament voltage	2.5	V
Filament current at 2.5 V		
Average	12	A
Maximum	13.5	A
Anode to control-grid capacitance	0.8	pF
Control-grid to cathode capacitance	45	pF
Deionisation time (approx.)		
(a) $V_g = -250$ V	40	μsec
(b) $V_g = -12$ V	400	μsec
Ionisation time (approx.)	10	μsec
Arc voltage (approx.)	16	V
Critical grid current at $V_a = 1.5$ kV	<20	μA

Mechanical

Type of cooling	Convection
Mounting position	Any position between horizontal and vertical with base downwards.

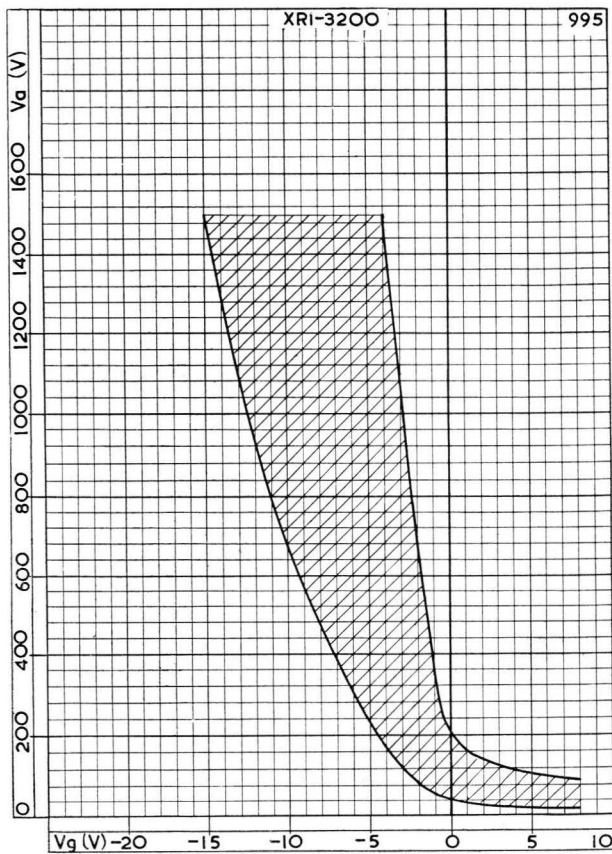
LIMITING VALUES (absolute ratings, not design centre)

Max. peak inverse anode voltage	1.5	kV
Max. peak forward anode voltage	1.5	kV
Max. peak cathode current	40	A
Max. average cathode current (max. averaging time 15 secs.)	3.2	A
Max. surge (fault protection) current (with max. duration of 0.1 sec.)	560	A
Max. negative control-grid voltage before conduction	250	V
Max. negative control-grid voltage during conduction	10	V

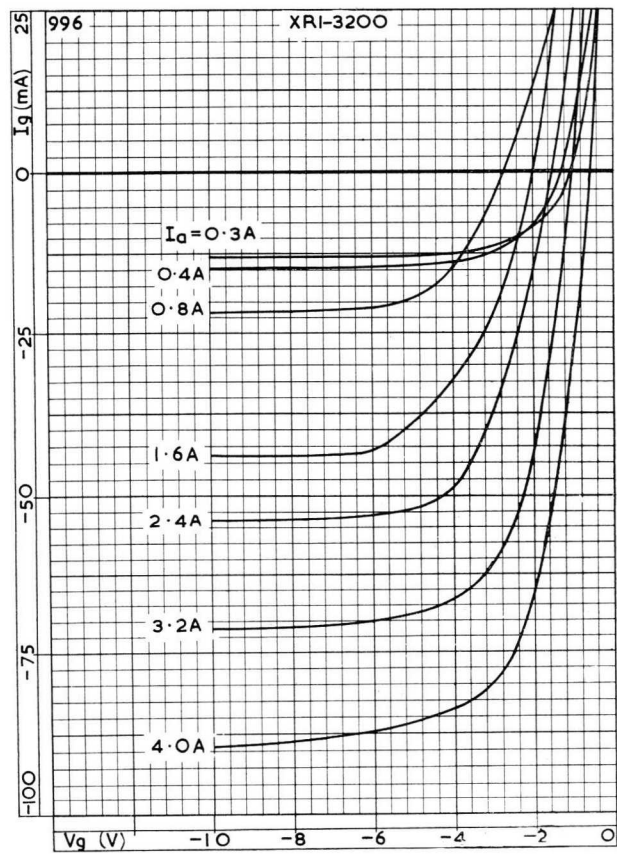
LIMITING VALUES (continued)

XRI-3200

Max. average positive control-grid current for anode voltage more positive than -10 V (averaging time one cycle)	200	mA
Max. peak positive control-grid current for anode voltage more positive than -10 V	2.5	A
Max. peak positive control-grid current for anode voltage more negative than -10 V	25	mA
Max. control-grid resistor	100	k Ω
Recommended min. control-grid resistor	500	Ω
Min. valve heating time	60	secs.
Ambient temperature limits	-55 to $+70$	$^{\circ}\text{C}$
Max. commutation factor	130	



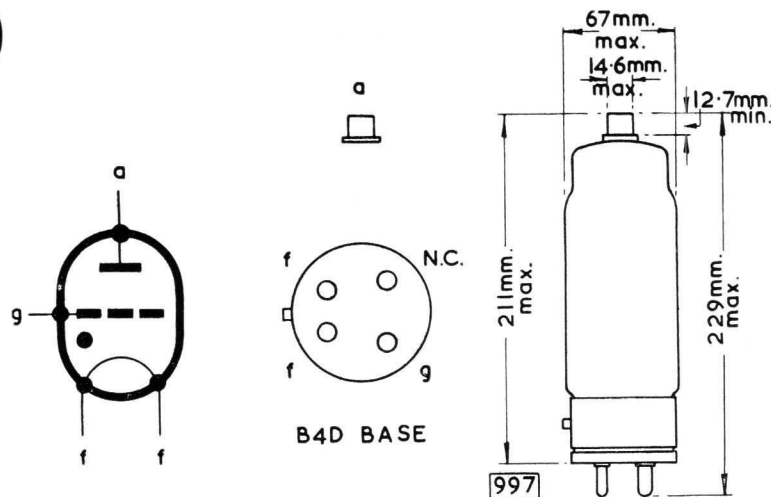
CONTROL CHARACTERISTIC



GRID ION CURRENT CHARACTERISTICS

XRI-6400

(MT5545)



The XRI-6400 is a triode thyratron with an inert gas filling and a directly-heated cathode, mounted on a B4D four-pin "super-jumbo" base.

The valve has a negative control characteristic which is similar to that of the XR1-3200; but the maximum average cathode current rating is increased to 6.4 amperes, with a maximum peak value of 80 amperes.

The valve is particularly suitable for use in motor and welding control circuits.

The Services type number is CV2215.

Max. net weight

{ 12 oz.
340 g

CHARACTERISTICS

Electrical

Filament voltage	2.5	V
Filament current at 2.5 V		
Average	21	A
Maximum	23	A
Anode to control-grid capacitance	0.8	pF
Control-grid to cathode capacitance	45	pF
Deionisation time (approx.)		
(a) $V_g = -250$ V	50	μ sec
(b) $V_g = -12$ V	500	μ sec
Ionisation time (approx.)	10	μ sec
Arc voltage (approx.)	16	V
Critical grid current at $V_a = 1500$ V	<20	μ A

Mechanical

Type of cooling	Convection
Mounting position	Any position between horizontal and vertical with base downwards

LIMITING VALUES (absolute ratings, not design centre)

Max. peak inverse anode voltage	1.5	kV
Max. peak forward anode voltage	1.5	kV
Max. peak cathode current	80	A
Max. average cathode current (max. averaging time 15 secs.)	6.4	A
Max. surge current (with max. duration of 0.1 sec.)	1120	A
Max. negative control-grid voltage before conduction	250	V
Max. negative control-grid voltage during conduction	10	V

LIMITING VALUES (continued)

XRI-6400

Max. average positive control-grid current for anode voltage more positive than -10 V (averaging time one cycle)	200	mA
Max. peak positive control-grid current for anode voltage more positive than -10 V	2.5	A
Max. peak positive control-grid current for anode voltage more negative than -10 V	25	mA
Max. control-grid resistor	100	k Ω
Recommended min. control-grid resistor	500	Ω
Min. valve heating time	60	secs.
Ambient temperature limits	-55 to +70	$^{\circ}\text{C}$
Max. commutation factor	130	

