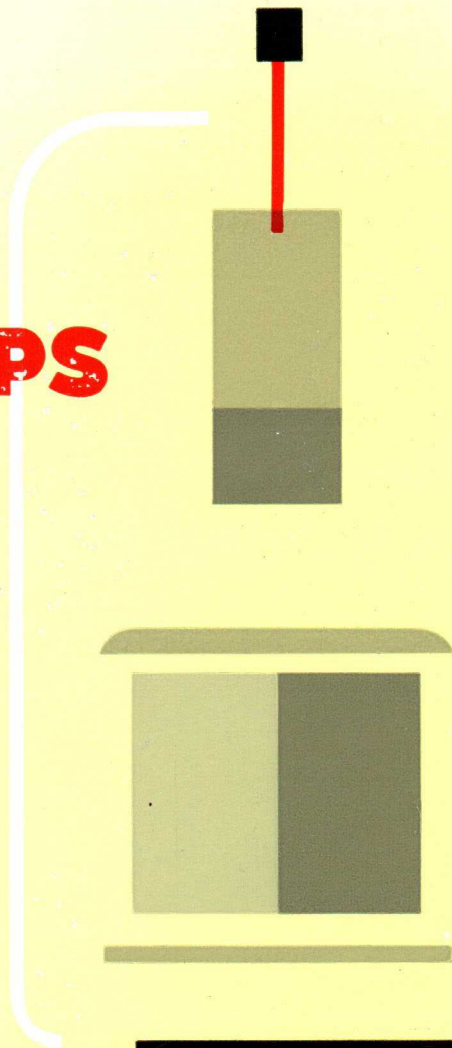
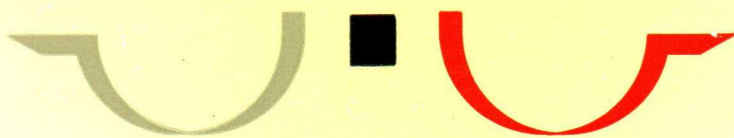


PHILIPS



THYRATONS



for modern industry

PHILIPS ELECTRON TUBE DIVISION



Preface

The use of electronic devices in industrial processes for measuring, controlling, power conversion and for many other applications is growing steadily.

There are various reasons for this common trend, the principal being mechanisation and automation of production. And although many operations can be carried out mechanically or electro-mechanically, electronic devices will often be preferred, since in many applications they have proved to be more reliable, more flexible and less expensive.

In all industrial processes where control of large currents is required — such as motor control, small welding apparatus, dimming of fluorescent lamps — thyratrons are used. This type of tube excels by the possibility of controlling large anode currents at the expense of only very small powers in the grid circuit.

This Bulletin gives a description of the basic principles of thyatron operation and furthermore full data of the most important types of thyatron. The second part of the Bulletin is devoted to the description of a number of applications of thyratrons in a wide variety of industrial processes. The circuits are so chosen that they can be used either for the purpose they are designed for, or as basic circuits, to be adapted or extended for other industrial applications. Equally, tubes of smaller or larger power may be used in the circuits described, but this is, of course, up to the design engineer.

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The information given in this Bulletin does
not imply a licence under any patent.

Part I
General Information
and
Tube Data



I. Introduction

PRINCIPLES OF OPERATION

There is an essential difference between the characteristics of thyratrons and those of grid-controlled vacuum tubes. Whereas in vacuum tubes the controlling action of the grid is maintained whether anode current flows or not, in a thyatron the controlling action of the grid is limited to determination of the moment of ignition, also called firing or striking point. Once the current flow in a thyatron has been initiated, the grid is shielded by an ion sheath and has no longer any control of the discharge. The anode current continues to flow until the voltage between the anode and the cathode has dropped below the extinction (or "arc") voltage. For each value of positive anode voltage there is a correspond-

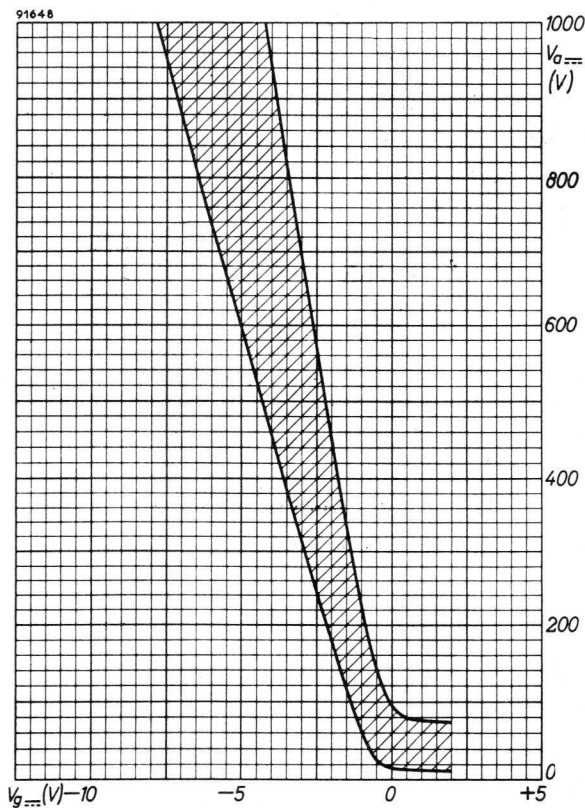


Fig. 1.1. Ignition characteristic of a thyatron.

ing value of grid voltage at which firing of the tube occurs. This connection between the anode voltage and the grid ignition voltage is usually plotted in a graph, termed the *critical control characteristic* of the tube. The characteristic is called "critical", because at the grid voltage corresponding to that characteristic the tube suddenly shifts from the non-conducting to the conducting state.

Since the operating conditions of thyratrons depend not only on the grid and anode voltages, but also on external conditions, in particular the ambient temperature, this characteristic is not represented by a single curve but by a shaded area indicating the range within which ignition may occur (see Fig. 1.1). In the region to the left of the curve the tube remains non-conducting, in the region to the right it is conducting.

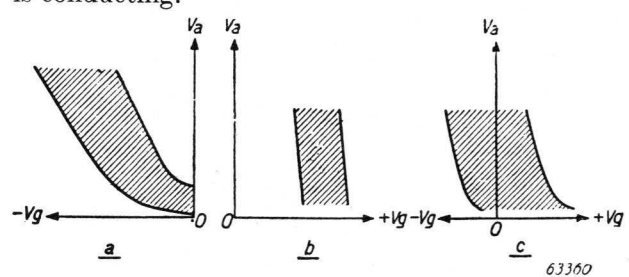


Fig. 1.2. Control characteristics of mercury-vapour thyratrons with makers tolerances: a) negative control characteristic; b) positive control characteristic; c) transitory control characteristic.

Thyratrons may have either a negative, a transitory or a positive control characteristic, examples of which are given in Fig. 1.2. At first sight it may be considered to be an advantage that tubes having a positive control characteristic do not require a negative grid bias source. This advantage, however, is counteracted by the fact that such tubes draw a considerably higher grid current than thyratrons with a negative control characteristic.

GRID CONTROL

There are, in principle, two methods of grid control, known as vertical and horizontal control. To inves-

tigate these methods of control, the ignition characteristic shown in Fig. 1.1 will be converted into a control characteristic by plotting the grid voltage V_g which must be reached or exceeded to ensure that the thyatron is fired, as a function of the phase angle ϑ (firing angle) of the alternating anode voltage V_a .

Vertical control

For vertical control an alternating voltage $V_{g\sim}$, which is in quadrature to the alternating voltage V_a and is superimposed on a variable direct voltage $V_{g=}$, is applied to the grid of the thyatron as represented in Fig. 1.3. The hatched area corresponds to that indicated in Fig. 1.1, the anode voltage being assumed to have a peak value of 750 V.

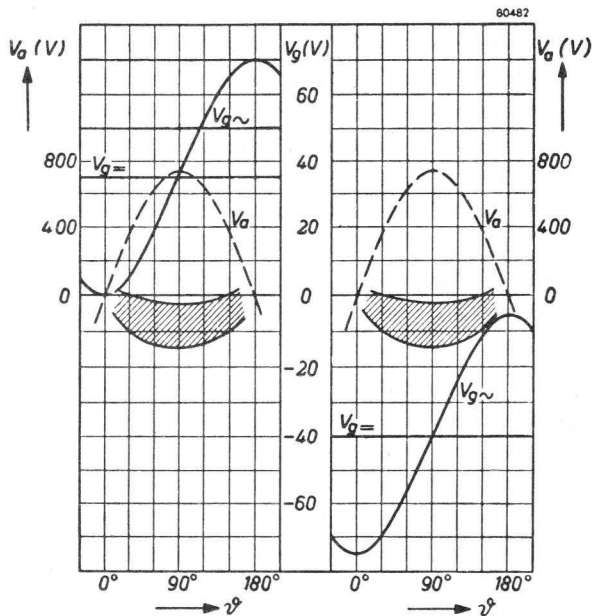


Fig. 1.3. Vertical control of a thyatron by means of an alternating grid voltage $V_{g\sim}$ superimposed on a variable direct grid voltage $V_{g=}$. At the left ($V_{g=} = +35$ V) the control characteristic (hatched area) is intersected almost without phase delay (small firing angle ϑ). At the right ($V_{g=} = -40$ V) the control characteristic is not intersected at all, so that the thyatron will not be fired.

It will be assumed for the time being that the firing range, i.e. the range of the firing angle ϑ , is required to be approximately 150° . Fig. 1.3 shows that at an alternating grid voltage of $V_{g\sim} = 35$ V (peak value) the direct grid voltage $V_{g=}$ should then range from $+35$ V to -40 V. At $V_{g=} = -40$ V the control characteristic will not be intersected by the curve which represents the grid voltage, so that the thyatron remains extinguished, whereas at $V_{g=} = +35$ V the firing angle is a few degrees only,

in other words the thyatron will be conducting during almost the entire positive half cycle of the alternating anode voltage.

Horizontal control

In the case of horizontal control an alternating voltage $V_{g\sim}$ of constant amplitude but of varying phase is applied to the grid of the thyatron.

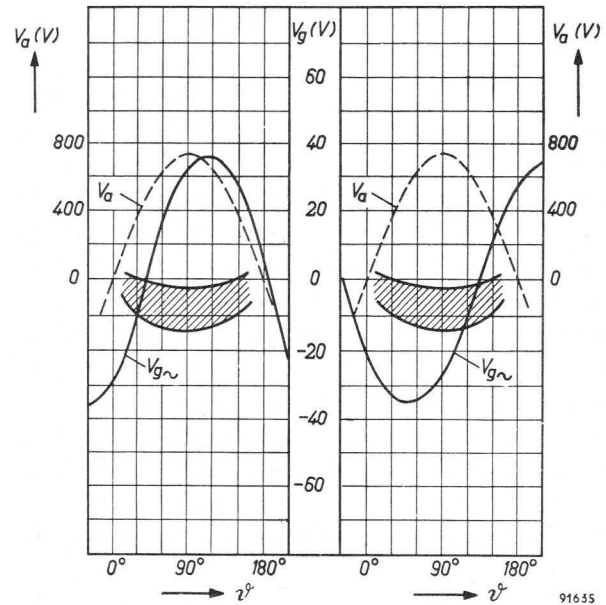


Fig. 1.4. Horizontal control of a thyatron by means of an alternating grid voltage V_g the phase angle of which can be shifted. At the left the control characteristic is intersected almost without phase delay, at the right the tube is fired with a large firing angle.

In Fig. 1.4 the control characteristic of a thyatron has been plotted once again for an alternating anode voltage with a peak value of 750 V and an alternating grid voltage of $V_{g\sim} = 35$ V (peak value). By varying the phase-shift of the alternating grid voltage, the thyatron may be made to remain non-conducting or conducting during the entire positive half cycle of the alternating anode voltage, as in the case of vertical control.

A detailed discussion on controlling circuits of thyatrons is given in chapter V.

TRIODES AND TETRODES

Nearly all types of thyatron are equipped with one control grid, but in a few types the control grid is screened from the anode and the cathode by means of a screen grid. This tetrode type of thyatron has some properties which may be important in special applications, such as circuits in which the grid im-

pedance is high, in computers where high demands are made on the anode-to-grid capacitance, etc. However, in almost any circuit in which large powers are handled, triodes are used since the properties of tetrodes are mostly of no use in these applications. When a thyatron is provided with a screen grid, the capacitance between the control grid and the anode is small. The instantaneous control-grid voltage is consequently but little influenced by sudden variations in the anode voltage.

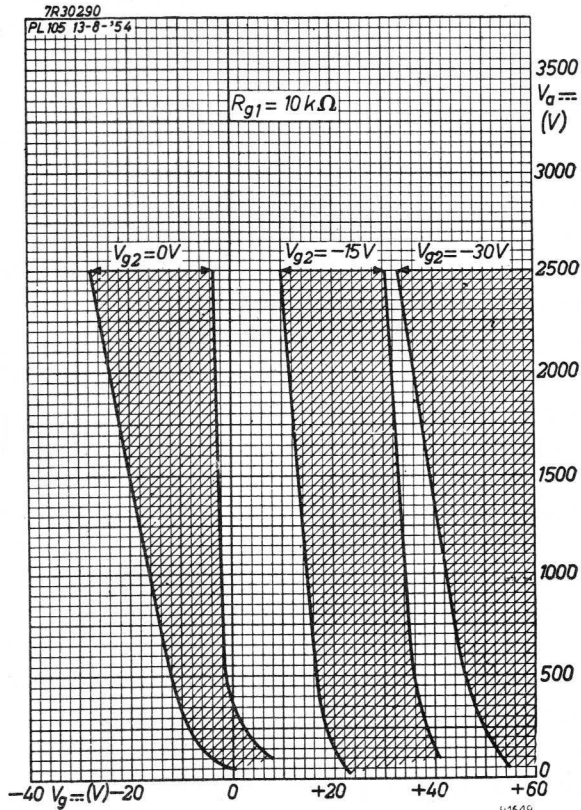


Fig. 1.5. Critical control characteristics of a PL 105 for different values of the screen-grid voltage V_{g2} .

The screen grid of a tetrode is usually connected to the cathode via a resistor so that no additional supply voltage is required for this electrode. It is possible, however, to shift the control characteristic by applying a d.c. voltage to the screen grid. This is elucidated by Fig. 1.5 in which the average control characteristics of a PL 105 are given for different screen-grid voltages, the control characteristic being shifted to the left when positive voltages are applied.

GAS FILLING OF THYRATRONS

Apart from structural differences, thyratrons may differ with regard to the gas filling. There are thyratrons filled with a rare gas, such as argon or xenon,

at a pressure of about 0.025 mm at room temperature. Other types are filled with mercury vapour, whilst a few types of thyatron have fillings consisting of a mixture of a rare gas and mercury vapour. Since discharges in a gas-filled tube are always accompanied by absorption of the gas by the glass wall and the electrodes, the original quantity of gas introduced into the tube will be gradually reduced. The gas pressure in the tube will therefore decrease continuously until a point is reached at which the tube no longer functions. The rate of the gas cleanup is determined by the commutation factor (see page 19) of the thyatron, so that it depends on the circuit in which the tube is used, whether the tube life will be seriously influenced.

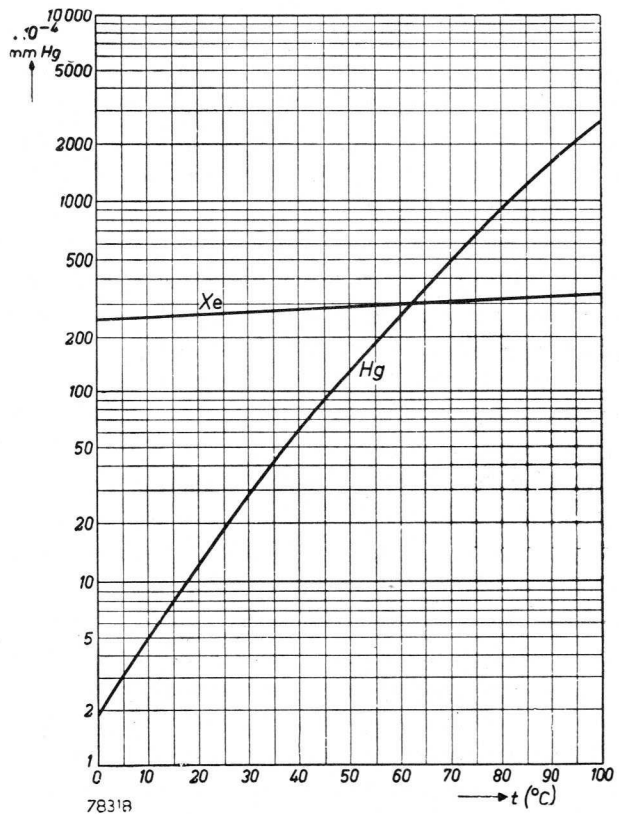


Fig. 1.6. Relation between temperature and pressure of saturated mercury vapour and xenon gas. The xenon gas pressure at 0 °C is 0.025 mm Hg. The graph shows that when the temperature rises, the mercury vapour pressure rapidly increases, whereas the gas pressure curve remains substantially flat.

This effect can be avoided by keeping the current passing through the tube at a low value, but this value is often lower than is desirable. Another solution is achieved by providing a large reserve of gas, as, in fact, is done in thyratrons filled with mercury vapour, because the few drops of mercury which are present in the tube constitute a practically inexhaustible reserve of mercury vapour.

In contrast to tubes filled with a rare gas, the vapour pressure in mercury-filled tubes does not depend on the temperature in accordance to the laws relating to gases, but on the pressure of mercury vapour above liquid mercury for the given temperature. This saturated vapour pressure varies greatly with the temperature, it being determined by the temperature of the spot at which the mercury condenses (usually a part of the glass wall near the tube base). The electrical characteristics of a mercury-vapour thyatron depend to a very great extent on the temperature of its coldest part.

Fig. 1.6 shows the relation between the pressure of mercury vapour above mercury in the temperature range that is of interest with regard to thyratrons, as well as the relation between the vapour pressure of a rare gas and the temperature.

In spite of the difficulties encountered as a result of the great variations in vapour pressure due to temperature changes, it has been found possible to construct thyratrons filled with mercury vapour which are able to function reliably over a fairly large temperature range and which excel by a very long life. It is nevertheless obvious that the thyratrons filled with a rare gas are usable over a wider temperature range, but the tube life may be shorter owing to the unavoidable binding of gas by the electrodes and the glass bulb¹⁾.

The advantages of mercury-vapour and of rare-gas types have been partly combined in thyratrons filled with a mixture of rare gas and mercury vapour. The mercury vapour in these tubes accounts for an extremely long life, whilst the rare gas considerably increases the temperature range at which the tubes can be used, compared to mercury-vapour thyratrons. The heating-up time is short: during the first moments of operation the rare gas is already active and the mercury vapour comes into action when it has reached its correct operation temperature.

It follows from the above that for applications in which wide variations in temperature may occur, and where the tube life is not the decisive factor, the rare-gas filled thyratrons will be preferred. For applications where the tubes are continuously in service, such as motor control, temperature control of furnaces, etc., mercury-vapour thyratrons are recommended. A thyatron with mixed filling will be

¹⁾ Gas clean-up only occurs when a rare-gas filled thyatron is in operation; the shelf life of gas tubes is therefore not shorter than that of mercury-vapour filled tubes.

chosen when it must operate at a rather wide temperature range, and long life or continuous service is required as well.

The warming-up time of the cathode is an important factor in the use of thyratrons. With rare-gas thyratrons the anode voltage may be switched on only after the cathode has reached its correct emission temperature. This warming-up time is short so that this type of thyatron is also recommended for applications in which the short warming-up time is of paramount importance. In the case of mercury-vapour thyratrons, the anode voltage may not be switched on even when the cathode has reached the emission temperature. The hot cathode must first act as a heat radiator to bring the mercury in the whole tube up to the correct temperature. This means, since the vapour pressure of the mercury is determined by the coldest part of the tube, that the tube with its component parts must be heated up to the required temperature. Only when these conditions are satisfied, the anode voltage may be applied. The pre-heating time depends obviously also on the ambient temperature.

The published characteristics of thyratrons hold for tubes in operation condition i.e. when the tubes have reached their final working temperature, which is due after about half an hour of operation. When the tube characteristics are measured immediately after the minimum cathode heating time has elapsed, they may slightly deviate from the published characteristics, since not all electrodes of the tube have reached their final working temperature. The deviations are, however, not large and, when the grid-control circuit is properly designed (see Chapter V), they may be neglected.

Influence of temperature

As shown in Fig. 1.7 the control characteristics of mercury-vapour thyratrons are shifted according to

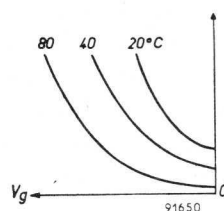


Fig. 1.7. The critical control characteristic of a mercury vapour filled thyatron is shifted according to the temperature of the condensed mercury.

the temperature of the condensed mercury. This shift is caused by changes in the mercury-vapour density. The gas density of rare-gas thyratrons being practically constant, this phenomenon will hardly be noticeable with these tubes.

Peak inverse voltage

Since the life of gas-filled thyratrons would be considerably shortened if the gas pressure would drop below a given value, due to absorption during operation, an ample quantity of gas had to be introduced. To achieve this, either the gas pressure, or the dimensions of the bulb would have to be made fairly large. For practical reasons the first solution is adopted, albeit at the expense of the permissible peak inverse voltage. In practice the maximum peak inverse voltage of rare-gas thyratrons is approximately 1500 V for normal life and size.

Mercury-vapour thyratrons can withstand considerably higher peak inverse voltages — up to approximately 10 kV — provided the prescribed mercury-vapour temperature is observed.

IONIZATION AND DEIONIZATION TIME

The voltage between anode and cathode does not drop instantaneously from the firing voltage to the arc voltage when the tube starts to be conductive. The time required is called the *ionization time* and depends upon the amplitude and wave form of the grid voltage initiating the discharge, upon the geometry of the tube construction, and upon the gas pressure. During the ionization time the voltage between anode and cathode is many times the normal arc voltage drop. This results in a bombardment of the electrodes by high-velocity ions and electrons. To limit the damage caused by this bombardment the current flowing in the tube during the ionization time should be kept small, and peak currents should be permitted to flow only after the published ionization time has elapsed. This limits the permissible rate of rise of the cathode current.

When conduction ceases it will take some time before the positive ions are neutralised because these form a sheath around the grid preventing this from controlling the flow of current in the tube. After the ion density has dropped to a sufficiently low value, the grid will regain control. This time interval is known as the *deionization time*¹⁾; it depends on a number of factors, such as: the geometry of the tube, the anode current just before conduction ceases, the grid voltage and the grid-to-cathode impe-

¹⁾ The term "recovery time" would be preferable in this case, since "deionization time" is a physically defined term, whereas "recovery time" indicates a property of tube and circuit together.

dance and the temperature of the gas or condensed mercury.

A high negative voltage at anode and grid during the deionization period, as well as a low impedance in the grid circuit contribute to quick deionization. With mercury-vapour thyratrons a low temperature of the condensed mercury, resulting in a low vapour pressure, has the same effect.

The figures given for the ionization and deionization time are on the conservative side, and in practice shorter times may frequently be reached.

The deionization time sets a limit to the maximum frequency at which a thyatron can operate. If the non-conducting periods are shorter than the deionization time, the time available for the grid to regain control is too short, and the thyatron will act as a normal rectifier. Mercury-vapour thyratrons have a frequency limit at about 500 c/s, whilst gas-filled thyratrons can operate at frequencies up to 5 kc/s. A much lower frequency limit is often prescribed for thyratrons; this is done to diminish gas absorption and to prevent damage to the electrodes due to the impinging ions, and consequently to lengthen the life of the tube.

CONSTRUCTIONAL DETAILS

Fig. 1.8 shows the internal construction of a PL 255 thyatron.

The bulb consists of thick glass to withstand the rough treatment which may be encountered in industrial service. The anode is made of graphite and is shaped so as to provide good heat dissipation and thus to avoid excessive temperature rise and the consequent risk of secondary emission.

The cathode is oxide-coated and is capable of giving high emission. Thyratrons may be equipped with directly or indirectly heated cathodes, the construction of which differs, however, from those used in high-vacuum tubes. Indirectly heated cathodes are usually surrounded by a heat shield consisting of concentric metal cylinders. Since the anode current of a directly heated tube traverses the cathode, the heavier types of thyatron are as a rule provided with an indirectly heated cathode, since a cathode of the filamentary type would be too bulky.

The type of cathode and its size determine the value of the cathode heating time. Directly heated cathodes generally require a very short pre-heating time, whereas indirectly heated cathodes take several minutes to reach the prescribed temperature for full emission. In the case of mercury-vapour thyratrons

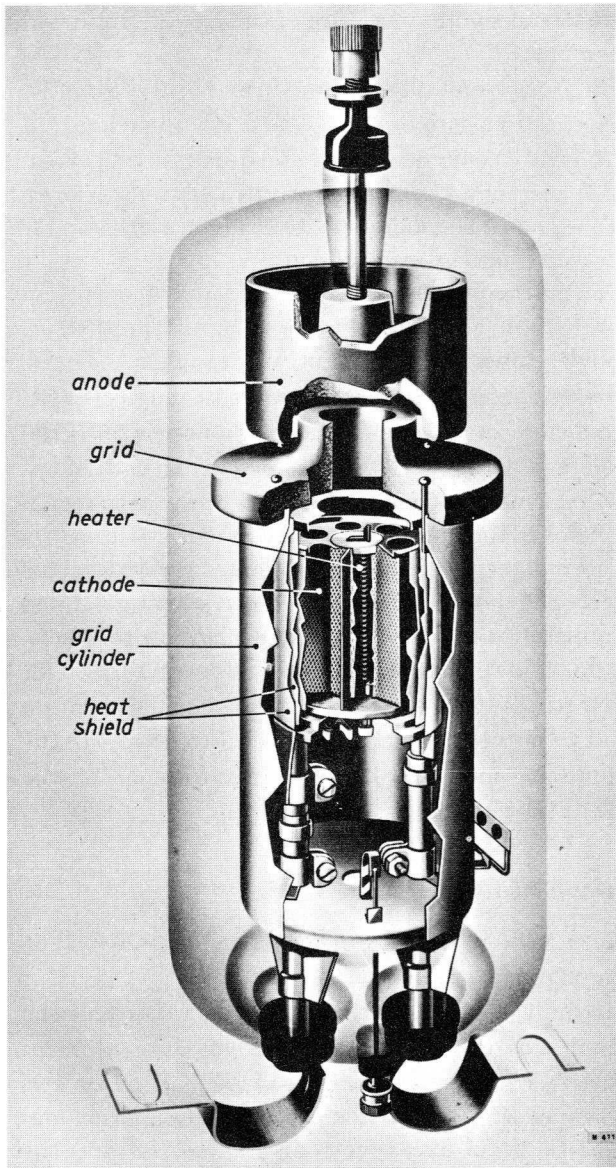


Fig. 1.8. Construction of a PL 255 mercury-vapour thyatron.

the tube heating time must, moreover, be taken into account since this type of tube will only operate satisfactorily when the vapour pressure has reached a determined value. The evaporation of the mercury is brought about by heat radiation of the cathode, the time required being dependent on the ambient temperature and the size of the tube.

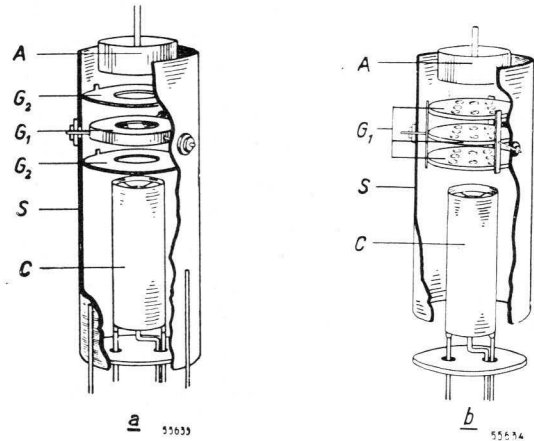


Fig. 1.9. Example of the construction of a thyatron a) with a negative control characteristic and b) with a positive control characteristic. A = anode; G_1 = control grid; G_2 = screen grid; S = cylindrical screen connected to G_2 ; C = cathode.

The control grid generally takes the form of a ring or screen and consists of graphite or metal. Thyratrons with negative control characteristics have an annular control grid with a rather wide aperture. Tubes with a positive control characteristic usually contain a system of perforated metal screens (see Fig. 1.9). On account of the screening thus provided, firing occurs only at positive values of the control-grid voltage.

In tetrode thyratrons the additional grid also consists of perforated metal screens.

II. Notes on application

MOUNTING

Mercury-vapour thyratrons and thyratrons with a mixed filling must generally be mounted and stored vertically with the base down. With small types a deviation of $\pm 45^\circ$ with the vertical position is permissible provided a suitable tube socket is used. Gas-filled thyratrons may be mounted and stored in any position. All types of thyratrons must be so mounted in a circuit that the air can freely circulate around them. When additional cooling is required, forced air should assist the natural convection. This is specially important with mercury-vapour filled thyratrons since the mercury must condense in the lower part of the tube.

The clearance between the tubes and the other components of the circuit, and between the tubes and the walls of the cabinet should be at least half the maximum tube diameter. If the tube is mounted in a closed cabinet the heat dissipated by the tube and other components must be taken into account with the determination of the dimensions of the cabinet and the mounting of the components. Precautions must be taken that a thyatron, when operating, does not touch any other part of the apparatus, or that it is exposed to falling particles or drops of liquid.

Thyratrons must be so mounted that they are not subjected to shocks or vibration which may damage the tubes. If the shocks or vibration exceed 0.5 g, special precautions against it must generally be taken.

The electrode connections, except for those of the tube holder, must be flexible. The nuts (e.g. of the anode connection) should be well tightened. Care must, however, be taken that no undue forces are exerted on the tube bulb. The contacts of the tubes must be regularly checked and kept clean to avoid excessive heating of the glass-metal seals. The cross section of the conductors and leads should be sufficiently large for carrying the rms value of the currents flowing through them ¹⁾).

HEATER OR FILAMENT SUPPLY

The heater or filament supply of a thyatron should be kept within its rated limits. A high heater or filament voltage causes a high cathode or filament temperature so that the grid may be heated and grid emission may occur due to cathode or filament material being evaporated onto the grid. This will result in loss of grid control, and the life of the tube is shortened by the higher rate of cathode or filament evaporation. On the other hand, at a low heater or filament voltage the cathode or filament temperature is low resulting in excessive arc voltage drop and cathode or filament sputtering by which the life of the tube is reduced. The anode voltage must therefore never be switched on before the required warming-up time has expired. The heater or filament voltage must — for the same reason — never be switched off before the anode supply is switched off.

The time which is required for each type of tube to reach its full working temperature is given in the technical data of the tube concerned. Only after expiration of this time anode current is allowed to flow. It is very important that the heater or filament voltage is accurately adjusted to the correct value; therefore, it should be measured at the tube pins rather than at the tube holder contacts. If no limits for the heater or filament voltage are given, a maximum permanent deviation of only $\pm 2.5\%$ of the published value can be accepted. It is therefore recommended to have tapplings on the heater transformer. In the design of the heaters or filaments of the tubes a mains fluctuation of 5% is taken into account; fluctuations of 10% of the nominal mains voltage are, however, admissible during short intervals. In order to obtain the maximum life of a directly heated thyatron, a filament transformer with centre-tapping is recommended. Moreover, the filament

¹⁾ It should be noted that in grid-controlled rectifier circuits the rms value of the anode current may reach 2.5 times the average d.c. value, and even more.

supply should preferably be 90° out of phase with the anode voltage. The influence of this on the life of the tube can be explained as follows. Fig. 2.1 shows a sketch of the electrodes of the tube and the filament transformer.

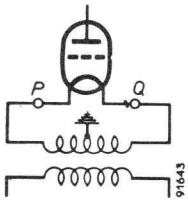


Fig. 2.1. Directly heated thyatron with filament transformer.

The part of the filament which has the lowest potential with respect to the anode tends to be overloaded. If the anode and filament voltages have no difference in phase, each half cycle of the a.c. filament voltage the potential difference between the anode and the point P or the point Q of the filament is maximum.

Fig. 2.2a shows a simplified diagram of the voltages as they may occur in a thyatron when the anode and filament voltages are in phase. During the odd half cycles anode current flows and, since the potential difference between the anode and the point

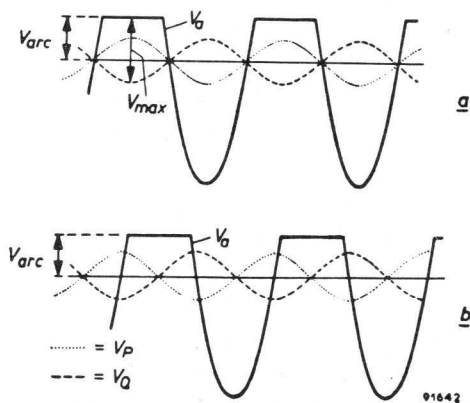


Fig. 2.2a. Diagram of anode and filament voltages of a thyatron for the case both voltages are in phase.

Fig. 2.2b. Similar to Fig. 2.2a. Both voltages, however, are now 90° out of phase.

Q of the filament is largest during these half cycles (V_{max}), the anode current will mainly flow through the right side of the filament. Since the arc voltage is relatively low, even small variations in the potential difference between parts of the filament and the anode seriously influence the field strength distribution at the surface of the filament.

When the anode voltage and the filament voltage are 90° out of phase, the anode current will flow through the right part of the filament (Q) during the first part of the half cycle in which anode current

flows, and through the left part (P) during the second part of this interval. Both parts of the filament are more equally loaded in this way so that the risk of damage to the filament by overloading is diminished.

It is clear that these requirements only hold for the filament transformer of directly heated tubes since the cathode current of indirectly heated tubes does not flow through the heater.

In calculating the ratings of transformers for the filament or heater of thyratrons a variation of $\pm 10\%$ in the heater current of different samples of tubes should be taken into account. For directly heated tubes the d.c. current flowing through the filament should also be considered.

TEMPERATURE AND HEATING TIME

A. Thyratrons with mercury-vapour or mixed-gas filling

Limits for the temperature of the condensed mercury are given for all these types of thyatron. Care must be taken that the mercury temperature remains within these limits during operation of the tube. When the temperature drops below the lower limit the pressure of the mercury vapour becomes inadmissibly low which results in a low anode current, a high arc voltage and consequently cathode or filament sputtering. The latter phenomenon obviously reduces the life of the tube considerably.

If the temperature of the mercury becomes higher than the upper limit, the vapour pressure in the thyatron becomes excessive which may cause back firing.

Since the minimum required mercury temperature (40°C) is usually higher than the room temperature it is necessary to allow some time for the cathode to reach its operating temperature and to warm the condensed mercury. Therefore, a certain heating time is given in the technical data. If necessary the anode voltage may be switched on at a temperature of the condensed mercury which lies 5 to 10°C below the minimum Hg temperature of 40°C (minimum required waiting time). The value of the waiting time T_w indicated with the heater data is the minimum required waiting time at an ambient temperature $\geq 25^\circ\text{C}$. The heating time should therefore never be shorter than this value of T_w . The required lengthening of the waiting time at low ambient temperatures can be read from the curve $T_w = f(t_{amb})$ which is given with the data of most mercury filled

thyratrons. However, it is good practice to switch on only after the *Hg* temperature has reached its minimum published value (recommended waiting time). In order to avoid long heating times it is recommended to apply 60-80% of the nominal heater voltage to the heater during the time the tube is inoperative (e.g. during break or overnight). A constant heating time is often used in practice. This is possible since the temperature range of most types of mercury-vapour filled thyratrons is large (about 40 °C). In that case an ample heating time must obviously be chosen.

When a thyatron is put into use after transport or after a considerable interruption of operation the heating and switching on should be accomplished according to the instructions for use which are packed with the tube.

b. Thyratrons with rare-gas filling

For those tubes only the limits of the ambient temperature are given. It is clear, however, that the cathode must have reached its operating temperature before anode current may flow. Therefore, the minimum cathode heating time is published after which the anode voltage may be switched on when the ambient temperature is not below the minimum published value.

SCREENING AND INTERFERENCE

Sometimes it may be necessary to enclose the thyatron in a separate earthed screening box in order to prevent unwanted ionization of the gas-filling

— and consequent flash over — due to strong *RF* fields.

In circuits with gas-filled tubes oscillations in the transformer windings and other circuit components may occur, resulting in excessive peak inverse voltages and arc back. Damping of these oscillations is necessary especially at higher voltages. Parallel *RC*-circuits are recommended for this purpose (see page 19).

SMOOTHING CIRCUITS

In order to limit the peak anode current in a rectifier it is necessary that a choke should precede the first smoothing capacitor.

To ensure good voltage regulation on fluctuating loads the inductance value of the choke should be large enough to give uninterrupted current at minimum load.

The choke and capacitor must not resonate at the supply or ripple frequency. In grid controlled rectifier circuits under phased-back conditions the harmonic content of the d.c. output will be large unless the inductance is adequate.

PARALLEL OPERATION

As individual gas-filled thyratrons may have slightly different characteristics two or more tubes must not be connected directly in parallel. An alternative expedient must be adopted if a higher current output is required. Information on suitable methods will be supplied on request.

III. Ratings and characteristics

LIMITING VALUES

Normally the ratings of thyratrons which are necessary for adjustment of the tubes (such as currents, voltages, etc.), are given as limiting values.

In general these values are absolute maxima, i.e. maxima which should not be exceeded under any condition, even not at mains voltage fluctuations, load variations, tolerances in components, etc. Below an explanation is given of the meaning of some limiting values.

Negative grid voltage

Two maximum values of the negative grid voltage are mostly given: one of them applies to the conductive state of the tube, the other one to the non-conductive state.

When a thyatron is conducting, a positive ion current of a magnitude proportional to the cathode current is generated. This current will generally flow to that electrode that is at the most negative potential during conduction. In most circuits this will be the grid. In order to prevent damage to the tube it is necessary to ensure that the voltage of the grid is more positive than -10 V during this phase. This precaution will prevent an increase in grid emission due to excessive grid dissipation; further it prevents sputtering of the grid material, changes in the control characteristics due to shifts in contact potential and — in the case of rare-gas filled tubes — a rapid gas clean-up.

In circuits where the grid is at a negative potential during the periods of conduction an effective grid bias more positive than -10 V can be obtained by means of a resistor of suitable value in series with the grid. The minimum permissible value of this resistor is in general 0.1 times the recommended value. In those circuits where the anode potential changes very rapidly from a positive to a high negative value, such as with inductive loads fed from polyphase supplies, there will be residual positive ions in the tube. These ions will be drawn towards the anode

with considerable energy. In the case of a rare-gas filled tube this would result in excessive gas clean-up. It is therefore necessary to observe the limitations imposed by the commutation factor (see page 19).

The magnitude of the positive ion current to the anode can be limited by severely restricting the electron current flowing from the cathode to the grid, since the latter current causes the ion current to flow. The electron current can be reduced by using the maximum permitted grid series resistor, or preferably by using a fixed negative bias and a narrow positive firing pulse.

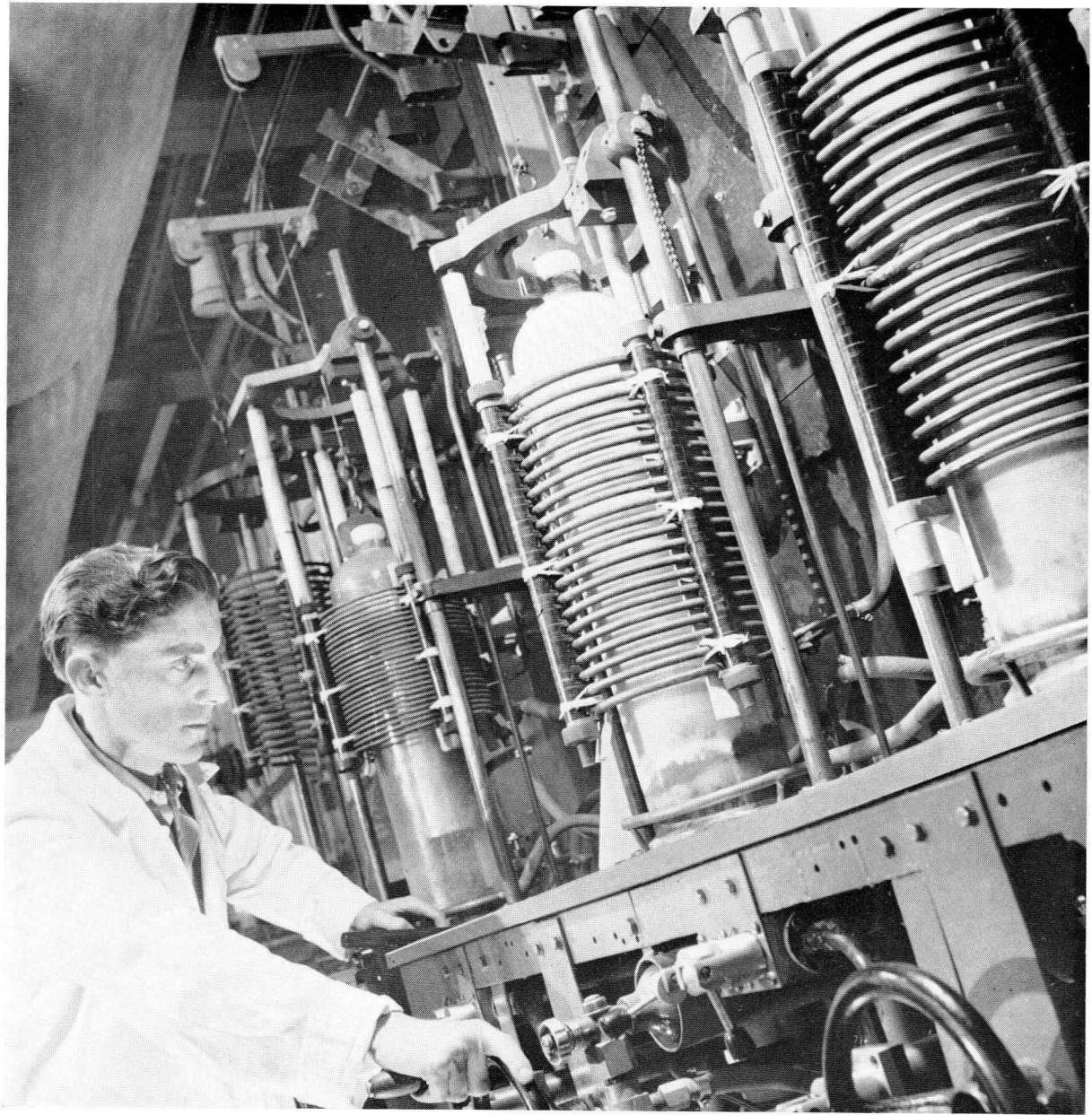
The second limiting value of the negative grid voltage which is given in the tube data applies to the non-conducting state of the tube. This value is the largest of both and it is the maximum negative voltage that may be applied to the grid without causing ignition of the tube in the grid-cathode and grid-anode space.

Although a large grid resistor is desirable with respect to reduction of the positive ion current to the anode this resistor may on the other hand not be chosen too large, as can be explained as follows.

With thyratrons it is not impossible that a small amount of the cathode coating material precipitates on the grid. When, therefore, the anode becomes positive a small electron current may flow between the grid and the anode. If the grid leak resistor has a high value the voltage drop across this resistor which is caused by the electron current, may render the grid so much less negative that firing of the tube occurs. The same effect may be produced in small thyratrons if the anode-to-grid capacitance has a high value. A sudden variation of the anode voltage may be passed to the grid with such an amplitude that firing of the tube occurs. It is clear that the higher the value of R_g , the higher the voltage peaks fed back to the grid will be.

Surge current (fault current)

In order to prevent the tube from being damaged



Degassing of components by means of high-frequency heating



The anode connection is sealed to the tube envelope

by passing too high a peak current, a value for the surge current is given. This value is intended as a guide to equipment designers. It indicates the maximum value of a transient current resulting from a sudden overload or short circuit which the thyatron can pass for a period not exceeding 0.1 sec without resulting in its immediate destruction. Several overloads of this nature will, however, considerably reduce the life of the tube.

The equipment designer has to take into account this maximum surge current when calculating the short-circuit impedance of the equipment.

This surge current value is not intended as a peak current that may occur on switching or during operation.

A simple method to limit the surge current to the maximum rating is to incorporate a series resistance and/or a proper fuse in the anode circuit.

Maximum average and peak currents

For each rating of a maximum average current a maximum averaging time is quoted. This is to ensure that a current larger than the maximum continuously permissible average value will not flow for such a length of time that it would give rise to damage to any of the electrodes of the tube.

The limits which are given for the peak and average anode currents are determined by the cathode emission and by the maximum anode dissipation. With the PL 255, for example, the maximum peak anode current is 80 A and the average value 12.5 A. If it is assumed that the tube conducts half cycles of a sinusoidal current and that the peak value of this current is 80 A, the average anode current will be 25.4 A, which is twice the permissible value.

Excessive heating of the anode and overloading of the cathode will be the result. At first sight it would seem possible to keep the anode current below the average limit by operating the tube under the above conditions during half an hour, then switching off for half an hour and after that resuming operation. Normally, however, the thermal inertia of the tube is too low to permit an overload during half an hour. Therefore the anode current and also the currents of the other electrodes must be averaged over a considerably shorter interval. This inter-

val, the maximum averaging time, which depends to a great extent upon the thermal inertia of the electrodes is always indicated together with the maximum values of the peak and average anode currents. The averaging time is expressed in seconds; in the case of the PL 255, for instance, it is 15 seconds.

In the above example where the anode current has the shape of half sinusoids the maximum permissible average current is the limiting factor. It is obvious that if the conducting periods are very short compared with the non-conducting periods, the maximum permissible peak anode current will be the limiting factor.

TYPICAL CHARACTERISTICS

Arc voltage

The value published for V_{arc} applies to average operating conditions: under high peak current conditions, e.g. 6-phase rectification, V_{arc} will be higher.

The spread which depends on the type of circuit in which the thyatron operates can be expected to amount to ± 1 V. An increase of approximately 2 V during life of the tube must be taken into account.

Frequency

Unless otherwise stated the maximum frequency at which thyatrons may operate under full load conditions is 150 c/s. Under special conditions higher frequencies may be used.

CONTROL CHARACTERISTICS

The control characteristics of most types of thyatron are given as a shaded area within which the actual characteristic of each sample of the tube type concerned is situated whatever the tube temperature or life may be.

The spread in the characteristics of a number of tubes which operate in the same circuit under the same conditions will generally be smaller than indicated in the tube characteristics. The published curves are, therefore, to be considered as extreme limits. This should be taken into consideration when designing grid excitation circuits.

IV. Anode circuits

NON-REACTIVE LOAD

In order to investigate the influence of the anode load on the operation of a thyatron, it will first be assumed that this load consists of a non-reactive resistor connected to an alternating voltage source V_{tr} (see Fig. 4.1). No current will obviously flow through the anode load until the thyatron has been fired. The instant at which the thyatron is fired depends on the grid control circuit, which has been omitted in this figure for the sake of simplicity.

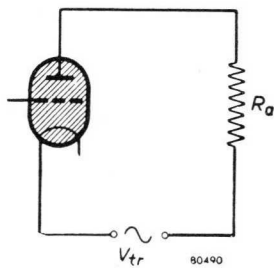


Fig. 4.1. Thyatron with a non-reactive anode load R_a .

The firing angle ϑ_1 is defined as the phase angle of the alternating anode supply voltage at which the tube is ignited. The tube will be extinguished again when the potential difference between the instantaneous value of the anode potential and the cathode potential drops below the arc voltage V_{arc} of the tube and, in analogy with the firing angle, the extinction angle ϑ_2 is defined as the angle of the alternating anode supply voltage at which the tube is extinguished; ϑ_2 thus amounts to approximately 180° when the load is non-reactive.

The operation of the tube loaded by a non-reactive resistance is schematically represented in Fig. 4.2. In Fig. 4.2a the alternating supply voltage V_{tr} has been plotted as a function of its phase angle ϑ , the dashed line representing the firing point, which is assumed to be 75° . In Fig. 4.2b the fully drawn line represents the resulting anode current I_a , whilst the dashed line indicates the mean value of the output current I_o . Fig. 4.2c finally shows the voltage V_a

across the periodically fired thyatron. As soon as firing has taken place, the voltage across the tube drops to the arc voltage V_{arc} . This graph clearly shows the peak inverse voltage produced across the thyatron when it is extinguished.

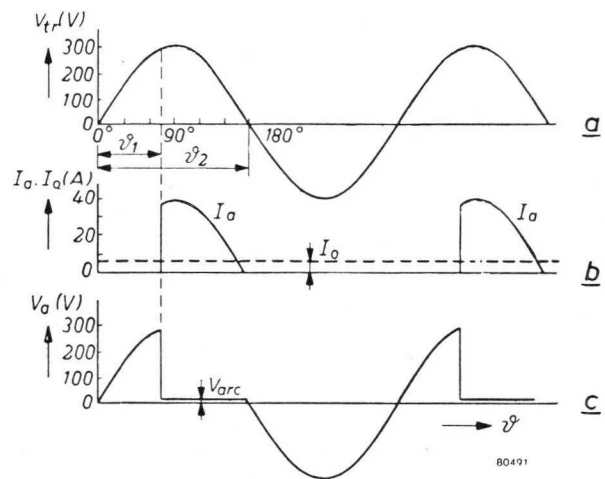


Fig. 4.2. Operation of a thyatron with a non-reactive load; (a) alternating supply voltage V_{tr} , (b) anode current I_a and mean value of the output current I_o (dashed line), and (c) anode voltage V_a appearing across the thyatron.

INDUCTIVE LOAD

Conditions become less simple when the load in the anode circuit consists, for example, of a non-reactive resistance and an inductance connected in series. Due to the action of the inductance the anode will remain positive with respect to the cathode during a longer period of time, so that the extinction angle ϑ_2 may exceed the 180° point of the mains sine wave. This angle depends on the phase shift of the load, which is given by:

$$\tan \varphi = \frac{\omega L}{R}$$

In Fig. 4.3 the extinction angle ϑ_2 has been plotted

as a function of the firing angle θ_1 with the phase shift φ of the load as parameter.

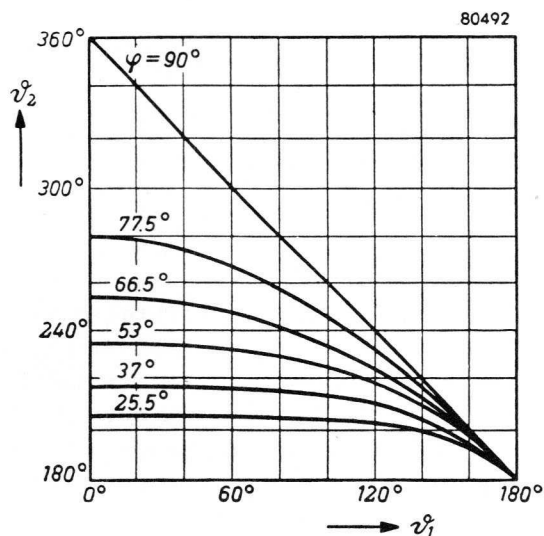


Fig. 4.3. Extinction angle θ_2 as a function of the ignition angle θ_1 with the phase shift φ of the load as parameter.

The current flowing through the load will no longer consist of sinusoidal parts under these conditions, because the inductance prevents this current from following the sudden voltage rise which occurs when

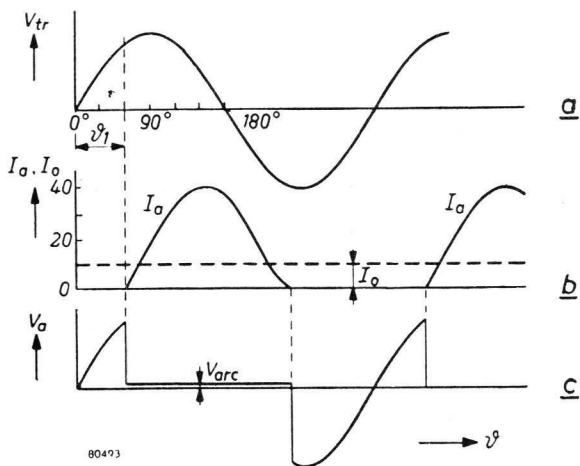


Fig. 4.4. Operation of a thyatron with an inductive anode load; (a) alternating supply voltage V_{tr} , (b) anode current I_a and mean value of the output current I_o (dashed line), and (c) anode voltage V_a appearing across the thyatron.

the thyatron is fired. In Fig. 4.4 the alternating supply voltage V_{tr} , the anode current I_a and the voltage V_a across the thyatron have been plotted as functions of the phase angle θ for a firing angle of $\theta_1 = 60^\circ$, the load being partly inductive.

COMMUTATION FACTOR

Immediately after conduction has ceased in a thyatron and the anode voltage drops to a more or less negative value as indicated in Fig. 4.4, a certain number of residual ions are present in the tube. The combination of residual ionization and a high initial inverse voltage increases the possibility of arc-back in mercury-vapour filled tubes. In rare-gas filled tubes the de-ionization time is shorter, so that the danger of arc-back is reduced. However, the positive ions, accelerated by the high inverse voltage, bombard the anode with sufficient energy to penetrate the surface. Some of the ions are trapped, and gas clean-up occurs so that the life of the tube is affected.

To give an estimate of the tendency of a circuit to cause gas clean-up the term "commutation factor" has been introduced, connecting the current and voltage conditions. The usually accepted definition is:

The product of the rate of anode current decay (in amps per microsecond) and the rate of the initial inverse voltage rise (in volts per microsecond) immediately following the current decay.

The values are taken as the average rate of current decay over the last 10 μsec of conduction, and the average rate of voltage rise over the first 200 V.

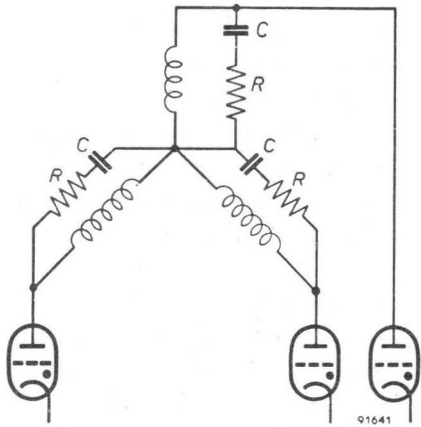
For certain thyratrons the maximum permissible commutation factor is included in the published data usually as a number, although the unit is: (amps \times volts) per μsec^2 . The commutation factors of various types of tube range from 200 to 0.66. Certain tubes have been specifically developed to operate under conditions of high commutation factor. For example the PL 5545 and PL 5544 are so constructed that the ionization time is short; consequently the bombardment by positive ions is minimized and high initial gas pressures may be used. Wherever possible a tube with a high commutation factor rating should be used.

DAMPING CIRCUIT

In rectifier circuits in which a thyatron is connected to a transformer winding difficulties may arise caused by the occurrence of oscillations in the anode load. These oscillations are due to the abrupt starts and interruptions of the current flowing through the transformer windings. It, therefore, may be use-

ful to shunt these windings with an *RC*-damping circuit (see Fig. 4.5).

Dimensioning of the circuit may be done according to the following formulae



$$C \approx 4/Z \dots \dots \dots (1)$$

$$R \approx 13Z \dots \dots \dots (2)$$

$$Z = \frac{V_{rms}}{I_{rms}} \dots \dots \dots (3)$$

Fig. 4.5. An *RC* circuit is shunted across the transformer windings to prevent the occurrence of oscillations.

In these formulae the value of *R* is indicated in ohms and the value of *C* in μ F. *Z* means the impedance of the transformer winding: V_{rms} is the voltage across the winding and I_{rms} the r.m.s. value of the current through the thyatron. The formulae given above hold for operation at a frequency between 40 and 60 c/s.

V. Control circuits for thyratrons

The grid voltage at which a thyatron ignites can be found from the $V_a = f(V_g)$ characteristic of the tube concerned. Since a certain spread exists in the characteristics of thyratrons of the same type, care must be taken in designing control circuits that always the correct moment of ignition is obtained independent of the tube sample used and of other conditions. Obviously, it is also required that the tube never will be fired prematurely e.g. due to over-voltages.

The characteristics of thyratrons for industrial purposes — i.e. for rectifying voltages up to 600 V — can roughly be described as follows:

- a. At anode voltages up to 1000 V a negative grid voltage of 1-15 V is necessary to prevent ignition of the tube. In practice, however, a much larger grid bias will be applied to prevent difficulties at overvoltages and to obtain more exactly timed ignition of the thyatron when it is controlled by means of a sinusoidal grid voltage.
- b. If the anode voltage is between 30 V - 500 V the tube ignites at a grid voltage of about 0 V.
- c. When the anode voltage is lower than 30 V¹⁾ a positive grid voltage is required for ignition of the thyatron. It is even necessary that the grid voltage becomes higher than +10 V with the larger types of thyatron. In that case a grid current of a few milliamperes may flow; the grid circuit must, therefore, be so designed that this will cause no troubles.

In designing control circuits care must be taken that the grid impedance caused by the grid leak resistor, the grid bias generator etc., is so small that grid current due to grid emission and insulation leak does not influence the actual grid voltage.

¹⁾ These low anode voltages will occur in polyphase rectifiers which must deliver the highest possible output voltage. A low anode voltage may also occur when a counter - e.m.f. is present in the anode circuit (motor or battery).

TYPES OF CONTROL CIRCUIT

Several different types of control circuit can be used for thyratrons. The choice of a circuit mainly depends on the accuracy of ignition which is required in the circuit concerned.

1. A simple form of control is obtained by applying to the grid of the thyatron a variable d.c. bias on which an a.c. voltage is superimposed. This a.c. voltage is lagging 90° with respect to the anode voltage. A variation in the d.c. bias changes the intersection point of the a.c. grid signal with the critical control characteristic (vertical control).
2. The point of ignition can also be varied by shifting the phase of an a.c. voltage applied to the grid with respect to the anode voltage. The grid voltage may be superimposed on a constant d.c. grid bias (horizontal control).
3. The most exact timing of the ignition of thyratrons will be achieved by applying to the grid voltage peaks superimposed on a constant bias voltage. The peaks must have a steep leading edge and their phase with respect to the anode voltage must be variable (horizontal control).

Below an extensive description is given of each of the three control circuits indicated above.

1. Sinusoidal control voltage on variable d.c. bias

Fig. 5.1 shows an example of controlling a thyatron by means of a sinusoidal grid voltage which is superimposed on a variable d.c. grid bias. With this method of vertical control the a.c. control voltage must be lagging 90° with respect to the anode voltage. In order to reach a variation in the firing angle of about 180° it is necessary that the d.c. bias can be varied from a positive voltage equal to the peak a.c. grid voltage to a negative voltage that is also equal to the peak a.c. grid voltage.

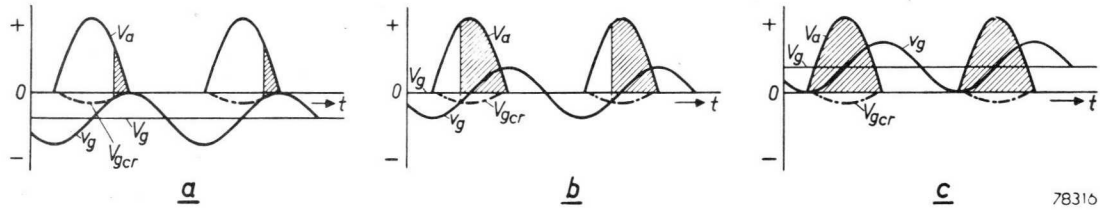


Fig. 5.1. Control of a thyatron by means of a sinusoidal voltage and a variable d.c. voltage.

When the control characteristic of the thyatron is varied by some external influence, such as the temperature, or when the thyatron is replaced by another sample having a slightly different characteristic, the critical control characteristic will also vary. This results in a shift of the moment of ignition as will be obvious in considering Fig. 5.1. In order to minimize this effect the peak value of the a.c. grid voltage should be much higher than the maximum spread of the negative grid voltage as indicated by the critical control characteristic.

As appears from the Figs 5.1a and 5.1c the slope of the a.c. control voltage is very low at small and large firing angles. This results obviously in a rather unreliable timing of the ignition at these points. Since, however, many control devices never come up to severe requirements, and a d.c. control voltage is much easier produced in automatic control circuits than an a.c. control voltage with a phase relation varying to the anode voltage of the thyatron, this system is frequently used in automatic control devices.

The influence of the slope of the sinusoidal control voltage on the moment of ignition can be calculated as follows.

If the control voltage is equal to: $V_{\text{contr}} = V_g \sqrt{2} \sin \alpha$, the slope of the sinus will be (see Fig. 5.2):

$$\frac{dV}{d\alpha} = \frac{2\pi}{360} V_g \sqrt{2} \cos \alpha$$

$$\text{from which } \Delta \alpha = \frac{360}{2\pi \sqrt{2}} \frac{\Delta V}{V_g \cos \alpha} \approx 40 \frac{\Delta V}{V_g \cos \alpha}$$

where $\Delta V = dV =$ variation in grid voltage,
 $\Delta \alpha = d\alpha =$ variation in ignition angle.

With the aid of the above formula the variation in the ignition angle due to spread in the critical control characteristics or fluctuations in the a.c. or d.c. grid voltage can be calculated.

Suppose the control voltage to be $50 V_{\text{rms}}$ and the

spread in the control characteristic $\Delta V = 5 \text{ V}$. When ignition must occur at $\alpha = 0^\circ$ the variation in the angle of ignition is

$$\Delta \alpha = 40 \frac{\Delta V}{V_g \cos \alpha} = 40 \frac{5}{50} = 4^\circ.$$

When using the above formula it must be borne in mind that α indicates the angular velocity of the a.c. grid voltage and not of the anode voltage; at $\alpha = 0^\circ$ the anode voltage is at its maximum value (see Fig. 5.1).

When α grows in positive or negative direction $\cos \alpha$ becomes smaller so that the variation $\Delta \alpha$ per volt variation ΔV of the control voltage becomes larger. A rather exact timing of the moment of ignition is therefore only possible at small values of α .

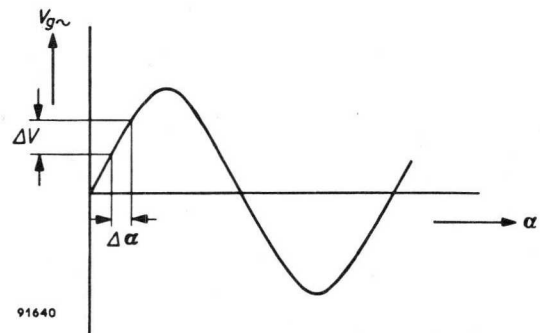


Fig. 5.2. Sinusoidal grid voltage; $\Delta \alpha =$ variation in ignition angle caused by ΔV .

The variation in α can be kept small when $V_{g\sim}$ has a large value, as appears from the above formulae. For applications in which the required accuracy of ignition is not high, $V_{g\sim}$ may be equal to 8 times the spread in the control characteristic. When, however, the thyatrons must deliver the maximum permissible anode current at large angles of ignition — as will be the case with motor control — the accuracy required to prevent overloading of the tubes and irregular hum voltages must be much closer. The value of $V_{g\sim}$ must then be chosen about twice as large, i.e. equal to 15 times the spread in the control characteristic.

As to the choice of the grid series resistor, the contingent currents due to leakage paths, grid emission etc. must be taken into account. These currents may not influence the grid potential of the thyatron. Since they are larger with larger tubes, a smaller grid series resistance must be used with large tubes than with small tubes. When the control voltage shows oscillations or other irregularities, a capacitive load may be connected across the secondary of the grid transformer (C_1 in Fig. 5.3).

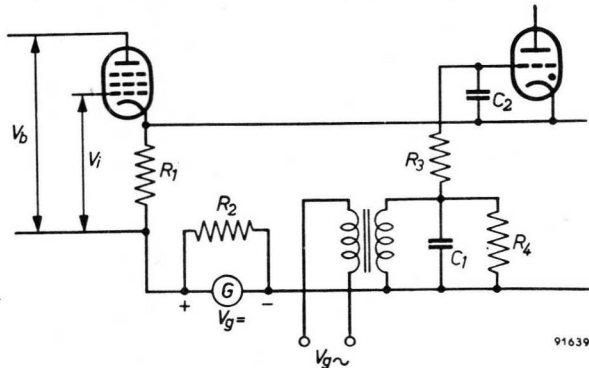


Fig. 5.3. Simplified diagram of control circuit for vertical control. In the table below the values of the components are indicated for various types of thyatron.

Type of thyatron	PL2D21 PL 1607	PL 105 PL 5557	PL 255 PL 150	PL 260
R_1	50	20	8	3.3 k Ω
R_2	100	50	20	20 k Ω
R_3	100	50	20	10 k Ω
R_4	100	50	20	10 k Ω
C_1	0.01	0.05	0.1	0.2 μ F
C_2	20	100	300	500 pF
$V_{g\sim}$	25	40	50	75 V _{rms}
$V_{g=}$	90	130	160	200 V
V_b	180	250	300	350 V

In certain circuits the anode voltage may influence the grid voltage via the anode-to-grid capacitance. In that case it is recommended to connect a capacitor between the grid and the cathode (C_2 in Fig. 5.3) so that a capacitive voltage divider is formed between the anode and the cathode. The value of C_2 may be equal to 10-100 times the anode-to-grid capacitance.

In Fig. 5.3 a circuit is given of a thyatron and a preceding control stage. The values of the components that can be used with different types of thyatron are indicated under the figure.

2. Sinusoidal control voltage with phase shift

The method of controlling a thyatron by means of a sinusoidal grid voltage the phase of which with re-

spect to the anode voltage can be varied, is more accurate for very small and very large ignition angles than the circuit described above. Graphs of two different firing angles are given in Fig. 5.4a and b. The control voltage must be chosen so large that

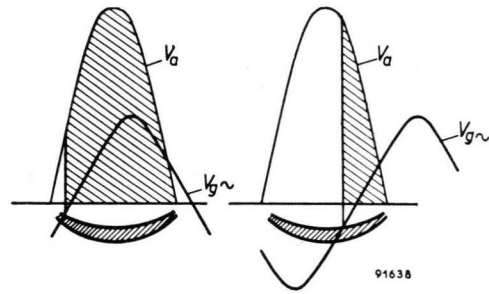


Fig. 5.4. Two different firing angles with horizontal control of thyatrons.

the intersection of the control characteristic and the control voltage occurs at a steep part of the latter. This can be obtained by applying the sinusoidal control voltage to the grid without a d.c. bias. The ignition will then always occur at $\alpha \approx 0^\circ$.

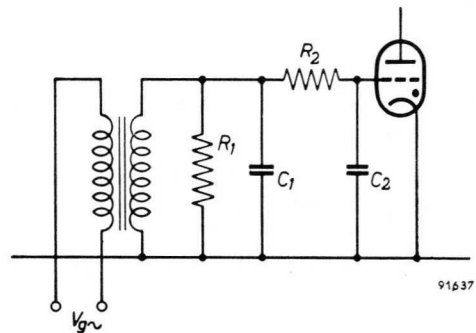


Fig. 5.5. Simplified diagram of a control circuit for horizontal control. The values of the components and grid voltages at different types of thyatron are indicated below.

Type of thyatron	PL2D21 PL1607	PL 5557 PL 5559 PL 105 PL 5544	PL 150 PL 255 PL 5545	PL 260
R_1	100	50	20	10 k Ω
R_2	100	50	20	10 k Ω
C_1	0.01	0.05	0.1	0.2 μ F
C_2	20	100	300	500 pF
$V_{g\sim}$	25	40	50	75 V _{rms}

For determination of most components the same considerations hold as for the circuit given in Fig. 5.3. Above an equivalent circuit is given for a thyatron controlled by a sinusoidal grid voltage that can be shifted in phase with respect to the anode voltage (Fig. 5.5).

3. Peaked control voltage

The above mentioned drawback of sinusoidal control voltages viz. shifting of the ignition point due to tube spread etc., can be eliminated by applying a pulse-shaped control voltage to the grid of the thyatron. The steep edges of voltage pulses or voltage peaks minimize the shift of the moment of ignition to a negligible value.

In addition to a steep leading edge, the voltage peaks must have a certain duration which is necessary to reach full ionization of the gas filling of the tube. The required duration varies between 10 and 100 μsec for most types of thyatron. In designing control circuits it must, moreover, be taken into account that a fairly large grid current (up to 3 mA with large types of thyatron) may flow during ignition due to the grid potential being positive with respect to the cathode.

Below several circuits for controlling thyratrons by means of voltage peaks are described.

PRACTICAL CIRCUITS

1. Hand-operated control circuit

In this circuit — and many other control circuits — a peaking transformer is used. The operation of such a transformer is briefly discussed below.

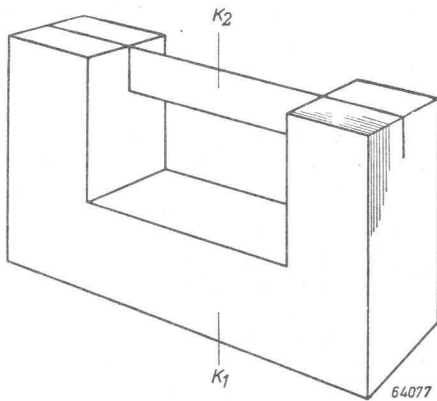


Fig. 5.6. Core of a peaking transformer. K_1 is made of normal transformer laminations, K_2 of a material of low magnetic saturation.

The core of a peaking transformer consists of two parts, one of normal transformer laminations (K_1 in Fig. 5.6) and the other, K_2 , made of a material in which magnetic saturation is reached at a low magnetic field strength (Fig. 5.7a). A sinusoidal alternating current passing through the primary wound on K_1 (Fig. 5.7b) produces in K_2 a magnetic induc-

tance B which, as a function of time, has practically the shape of a square wave (Fig. 5.7c). The voltage v_2 induced in a coil wound on K_2 is proportional to dB/dt , and it is therefore peak-shaped as represented in Fig. 5.7d.

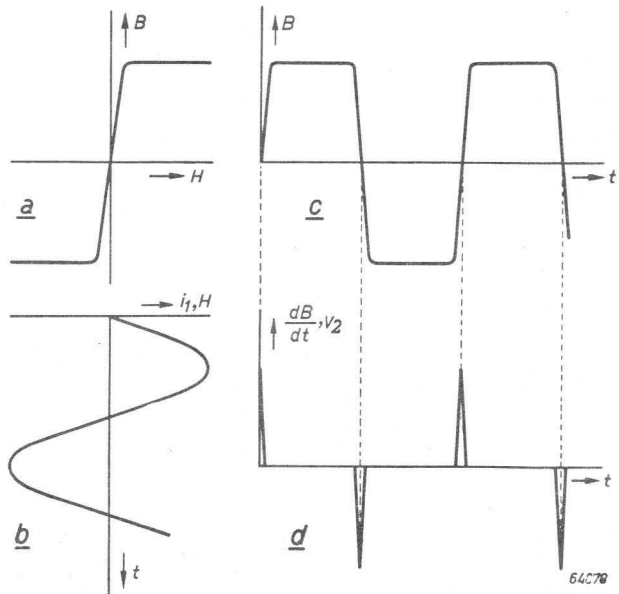


Fig. 5.7. Illustration of the operation of a peaking transformer.

- Magnetic inductance B as a function of the magnetic field strength for the core K_2 .
- The magnetic field strength H (proportional to the primary current i_1) as a function of the time t .
- Magnetic inductance B as a function of the time t for the core K_2 .
- The peak voltage v_2 (proportional to dB/dt) induced in the secondary as a function of the time t .

Fig. 5.8 shows the diagram of a hand-operated control circuit. In this circuit the peaking transformer Tr_2 code nr. 84590 is used; in Fig. 5.9, the output voltage of the transformer in the actual circuit is represented. The voltage peaks are superimposed on a small 50 c/s ripple voltage induced in the secondary of the transformer by lines of force passing through the air. The transformer is provided with two secondary windings which are both damped by a resistor of 680 k Ω to prevent the occurrence of interfering voltage peaks. It appears from Fig. 5.9 that the slope of the voltage peak is about 90 V per electrical degree. This means that a spread of 5 V in the control characteristic of the thyatron causes a shift of the ignition point of 0.055° . This figure contrasts very favourably with the figures of the phase shifts with thyratrons controlled by sinusoidal voltages.

The current through the diagonal branch (MN) of the bridge circuit is kept small so as to be able to

use small components. Consequently the inductive component of the primary of the transformer is compensated by shunting it by the capacitor C_2 . The current through the diagonal is in this way reduced to 14 mA.

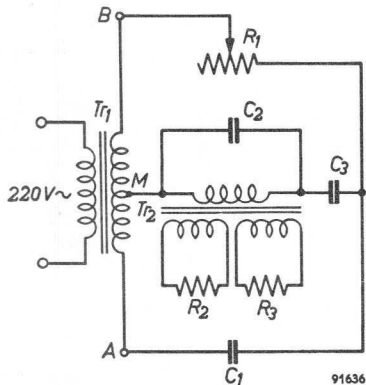


Fig. 5.8. Diagram of a hand-operated control circuit with peaking transformer.

- $R_1 = 10 \text{ k}\Omega$, 100 W, variable
- $R_2 = 680 \text{ k}\Omega$, 1 W
- $R_3 = 680 \text{ k}\Omega$, 1 W
- $C_1 = 1 \mu\text{F}$
- $C_2 = 0.5 \mu\text{F}$
- $C_3 = 0.5 \mu\text{F}$
- $Tr_1 =$ mains transformer
prim: 220 V
sec.: 95/125 V
- $Tr_2 =$ peaking transformer type 84590

When R_1 is varied between 0 and 10 k Ω the peaks are shifted over an angle of about 130°. By means of C_3 the range of the shift is made symmetrical with respect to the positive peak of the mains voltage.

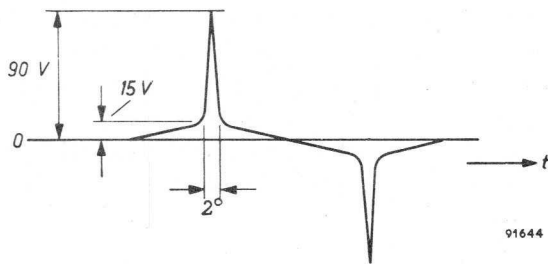


Fig. 5.9. Output voltage of the peaking transformer of Fig. 5.8.

When the choke Tr_1 (or mains transformer) is tapped in the middle a fairly large variation will occur in the amplitude of the voltage peaks at different angles of ignition. A much smaller variation is obtained when the voltage across $A-M$ is 127 V and across $B-M$ is 93 V.

Below a table is given of the electrical data of the circuit described.

Value of R_1 (k Ω)	Primary volt. at Tr_2 (volts)	Second. peak voltage at Tr_2 (volts)	Angle of ignition α
0	122	106	27
2	101	88	102
10	108	98	153

2. Electronically controlled peaking transformer

In many thyatron circuits it is desirable that the ignition angle can be varied by means of a d.c. voltage which is fed back from the thyatron load or elsewhere from another control unit. Fig. 5.10 shows

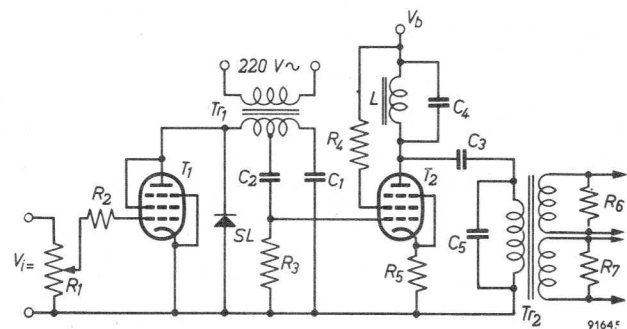


Fig. 5.10. Electronically controlled peaking transformer.

- $R_1 = 1 \text{ M}\Omega$
- $R_2 = 100 \text{ k}\Omega$
- $R_3 = 1 \text{ M}\Omega$
- $R_4 = 4.7 \text{ k}\Omega$
- $R_5 = 100 \Omega$
- $R_6 = R_7 = 680 \text{ k}\Omega$
- $T_1 = T_2 = \text{EL } 34$
- $SL =$ selenium rectifier BS 250 Y 10
- $L = 8 \text{ H}$
- $C_1 = 0.1 \mu\text{F}$
- $C_2 = 3300 \text{ pF}$
- $C_3 = 0.5 \mu\text{F}$
- $C_4 = 0.5 \mu\text{F}$
- $C_5 = 0.68 \mu\text{F}$
- $Tr_1 =$ mains transformer
- $Tr_2 =$ peaking transformer type 84590

the diagram of a circuit in which the variable resistor R_1 of Fig. 5.8 is replaced by an EL 34 tube, which operates as a triode. Variation of the control voltage V_{i-} results in a variation of the internal resistance of this tube. The charge, however, fed to the capacitor C_1 during the positive half cycle of the mains voltage by the tube T_1 , must be removed during the second half cycle. Therefore a selenium rectifier SL is connected parallel to T_1 .

In the diagonal of the bridge R_3 and C_2 are connected in series. The values of these components are so chosen that the voltage across R_3 is sufficient to control T_2 and, moreover, the phase shift is symmetrical with respect to the tops of the mains voltages. The total range of the phase shift amounts to about 165°.

The anode of T_2 , (EL 34) is fed via a choke; the capacitor C_4 is connected in parallel to this choke to improve the shape of the sinusoidal voltage at the primary of the peaking transformer Tr_2 .

Fig. 5.11 shows two curves of the phase shift α and of the amplitude of the voltage peak respectively. The phase shift is almost linearly proportional to the magnitude of the control voltage $V_{i=}$ at the grid of T_1 . The curve V_p shows the amplitude of the voltage peaks produced; it appears that the variation in V_p is so small that it can be neglected in practice.

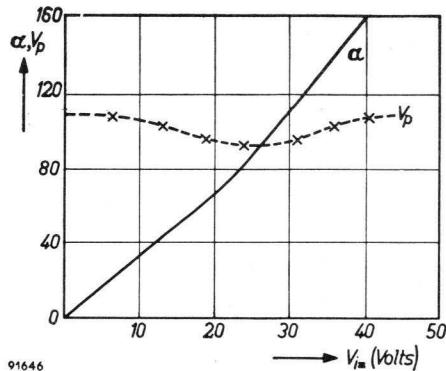


Fig. 5.11. Amplitude of the peak voltage V_p and the phase shift α as functions of the d.c. input voltage $V_{i=}$.

The voltage $V_{i=}$ can be used for controlling several circuits at the same time (polyphase rectifiers). Therefore R_1 is provided in the grid circuit of T_1 so that the adjustment of T_1 can be varied. As appears from Fig. 5.11, however, the range of the phase shift reduces when $V_{i=}$ is reduced.

3. Control circuit without peaking transformer

The use of many types of peaking transformer is limited to the smaller thyratrons. With large thyratrons a grid current of about 3 mA flows during ignition of the tube. This fairly large current flows through the secondary of the peaking transformer and often causes such a decrease of the voltage peak that the ignition is interrupted or at least badly influenced. Below a control circuit is described in which a voltage pulse of constant amplitude is generated with the aid of one thyatron PL 5727.

Fig. 5.12 shows a diagram of the circuit. The capacitor C_1 and the resistor R_1 have such values that the voltage across R_1 is almost sawtooth-shaped. This voltage is represented by $V_{g\sim}$ in Fig. 5.13. The rectifier S_1 is so connected that the sawtooth

is negative going (Fig. 5.12: B negative with respect to A). The sawtooth is applied to the grid of the thyatron Th_1 , which is vertically controlled. The d.c. voltage required for this control is derived from the potentiometer R_3 .

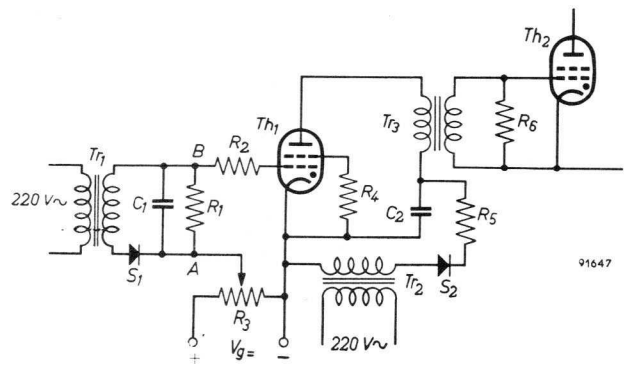


Fig. 5.12. Control circuit without peaking transformer (the grid circuit of Th_2 is simplified).

$R_1 = 150 \text{ k}\Omega$	$C_1 = 0.1 \mu\text{F}$
$R_2 = 330 \text{ k}\Omega$	$C_2 = 0.15 \mu\text{F}$
$R_3 = 10 \text{ k}\Omega$	$Th = \text{PL 5727}$
$R_4 = 10 \text{ k}\Omega$	$Tr_1 = \text{mains transformer } 220/65 \text{ V}$
$R_5 = 8.2 \text{ k}\Omega$	$Tr_2 = \text{mains transformer } 220/220 \text{ V}$
$R_6 = 22 \text{ k}\Omega$	$Tr_3 = \text{transformer}$
	$S_1 = \text{OA 85 (2 in series)}$
	$S_2 = \text{selenium rectifier}$

The anode of the thyatron is fed from the transformer Tr_2 . The primary of Tr_2 must be connected to a voltage that leads the primary voltage of Tr_1 by 60° to 90° . The secondary voltage of Tr_2 is rectified by S_2 . The RC -constant R_5-C_2 is so small that the voltage at C_2 reaches the peak value of the secondary voltage of Tr_2 after a quarter of a cycle, enabling it to remain at that value during nearly 270° . The rectified voltage is applied to the anode of Th_1 and is represented by V_{a1} in Fig. 5.13. As soon as anode current flows in Th_1 the capacitor C_2 is fully discharged and remains discharged until the next positive half cycle of V_{Tr_2} . When the thyatron Th_1 is fired a current peak flows through the primary of

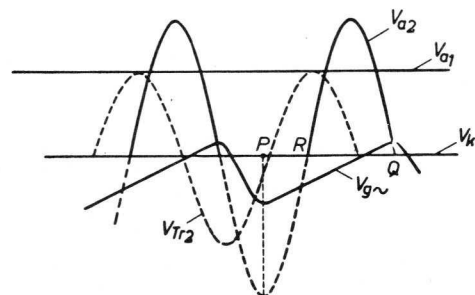


Fig. 5.13. Grid voltage of the thyatron PL 5727.

Tr_3 so that a voltage pulse appears at the secondary. Since the anode of Th_1 is at a constant potential (V_{a1} in Fig. 5.13) the amplitude of the voltage pulse is independent of the firing angle of the thyatron. When the anode would have been fed from a sinusoidal voltage, the amplitude of the pulse would vary greatly with the firing angle.

It appears from Fig. 5.13 that the voltage pulse may be shifted from P to Q , i.e. over a range of about 270° . In the range P to R , however, the amplitude

of the pulse generated decreases sinusoidally in the direction of P . In order to obtain a pulse of constant amplitude the range R to Q is therefore only usable. In the figure the anode voltage V_{a2} of the thyatron Th_2 to which the voltage peaks are applied, is also drawn. This voltage is in phase with the primary voltage of Tr_1 and consequently with the sawtooth voltage $V_{g\sim}$. It appears from Fig. 5.13 that only a shift from R to Q is required for the voltage pulse in order to be able to control Th_2 over half a cycle.

VI. Circuits for safeguarding thyratrons

A. DELAY CIRCUITS FOR WAITING TIME

A mercury-vapour thyatron must not be allowed to supply current until the cathode has reached the operating temperature and the gaseous atmosphere in the bulb has attained a certain minimum pressure. (See page 14.) For this reason it is necessary to switch on the filament for a certain length of time before the load is applied, the heat developed during this period causing the mercury in the bulb to evaporate and the vapour pressure to increase.

This heating time may be considerable, particularly in the case of large thyratrons: in the case of the thyatron PL 105 it is as much as 5 minutes. It is therefore necessary to protect the tubes by ensuring that the prior application of the filament voltage is automatic, as in the event of an accidental or intentional interruption of the supply voltage there is a risk that load conditions may return after the tubes have cooled down.

Automatic delay can be provided best by blocking the thyratrons during the heating-up time by applying a negative voltage to the grid.

Methods of blocking

Thyratrons may be kept extinguished by applying to their grids during the heating up time a negative bias with regard to the cathode, sufficiently high to prevent the tubes from igniting even at the highest anode voltages likely to occur in practice. In this way no expensive switches need be incorporated in the anode circuit, for the switching takes place in the grid circuit where the current to be interrupted is negligible. The following circuits must be considered.

1. *D.c.-operated thyratrons.* When thyratrons are d.c. operated, as, for example, in inverters, they can be blocked only by means of a negative grid bias. If the d.c. grid voltage is supplied by a rectifier provision must be made to ensure that the blocking voltage reaches the required value so

much sooner than the anode voltage that the tubes cannot ignite. If the rectifier for supplying the grid bias should become defective the tubes will, however, no longer be safeguarded.

2. *A.c.-operated thyratrons.* In this case the tubes can be blocked in the same way as indicated above, i.e. by applying a d.c. bias, or by means of an a.c. grid voltage in anti-phase with the anode voltage.

Practical circuit

The methods indicated above for keeping thyratrons extinguished during the pre-heating period are illustrated by means of the controlled rectifier circuit given in Fig. 6.1.

Two tubes PL 105 are connected to a 220 V mains across which an inductance L with centre tap is connected. By means of a suitable control unit TC

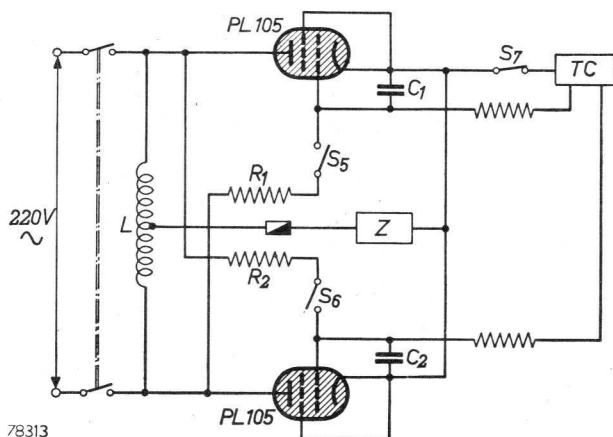


Fig. 6.1. Circuit of a controlled two-phase half-wave rectifier with two thyratrons PL 105. TC denotes the control device by means of which the point of ignition of the thyratrons can be adjusted. $R_1 = R_2 = 0.1 \text{ M}\Omega$, $C_1 = C_2 = 6000 \text{ pF}$, $Z =$ load of the rectifier, S_5 , S_6 and S_7 switches operated by a retardation circuit.

the point of ignition of the tubes and thus the output of the rectifier can be controlled.

During the heating-up time S_7 is opened, thereby cutting out the control device TC . Moreover, S_5 and S_6 are closed so that a voltage in anti-phase is applied

to the grids via the resistors R_1 and R_2 . During normal operation the switches S_5 and S_6 are open, S_7 being closed.

The operation of the switches S_5 , S_6 and S_7 is brought about automatically by means of the retardation circuit shown in Fig. 6.2.

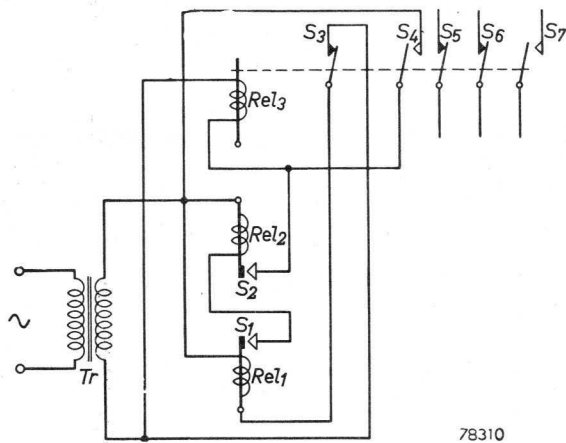


Fig. 6.2. Retardation circuit. Rel_1 and Rel_2 are thermo-relays with a delay time of $2\frac{1}{2}$ minutes each, operating the switches S_1 and S_2 . Rel_3 is a thermo-relay operating the contacts S_3 - S_7 up to about 1 minute after having been switched off.

To obtain a delay of 5 minutes between the instants of switching on the filament voltage and the load, thermo-relays may be used. For practical reasons two thermo-relays Rel_1 and Rel_2 , each with a delay time of about $2\frac{1}{2}$ minutes, are employed.

As the apparatus is switched on the heating element of relay Rel_1 is fed by the filament transformer Tr . After $2\frac{1}{2}$ minutes the contact S_1 of Rel_1 will be closed, thereby connecting the heating element of the second relay Rel_2 to the filament transformer. After another $2\frac{1}{2}$ minutes the contact S_2 will be closed, thus energizing the relay Rel_3 , which operates the contacts S_3 - S_7 .

Although in principle a normal magnetic telephone relay could be used for Rel_3 , it is preferable to use a thermo-relay equipped with the required contacts S_3 - S_7 , for this purpose too. The time this relay requires for heating may be of the order of $\frac{1}{4}$ minute, so that the delay caused thereby is of little importance, the main purpose in view being to introduce a delay of up to about 1 minute in releasing the contacts after the energizing current has been interrupted. This prevents the retardation circuit from operating on short interruptions of the supply voltage. If the supply fails for an interval of less than 1 minute the thyatrons may be safely switched on again immediately without any additional heating-up period, the vapour pressure still being sufficient-

ly high. (It will be realized that if a magnetic relay were used for Rel_3 any accidental interruption of short duration of the supply voltage would cause the apparatus to become inoperative for a period of 5 minutes!)

By the operation of Rel_3 the contact S_3 is opened whilst S_4 is closed. The thermo-relays Rel_1 and Rel_2 are thus disconnected and will cool down, but relay Rel_3 remains energized, contact S_4 taking over the function of S_2 . The further contacts S_5 , S_6 and S_7 correspond to the similarly marked switches of Fig. 6.1 and are required for blocking the thyatrons in the way already described.

If for any reason the supply voltage is accidentally interrupted the relay Rel_3 will be de-energized and, unless the supply voltage returns before contact S_4 is opened, it will take 5 minutes for the retardation circuit to operate relay Rel_3 anew, thereby unblocking the thyatrons.

It might be suggested that relay Rel_3 could be omitted and the required contacts added to Rel_2 . In that case, however, the conflicting requirements of heating up in $2\frac{1}{2}$ minutes and cooling down in less than 1 minute would have to be imposed on this relay.

B. RELAY OPERATION

Thyatrons are eminently suitable for energizing relays, since a fairly weak signal at the control grid is sufficient to operate a mechanism (switching electrical networks on or off, stopping, starting or reversing motors, etc.).

In most of these applications the electro-magnetic relay is incorporated in the anode circuit of the tube. To prevent fluttering of the relay when the tube is a.c. fed, a capacitor of sufficient capacitance can be shunted across the relay; this has the effect of smoothing the current pulses (see Fig. 6.3). This capacitor, however, forms a low impedance to the current pulses, so that there is risk of the maximum admissible peak current of the tube

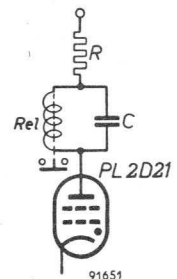


Fig. 6.3. Anode circuit of a thyatron in relay operation.

being exceeded. This can be avoided by connecting a current-limiting resistor in series with the supply voltage. The resistance of the relay is frequently sufficient for limiting the *average* anode current.

VII. Technical data

The tubes the technical data of which are given below have been divided into three main groups, viz.:

- a.* Rare-gas filled thyratrons,
- b.* Mercury-vapour filled thyratrons,
- c.* Thyratrons filled with a mixture of mercury vapour and rare gas.

The group *a* consists of the following types:

PL2D21
PL 6574
PL 1607
PL 5684/C3JA
PL 5632/C3J
PL 5544
PL 5545

Group *b* consists of:

PL 5557
PL 5559
PL 105
PL 255
PL 260

Group *c* consists of:

PL 3C23
PL 6755
PL 150

The PL₂D₂I¹⁾

The PL₂D₂I (Fig. 7.1) is a thyatron of the tetrode type filled with rare gas; it is a miniature version with an indirectly heated cathode. Its warming-up time is approx. 20 sec. The tube has been designed for an average anode current of 100 mA; the maximum cathode current is 500 mA. The maximum anode voltage is 650 V in the positive, and 1300 V in the negative direction.

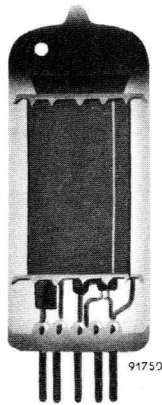


Fig. 7.1. The gas-filled tetrode PL₂D₂I.

The typical properties of the PL₂D₂I are:

- (a) high ratio of the anode voltage to the corresponding negative ignition voltage at the control grid, which, within wide limits, is independent of the temperature;
- (b) small anode-to-grid capacitance;
- (c) low control-grid current.

Due to the small anode-to-grid capacitance (C_{ag}) the functioning of the tube is hardly influenced by mains voltage pulses at the anode. The small grid current, moreover, permits the use of a relatively

high grid resistance. In this way high sensitivity is obtained, so that the PL₂D₂I can be directly operated by a high-vacuum phototube.

The tube can be used for energizing a relay, as a controlled rectifier, for stabilizing alternating voltages, in electronic timers, and in the grid circuit of high-power thyatrons.

The base of the PL₂D₂I fits into a 7-pins miniature tube socket. The use of the type 5909/36 is recommended; this tube socket is made of highly insulating material, so that the leak current is small in proportion to the grid current when the tube is in the non-conducting condition.

Since the control-grid current of the tube is small, a resistance of maximum 10 M Ω may be applied between the control grid and the cathode. When such a high resistance is used, care should, however, be taken that the tube base and the socket are clean and dry in order to minimize the influence of leak currents. For this reason a resistance of maximum 1 M Ω is recommended.

When the tube is a.c. fed and a high grid resistance is used, it will be necessary to keep the capacitance of the wiring between the anode and the control grid as low as possible. This can be effected by soldering the grid resistor directly to the tube socket and by joining the connections from the screen grid and the cathode at the tube socket. A screen jointed to the cathode connection may also be useful.

The screen grid is usually connected to the cathode, but it can also be used to shift the control characteristic. By making the screen-grid negative, the control characteristic is shifted in the positive direction. The insertion of a 1000 Ω resistor in the screen-grid lead is recommended to prevent the screen-grid current from growing too large.

¹⁾ A ruggedized version of this tube has type number PL 5727.

TECHNICAL DATA

HEATER DATA

Heating indirect by a.c. or d.c.
 Heater voltage $V_f = 6.3 \text{ V} \pm 10\%$
 Heater current $I_f = 0.60 \text{ A}$
 Waiting time $T_w = 20 \text{ sec}^1)$

Mounting position any
 Base miniature button 7-pin
 Socket type 5909/36
 Net weight 10 g
 Shipping weight 50 g

CAPACITANCES

Grid to all other electrodes $C_{g1} = 2.4 \text{ pF}$
 Anode to all other electrodes $C_a = 1.6 \text{ pF}$
 Anode to control grid $C_{ag1} = 0.026 \text{ pF}$

TYPICAL CHARACTERISTICS

Ionization time
 $V_{a\text{---}} = 100 \text{ V}$
 $I_{ap} = 0.5 \text{ A}$
 Grid over-voltage (square pulse) = 50 V
 $T_{\text{ion}} = 0.5 \mu\text{sec}$

Deionization time
 $V_{a\text{---}} = 125 \text{ V}$
 $-V_{g1} = 100 \text{ V}$
 $R_{g1} = 1 \text{ k}\Omega$
 $I_a = 0.1 \text{ A}$
 $T_{\text{dion}} = 35 \mu\text{sec}$

Deionization time
 $V_{a\text{---}} = 125 \text{ V}$
 $-V_{g1} = 10 \text{ V}$
 $R_{g1} = 1 \text{ k}\Omega$
 $I_a = 0.1 \text{ A}$
 $T_{\text{dion}} = 75 \mu\text{sec}$

Arc voltage $V_{\text{arc}} = 8 \text{ V}$

Control ratio between anode and control grid at striking point ($R_{g1} = 0 \text{ M}\Omega$; $V_{g2} = 0 \text{ V}$)
 $\frac{V_a}{V_{g1}} = 250$

Control ratio between anode and screen grid at striking point ($R_{g1} = 0 \text{ M}\Omega$; $R_{g2} = 0 \text{ M}\Omega$; $V_{g1} = 0 \text{ V}$)
 $\frac{V_a}{V_{g2}} = 1000$

BASE CONNECTIONS AND DIMENSIONS (in mm)

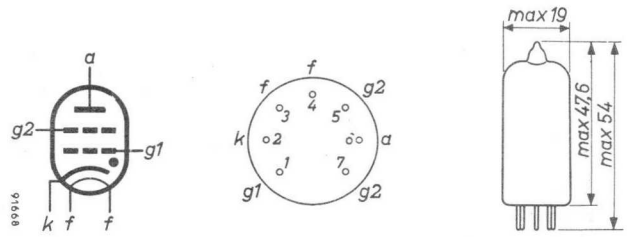


Fig. 7.2. Electrode arrangement, electrode connections and maximum dimensions in mm.

OPERATING CHARACTERISTICS FOR RELAY SERVICE

A.c. anode voltage $V_a = 117 \text{ } 400 \text{ V}_{\text{rms}}$
 Screen-grid voltage $V_{g2} = 0 \text{ } 0 \text{ V}$
 A.c. grid-bias voltage (phase difference between V_{g1} and V_a approx. 180°) $V_{g1} = 5 \text{ } \text{V}_{\text{rms}}$
 D.c. control-grid voltage $V_{g1} = -6 \text{ } \text{V}$
 Peak control-grid signal voltage $V_{g1p} = 5 \text{ } 6 \text{ V}$
 Anode resistor $R_a = 1.2 \text{ } 2.0 \text{ k}\Omega$
 Grid resistor $R_{g1} = 1.0 \text{ } 1.0 \text{ M}\Omega$

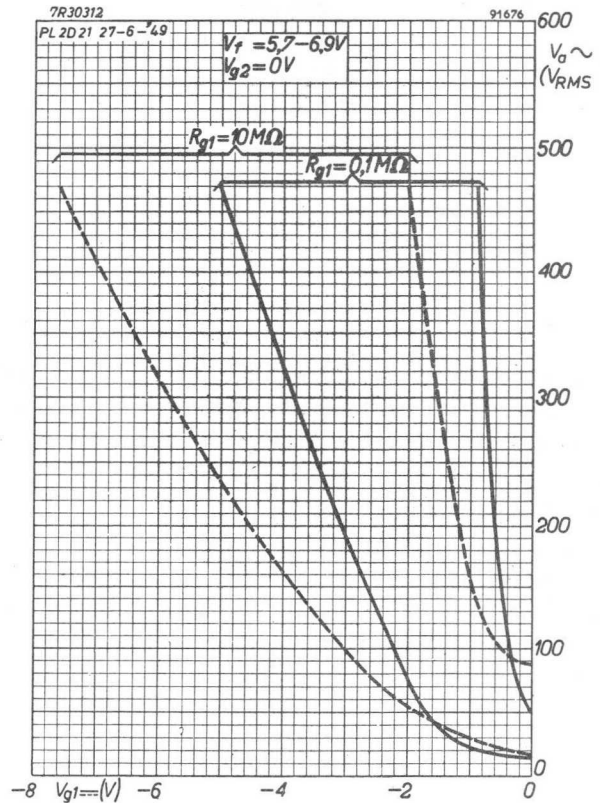
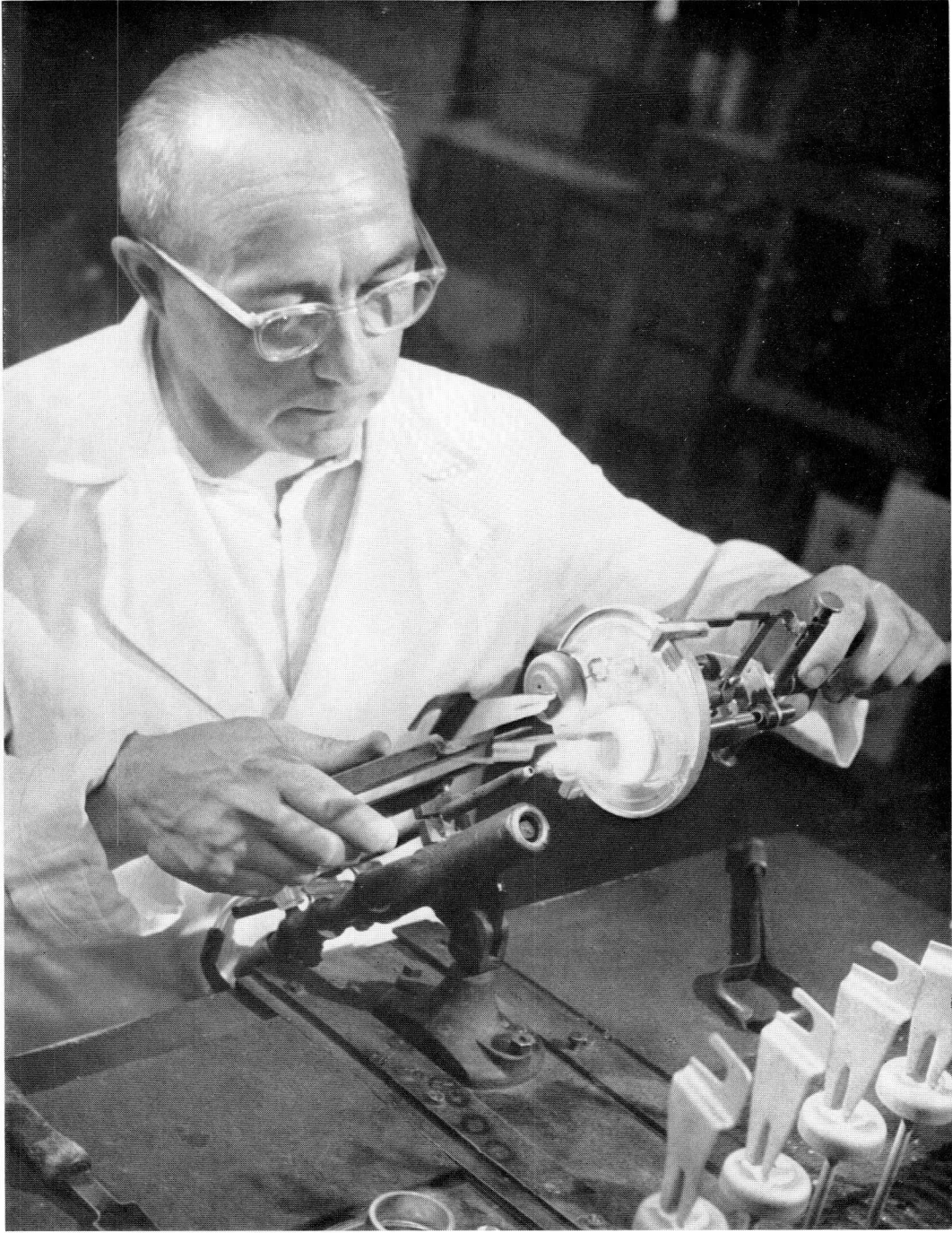


Fig. 7.3. Operational range of critical grid voltage of the PL2D21.

¹⁾ If urgently wanted T_w may be decreased to min. 10 sec.



Sealing of the cathode connectors to the tube base



A batch of tube bases is cleaned and degreased

LIMITING VALUES FOR RELAY AND GRID-CONTROLLED RECTIFIER SERVICE

Peak forward anode voltage	V_{ap}	= max.	650 V
Peak inverse anode voltage	V_{ainvp}	= max.	1300 V
Screen-grid voltage before conduction	$-V_{g2}$	= max.	100 V
Screen-grid voltage during conduction ($T_{av} = \text{max. 30 sec}$)	$-V_{g2}$	= max.	10 V
Control-grid voltage before conduction	$-V_{g1}$	= max.	100 V
Control-grid voltage during conduction ($T_{av} = \text{max. 30 sec}$)	$-V_{g1}$	= max.	10 V
Peak cathode current	I_{kp}	= max.	0.5 A
Average cathode current ($T_{av} = \text{max. 30 sec}$)	I_k	= max.	0.1 A
Average screen-grid current ($T_{av} = \text{max. 30 sec}$) ¹⁾	I_{g2}	= max.	0.01 A
Average control-grid current ($T_{av} = \text{max. 30 sec.}$)	I_{g1}	= max.	0.01 A
External resistance between control grid and cathode	R_{g1}	= max.	10 M Ω
Recommended value			1 M Ω
Peak voltage between cathode and heater		cathode positive	V_{kfp} = max. 100 V
		cathode negative	V_{kfp} = max. 25 V
Heater voltage	V_f	= max.	6.9 V
		= min.	5.7 V
Ambient temperature range	t_{amb}	= max.	+ 90 °C
		= min.	- 75 °C

Remark: It is not recommended to use the second grid as control electrode.

¹⁾ In order not to exceed this maximum value it is recommended to insert a series resistor of 1000 Ω in the screen-grid lead.

Fig. 7.4. Average control characteristics of the PL2D21 for different values of the screen-grid voltage V_{g2} without control-grid and screen-grid resistors.

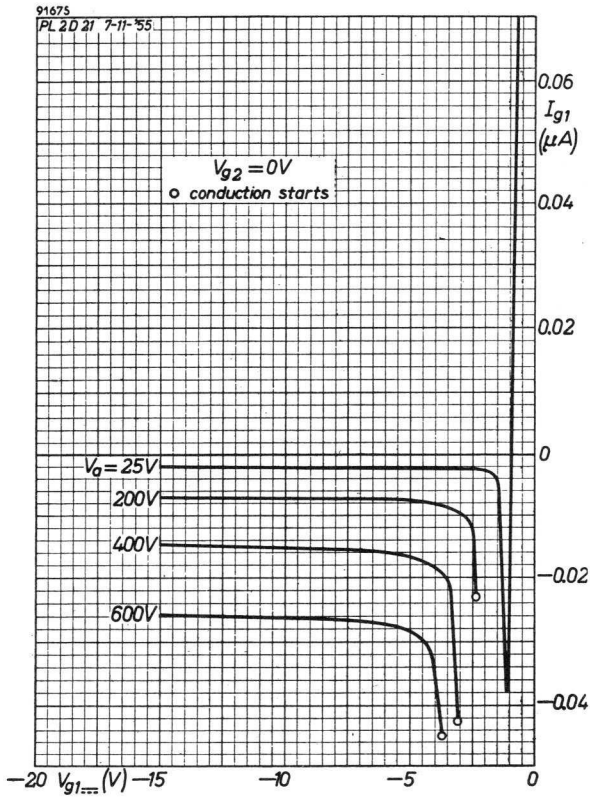
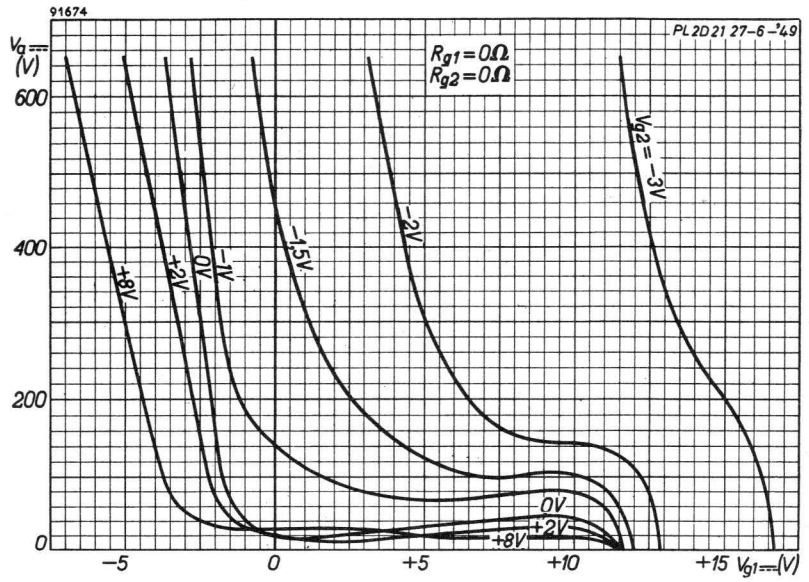


Fig. 7.5. Average grid characteristics of the PL2D21 before anode conduction at different anode voltages V_a and screen-grid voltage $V_{g2} = 0$ V.

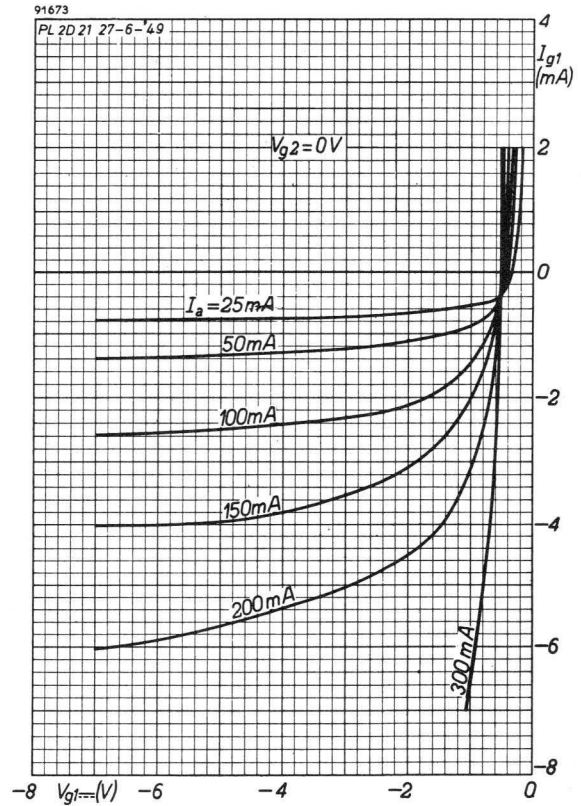
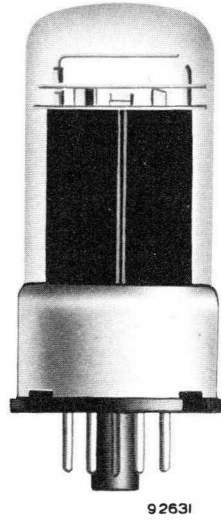


Fig. 7.6. Average grid characteristics of the PL2D21 during anode conduction at different values of the anode current I_a and a screen-grid voltage $V_{g2} = 0$ V.

PL 6574

rare-gas filled tetrode

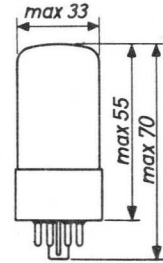
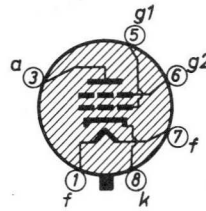
The PL 6574 is a tetrode thyatron with inert-gas filling and a negative control characteristic. The tube is primarily designed for relay and servo applications. It has an indirectly heated cathode and an octal base. The maximum average cathode current is 300 mA, the peak current amounts to 2 A. A high grid resistor (10 MΩ) may be used so that a high sensitivity can be obtained and the tube can be directly operated by a high-vacuum phototube. When the high grid resistance is used, care should be taken that the tube base and the socket are clean and dry in order to minimize the influence of leak currents.



92631

The PL6574 tetrode thyatron.

BASE CONNECTIONS AND DIMENSIONS (in mm)



92632

Electrode arrangement, electrode connections and maximum dimensions in mm.

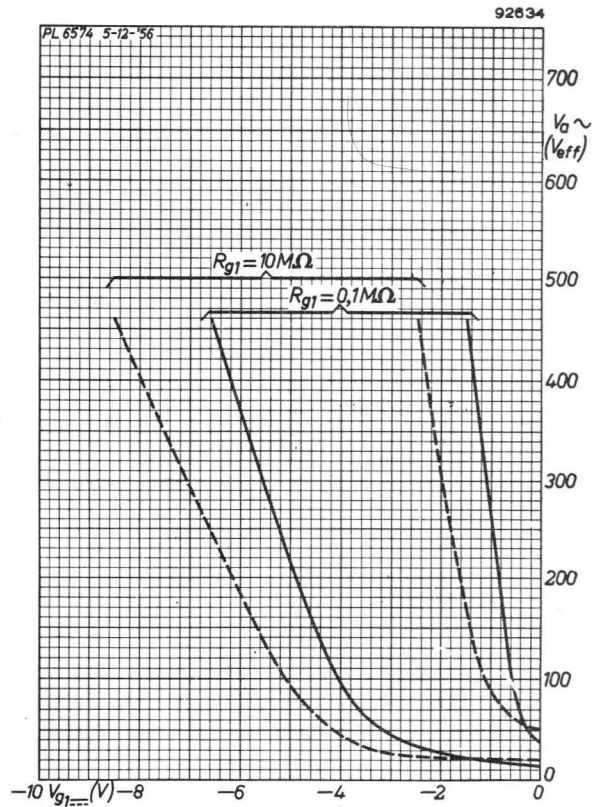
TENTATIVE DATA

HEATER DATA

Heating		indirect
Heater voltage	$V_f =$	6.3 V
Heater current	$I_f =$	950 mA
Waiting time	$T_w =$	min. 15 sec
Mounting position		any
Base		octal

TYPICAL CHARACTERISTICS

Arc voltage	$V_{arc} =$	10 V
Control ratio at striking point		
($V_{g2} = 0$ V; $R_{g1} = 0$ Ω)	$V_a/V_{g1} =$	275
($V_{g1} = 0$ V; $R_{g2} = 0$ Ω)	$V_a/V_{g2} =$	370



Control characteristics of the PL6574 for two different values of the grid leak resistor R_{g1} .

LIMITING VALUES (absolute limits)

Peak forward anode voltage.....	V_{ap}	= max.	650 V
Peak inverse anode voltage	V_{ainvp}	= max.	1300 V
Second grid voltage before conduction	$-V_{g2}$	= max.	100 V
Second grid voltage during conduction	$-V_{g2}$	= max.	10 V
Control grid voltage before conduction	$-V_{g1}$	= max.	250 V
Control grid voltage during conduction	$-V_{g1}$	= max.	10 V
Cathode current (averaging time = max. 15 sec)	I_k	= max.	300 mA
Peak cathode current	I_{kp}	= max.	2 A
Surge current ($T = \text{max. } 0.1 \text{ sec}$)	I_{surge}	= max.	10 A
Positive second grid current ($V_a > -10 \text{ V}$) ($T_{av} = 1 \text{ cycle}$)	$+I_{g2}$	= max.	20 mA
Positive control grid current ($V_a > -10 \text{ V}$) ($T_{av} = 1 \text{ cycle}$)	$+I_{g1}$	= max.	20 mA
Peak positive control grid current during the time that V_a is more negative than -10 V	$+I_{g1p}$	= max.	1 mA
External resistance between cathode and grid ($I_k = 200 \text{ mA}$) ...	R_{g1}	= max.	10 M Ω
Peak voltage between cathode and heater (k pos.; f neg.)	V_{kfp}	= max.	100 V
Peak voltage between cathode and heater (k neg.; f pos.)	V_{kfp}	= max.	25 V
Ambient temperature	t_{amb}	=	$-75/+90 \text{ }^\circ\text{C}$

PL 1607

rare-gas filled tetrode

The PL 1607 is a four-electrode xenon-filled thyatron with negative control characteristic and directly heated cathode. The required heating-up time is 30 seconds whilst the tube is designed for an

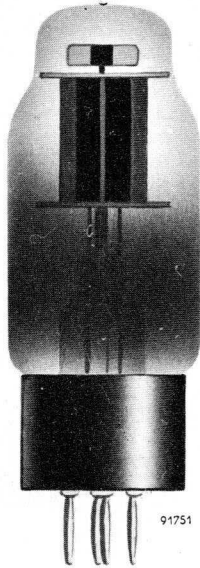


Fig. 7.7. The gas-filled tetrode PL 1607.

average anode current of 0.5 A, the permissible peak anode current being 2 A at frequencies of 25 c/s and above, and 1 A below 25 c/s. Both the forward and the peak inverse anode voltages are allowed to be as high as 650 V. The anode-to-grid capacitance

is very low, so that there is little risk of influence from anode voltage surges on the grid circuit. The low grid current allows it to be used with a high resistance in the grid circuit with resultant high circuit sensitivity, so that the PL 1607 can be operated directly from a high-vacuum phototube.

The main field of application of this tube is its use in electronic timers, particularly in high-precision timers as used in X-ray apparatus and in modern industry. The tube can further be used for grid-controlled rectifiers for obtaining a variable or constant d.c. output voltage.

The following ratings cover in detail the conditions under which this tube should be used.

The base of the PL 1607 fits the European 5-pin socket. The tube socket type 40465 is recommended, this being made of highly insulating material. All anode and grid return connections should be made to pin Nr. 3 of the tube base.

Since the control-grid current of the PL 1607 is low a control-grid resistor having a value as high as 5 M Ω may be used. For high resistance values it is, however, necessary to keep the tube base and socket clean and dry in order to minimize leakage currents. The screen grid is normally connected to the cathode via a resistor, but it can also be used to shift the control characteristic of the tube. When the screen grid is made negative the control characteristic is shifted in the positive direction.

TECHNICAL DATA

FILAMENT DATA

Heating direct
 Filament voltage $V_f = 2.0 \text{ V} \pm 5\%$
 Filament current $I_f = 2.6 \text{ A}$
 Waiting time $T_w = \text{min. } 30 \text{ sec}$

Mounting position any
 Base European 5-pin
 Socket type 40465
 Net weight 75 g
 Shipping weight (12 tubes) 2800 g

CAPACITANCES

Anode to control grid $C_{ag1} = 0.55 \text{ pF}$
 Anode to screen grid $C_{ag2} = 12 \text{ pF}$

BASE CONNECTIONS AND DIMENSIONS (in mm)

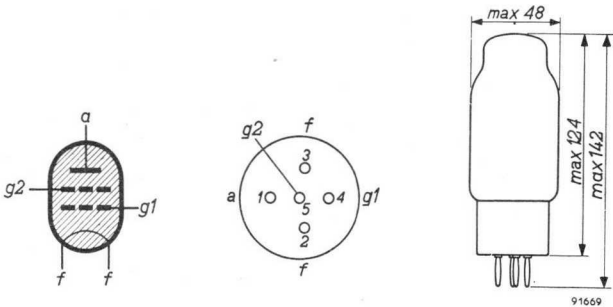


Fig. 7.7a. Electrode arrangement, electrode connections and maximum dimensions in mm.

TYPICAL CHARACTERISTICS

Arc voltage $V_{\text{arc}} = 15 \text{ V}$
 Deionization time $T_{\text{dion}} = 500 \mu\text{sec}$

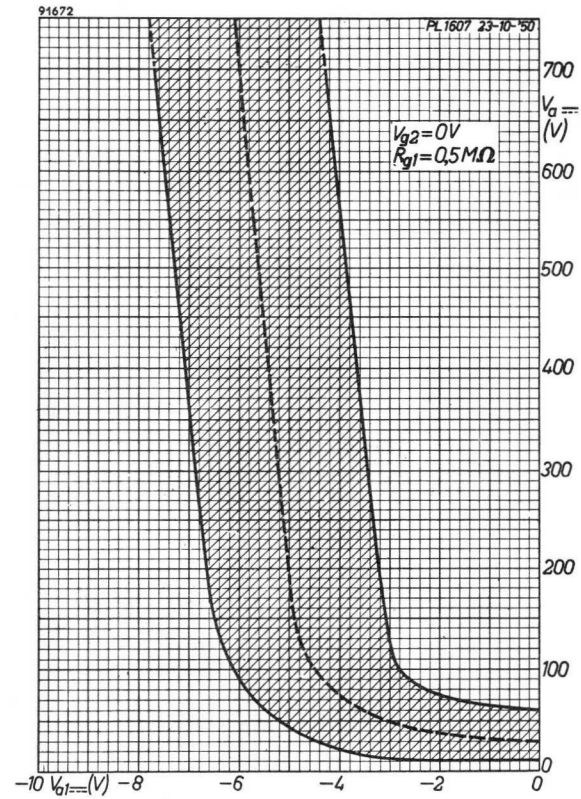


Fig. 7.8. Control characteristic of the PL 1607 at a screen-grid voltage $V_{g2} = 0 \text{ V}$ and a control-grid resistor $R_{g1} = 0.5 \text{ M}\Omega$.

LIMITING VALUES

Peak forward anode voltage	V_{ap}	= max.	650 V
Peak inverse anode voltage	V_{ainvp}	= max.	650 V
Screen-grid voltage before conduction	$-V_{g2}$	= max.	100 V
Screen-grid voltage during conduction	$-V_{g2}$	= max.	10 V
Control-grid voltage before conduction	$-V_{g1}$	= max.	100 V
Control-grid voltage during conduction	$-V_{g1}$	= max.	10 V
Peak anode current ($f < 25\text{c/s}$)	I_{ap}	= max.	1 A
Peak anode current ($f \geq 25\text{c/s}$)	I_{ap}	= max.	2 A
Anode current ($T_{av} = \text{max. } 15 \text{ sec.}$)	I_a	= max.	0.5 A
Peak screen-grid current	I_{g2p}	= max.	0.25 A
Screen-grid current ($T_{av} = \text{max. } 15 \text{ sec.}$)	I_{g2}	= max.	0.05 A
Peak control-grid current	I_{g1p}	= max.	0.25 A
Control-grid current ($T_{av} = \text{max. } 15 \text{ sec.}$)	I_{g1}	= max.	0.05 A
External resistance between screen grid and cathode	R_{g2}	=	0.1—1 MΩ
External resistance between control grid and cathode	R_{g1}	=	0.1—5 MΩ
Ambient temperature range	t_{amb}	=	-75 to +90 °C

PL 5684/C3JA

rare-gas filled triode

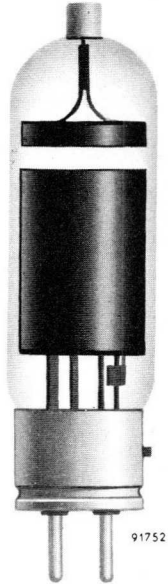
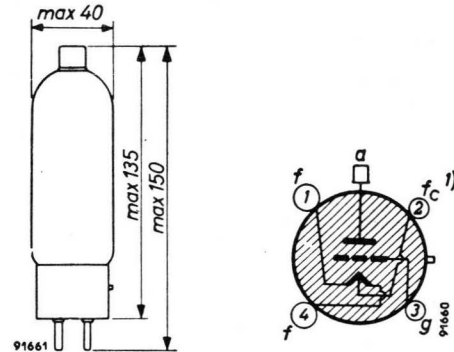


Fig. 7.9. The PL 5684/C3JA.

The PL 5684/C3JA is a rare-gas filled thyatron with a directly heated cathode. The minimum required heating time is 30 sec. The tube is designed for an average anode current of 2.5 A, the permissible peak anode current being 30 A. The peak forward voltage is as high as 1000 V; the peak inverse anode voltage amounts to 1250 V. The main field of application of this tube is ignitron firing circuits. It may further be used in relay and motor control circuits, especially servo-systems.

The tube fits the medium 4-pins socket with bayonet. The use of socket type B 8 700 90 is recommended, this being made of highly insulating material.

BASE CONNECTIONS AND DIMENSIONS (in mm)



Electrode arrangement, electrode connections and maximum dimensions in mm.

TENTATIVE DATA

FILAMENT DATA

Heating		direct
Filament voltage	$V_f =$	2.5 V
Filament current	$I_f =$	9.0 A
Waiting time	$T_w =$ min.	30 sec
Recommended value	$T_w =$	60 sec
Mounting position		any
Net weight		95 g
Base	Medium 4-pins with bayonet	
Socket		B 8 700 90
Anode cap		40619

CAPACITANCES

Anode to grid	$C_{ag} =$	3 pF
Grid to cathode	$C_{gk} =$	14 pF

TYPICAL CHARACTERISTICS

Arc voltage	$V_{arc} =$	10 V
Ionization time	$T_{ion} =$	10 μ sec
Deionization time	$T_{dion} =$	1000 μ sec

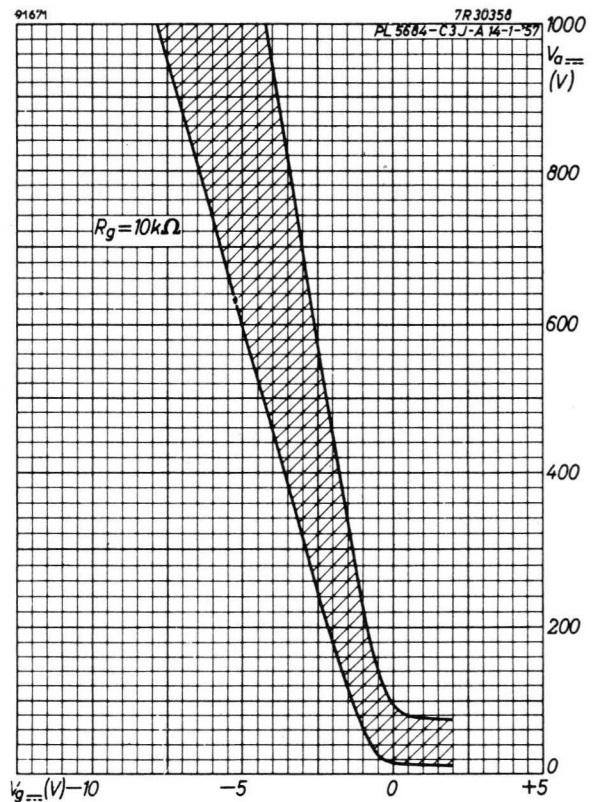


Fig. 7.10. Control characteristic of the PL 5684/C3JA.

¹⁾ Load return.

LIMITING VALUES (absolute limits)

Peak forward anode voltage	V_{ap}	= max.	1000 V
Peak inverse anode voltage	V_{ainvp}	= max.	1250 V
Grid voltage before conduction	$-V_g$	= max.	300 V ¹⁾
Grid voltage during conduction	$-V_g$	= max.	10 V
Peak cathode current	I_{kp}	= max.	30 A
Cathode current ($T_{av} = 5$ sec).	I_k	= max.	2.5 A
Fault current (max. duration = 0.1 sec).	I_{surge}	= max.	300 A ²⁾
Grid current ($T_{av} = 1$ cycle).	I_g	= max.	0.1 A
Peak grid current	I_{gp}	= max.	0.5 A
External resistance between grid and cathode	R_g	=	10 – 100 k Ω
Recommended value	R_g	=	33 k Ω
Ambient temperature	t_{amb}	=	–55 to +75 °C
Commutation factor	k	=	0.7 VA/ μ sec ²

¹⁾ 400 V may be tolerated up to $V_a = 900$ V and $R_g = 50$ –100 k Ω .
²⁾ Fuse in anode circuit max. 10 A (recommended 6 A).

PL 5632/C3J

rare-gas filled triode

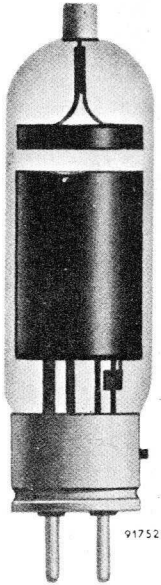


Fig. 7.11. The PL 5632/C3J.

The PL 5632/C3J is a rare-gasfilled thyatron with a directly heated cathode. The minimum required heating time is 30 sec. The tube is designed for an average anode current of 2.5 A, the permissible peak anode current being 30 A. The peak forward anode voltage is as high as 900 V; the peak inverse anode voltage amounts to 1250 V. The main field of application of this tube is ignitron firing circuits. It may further be used in relay and motor control circuits, especially servo-systems.

The tube fits the medium 4-pins socket with bayonet. The use of socket type B 8 700 90 is recommended, this being made of highly insulating material.

TENTATIVE DATA

FILAMENT DATA

Heating		direct
Filament voltage	$V_f =$	2.5 V
Filament current	$I_f =$	9.0 A
Waiting time	$T_w =$	min 30 sec
Recommended value	$T_w =$	60 sec
Mounting position		any
Net weight		95 g
Base	Medium 4-pins with bayonet	
Socket		B 8 700 90
Anode cap		40619

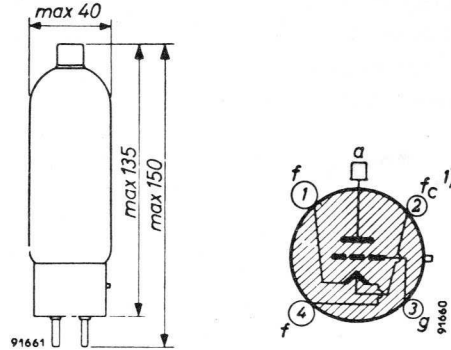
CAPACITANCES

Anode to grid	$C_{ag} =$	3 pF
Grid to cathode	$C_{gk} =$	14 pF

TYPICAL CHARACTERISTICS

Arc voltage	$V_{arc} =$	10 V
Ionization time	$T_{ion} =$	10 μ sec
Deionization time	$T_{dion} =$	1000 μ sec

BASE CONNECTIONS AND DIMENSIONS (in mm)



Electrode arrangement, electrode connections and maximum dimensions in mm.

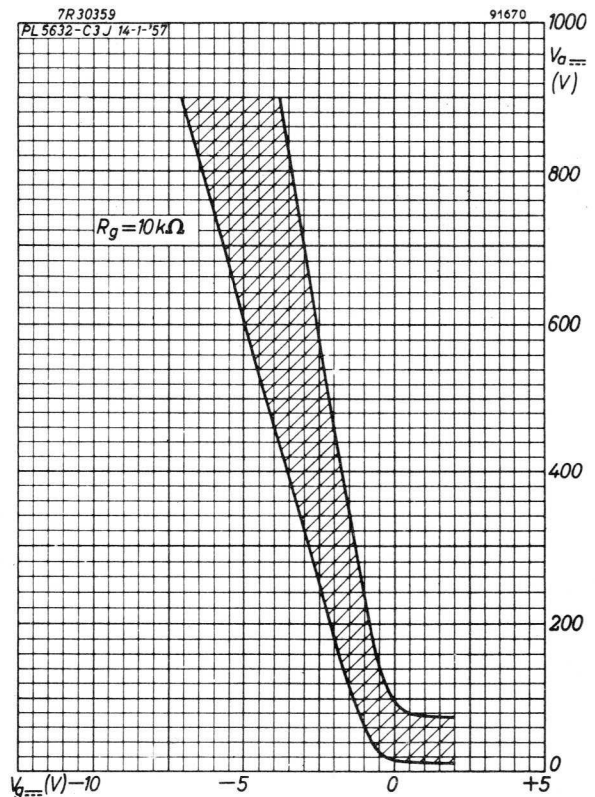


Fig. 7.12. Control characteristic of the PL 5632/C3J.

1) Load return.

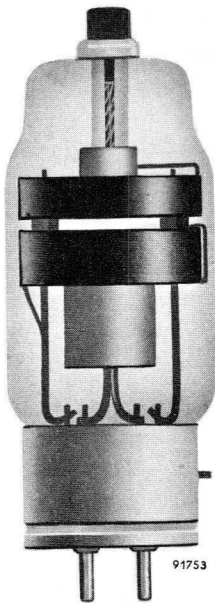
LIMITING VALUES (absolute limits)

Peak forward anode voltage.....	V_{ap}	= max.	900 V
Peak inverse anode voltage	V_{ainvp}	= max.	1250 V
Grid voltage before conduction	$-V_g$	= max.	300 V
Grid voltage during conduction	$-V_g$	= max.	10 V
Peak cathode current	I_{kp}	= max.	30 A
Cathode current ($T_{av} = 5$ sec)	I_k	= max.	2.5 A
Fault current (max. duration = 0.1 sec)	I_{surge}	= max.	300 A ¹⁾
Grid current ($T_{av} = 1$ cycle).....	I_g	= max.	0.1 A
Peak grid current.....	I_{gp}	= max.	0.5 A
External resistance between grid and cathode	R_g	=	10—100 k Ω
Recommended value	R_g	=	33 k Ω
Ambient temperature	t_{amb}	=	—55 to 75 °C
Commutation factor	k	=	0.7 VA/ μ sec ²

¹⁾ Fuse in anode circuit max. 10 A (recommended 6 A).

PL 5544

rare-gas filled triode



The PL 5544 is a xenon-filled thyatron with negative control characteristic. The cathode is directly heated and requires a heating-up time of 60 seconds. The tube is designed for an average anode current of 3.2 amperes, the permissible peak anode current being 40 amperes. Both the forward and the peak inverse anode voltage are allowed to be as high as 1500 V. The main field of application of this tube is in motor control and ignitron firing service.

Fig. 7.13. The PL 5544.

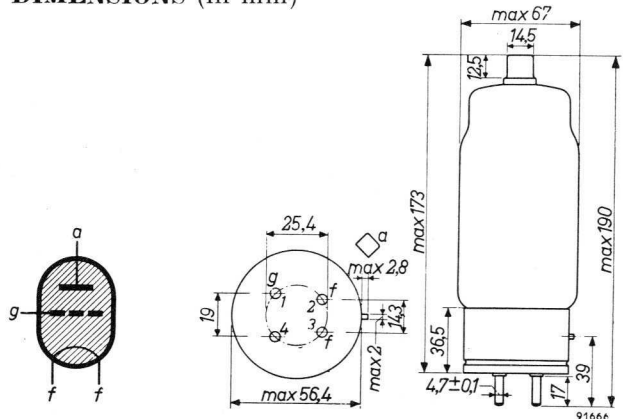
CAPACITANCES

Anode to grid
Grid to cathode

$$C_{ag} = 0.8 \text{ pF}$$

$$C_{gk} = 45 \text{ pF}$$

BASE CONNECTIONS AND DIMENSIONS (in mm)



TECHNICAL DATA (tentative)

FILAMENT DATA

Heating		direct
Filament voltage	$V_f =$	$2.5 \text{ V} \pm 5\%$
Filament current	$I_f =$	12 A
Waiting time	$T_w =$	min. 60 sec

Mounting position: Any between horizontal and vertical with base down.

Base	Super Jumbo with bayonet
Socket	type 40403/00
Top cap	type 40619
Net weight	300 g
Shipping weight	1350 g

TYPICAL CHARACTERISTICS

Arc voltage	$V_{arc} =$	12 V
Ionization time	$T_{ion} =$	10 μsec
Deionization time		
$V_g = -250 \text{ V}$	$T_{dion} =$	40 μsec
$V_g = -12 \text{ V}$	$T_{dion} =$	400 μsec

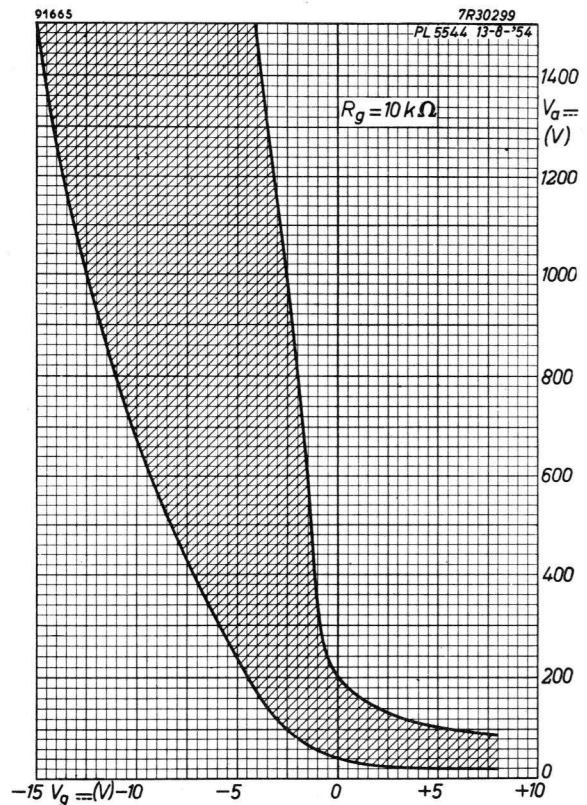


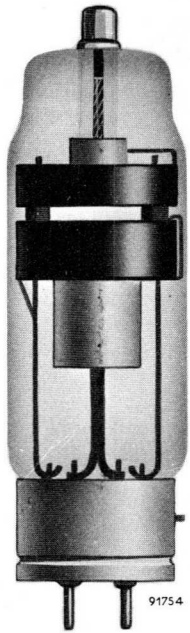
Fig. 7.14. Control characteristics of the PL 5544.

LIMITING VALUES (absolute values)

Peak forward anode voltage	V_{ap}	= max.	1500 V
Peak inverse anode voltage	V_{ainvp}	= max.	1500 V
Control-grid voltage before conduction	$-V_g$	= max.	250 V
Control-grid voltage during conduction	$-V_g$	= max.	10 V
Peak cathode current	I_{kp}	= max.	40 A
Cathode current ($T_{av} = \text{max. 15 sec}$)	I_k	= max.	3.2 A
Fault current (maximum duration = 0.1 sec)	I_{surge}	= max.	560 A
Control-grid current ($T_{av} = \text{max. 1 cycle}$)	I_g	= max.	0.2 A
External resistance between grid and cathode	R_g	=	0.5—100 k Ω
Recommended value	R_g	=	10 k Ω
Ambient temperature range	t_{amb}	=	-55 to +70 $^{\circ}\text{C}$

PL 5545

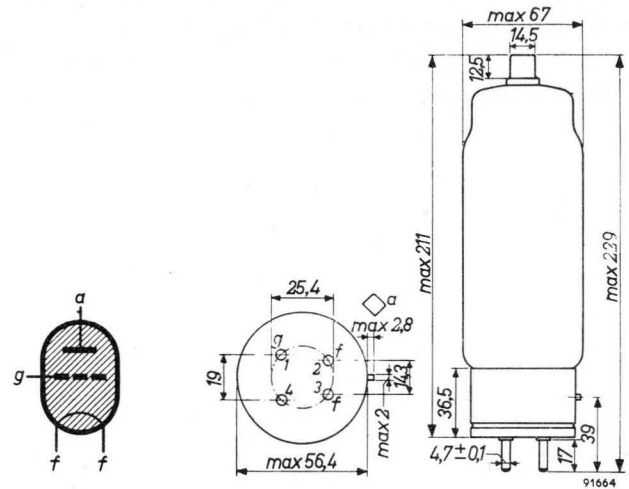
rare-gas filled triode



The PL 5545 is a xenon-filled thyratron with negative control characteristic. The cathode is directly heated and requires a heating-up time of 60 seconds. The tube is designed for an average anode current of 6.4 amperes, the permissible peak anode current being 80 A. Both the forward and the peak inverse anode voltage are allowed to be as high as 1500 V. The main field of application of this tube is in motor control and ignitron firing service.

Fig. 7.15. The gas-filled triode PL 5545.

BASE CONNECTIONS AND DIMENSIONS (in mm)



Electrode arrangement, electrode connections and maximum dimensions in mm.

TECHNICAL DATA

FILAMENT DATA

Heating		direct
Filament voltage	$V_f =$	$2.5 \text{ V} \pm 5\%$
Filament current	$I_f =$	21 A
Waiting time	$T_w =$	min. 60 sec

Mounting position: Any between horizontal and vertical with base down.

Base	Super Jumbo with bayonet
Socket	type 40403/00
Top cap	type 40619
Net weight	340 g
Shipping weight	1350 g

CAPACITANCES

Anode to grid	$C_{ag} =$	0.8 pF
Grid to cathode	$C_{gk} =$	45 pF

TYPICAL CHARACTERISTICS

Arc voltage	$V_{\text{arc}} =$	12 V
Ionization time	$T_{\text{ion}} =$	10 μsec
Deionization time		
$V_g = -250 \text{ V}$	$T_{\text{dion}} =$	50 μsec
$V_g = -12 \text{ V}$	$T_{\text{dion}} =$	500 μsec

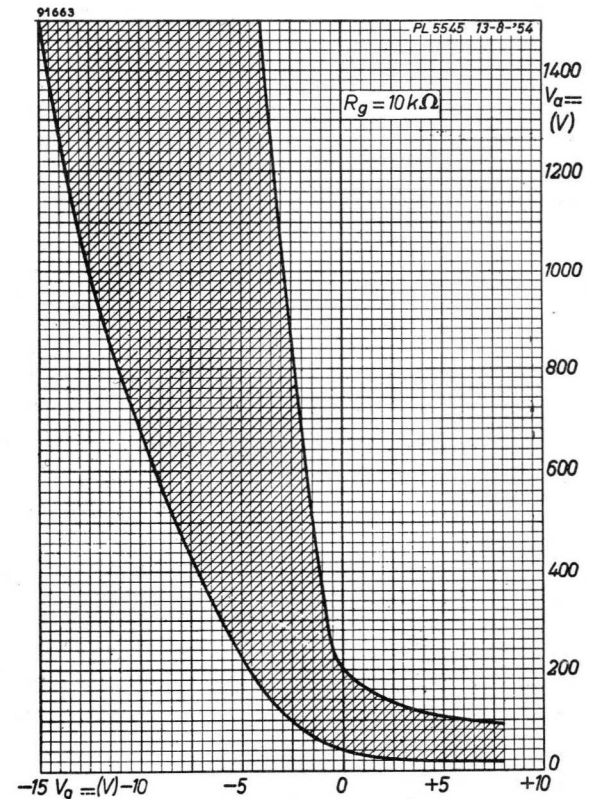


Fig. 7.16. Control characteristics of the PL 5545.

LIMITING VALUES (absolute values)

Peak forward anode voltage	V_{ap}	= max.	1500 V
Peak inverse anode voltage	V_{ainvp}	= max.	1500 V
Control-grid voltage before conduction	$-V_g$	= max.	250 V
Control-grid voltage during conduction	$-V_g$	= max.	10 V
Peak cathode current	I_{kp}	= max.	80 A
Cathode current ($T_{av} = \text{max. 15 sec}$)	I_k	= max.	6.4 A
Fault current (maximum duration = 0.1 sec)	I_{surge}	= max.	1120 A
Control-grid current ($T_{av} = \text{max. 1 cycle}$)	I_g	= max.	0.2 A
External resistance between grid and cathode	R_g	=	0.5—100 k Ω
Recommended value	R_g	=	10 k Ω
Ambient temperature range	t_{amb}	=	-55 to + 70 °C

PL 5557

mercury-vapour triode

The PL 5557 is a mercury-vapour filled triode with a filamentary cathode requiring a heating time of only 10 seconds. It is designed for an average anode

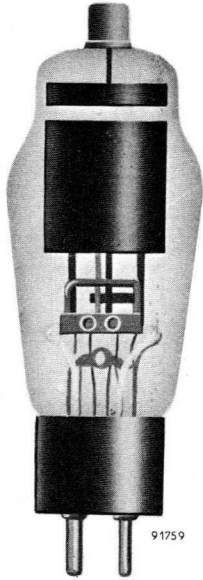


Fig. 7.17. The mercury-vapour triode PL 5557.

current of 0.5 A, the permissible peak anode current being 2 A at frequencies above 25 c/s and 1 A below 25 c/s. The peak inverse anode voltage may become as high as 5 kV and the peak forward anode voltage 2.5 kV.

The anode is brought out at the top of the bulb, thus ensuring safe operation at high anode voltages. Despite the absence of a screen grid the anode-to-grid capacitance has been kept low (3.3 pF) so that there is little risk of influence from anode voltage surges on the grid circuit.

The tube can be used for relay service, in alarm and protection installations, for d.c. and a.c. motor control and, when two tubes are connected in an inverse parallel circuit, for controlling a.c. currents.

It can also be used as a rectifier either in a half wave or full wave circuit. Also in the latter application it is possible to apply grid control, so that a variable or stabilized d.c. output can be obtained.

For the PL 5557 tube socket 40218/03 is recommended this being made of highly insulating material. The tube fits the medium 4-pin socket with bayonet.

TECHNICAL DATA

FILAMENT DATA

Heating		direct
Filament voltage	$V_f = 2.5 \text{ V} \pm 5\%$	
Filament current	$I_f = 5.0 \text{ A}$	
Waiting time	$T_w = \text{min. } 5 \text{ sec}^1)$	
Recommended time	$= 10 \text{ sec}$	

Mounting position	vertical, base down
Base	medium 4-pin with bayonet
Socket	type 40218/03
Top cap	type 40619
Net weight	100 g
Shipping weight (50 tubes)	7500 g

TYPICAL CHARACTERISTICS

Arc voltage	$V_{\text{arc}} = 12 \text{ V}$
Ionization time	$T_{\text{ion}} = 10 \mu\text{sec}$
Deionization time	$T_{\text{dion}} = 1000 \mu\text{sec}$
Operating frequency	$= \text{max. } 150 \text{ c/s}$

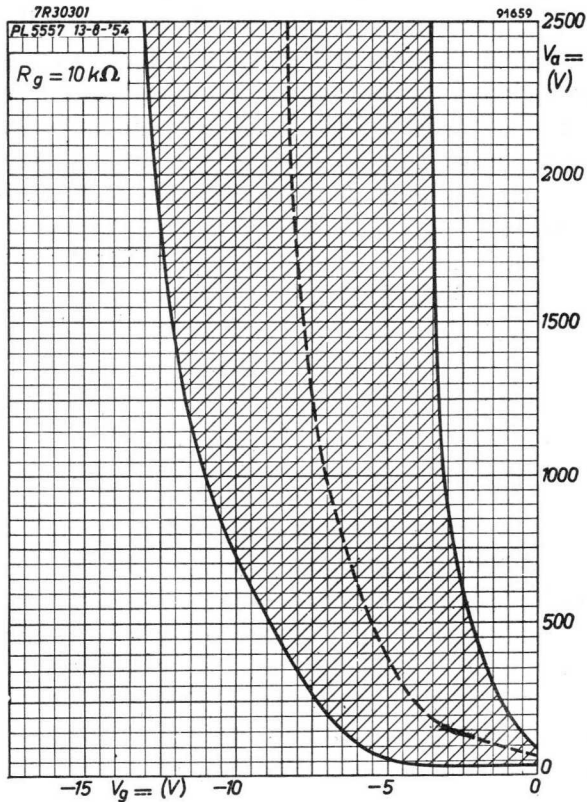


Fig. 7.18. Control characteristic of the PL 5557.

¹⁾ See fig. 7.19.

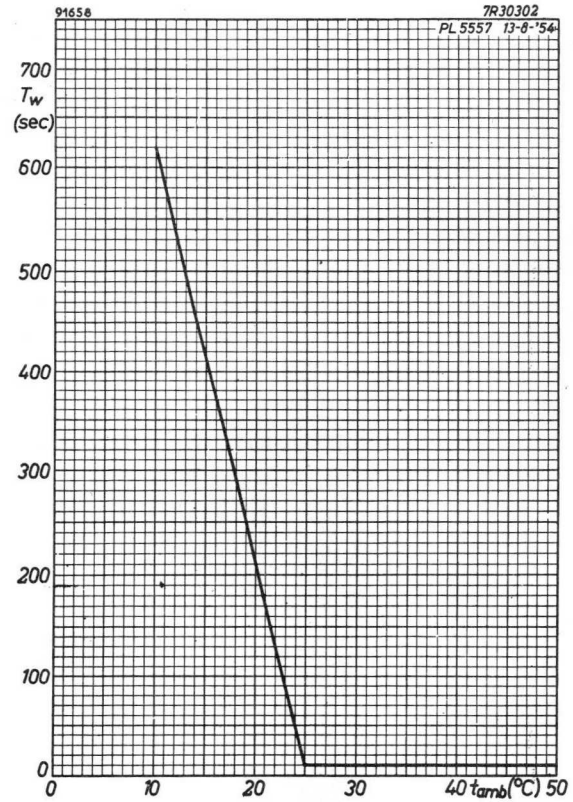
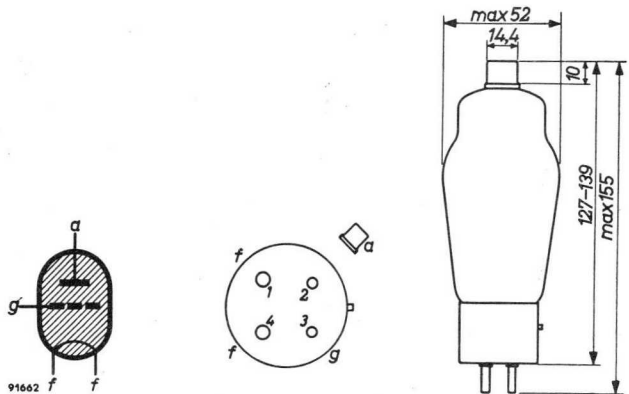


Fig. 7.19. Cathode preheating curve. The curve indicates the necessary preheating time as a function of the ambient temperature.

CAPACITANCES

Anode to grid	$C_{ag} = 3.3 \text{ pF}$
Grid to cathode	$C_{gk} = 5.0 \text{ pF}$

BASE CONNECTIONS AND DIMENSIONS (in mm)



Electrode arrangement, electrode connections and maximum dimensions in mm.

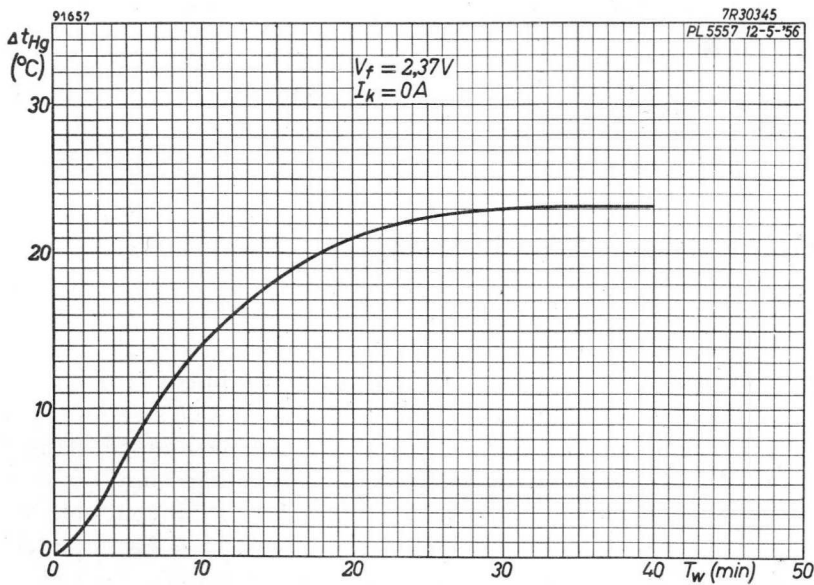


Fig. 7.20. Temperature rise characteristic indicating the rise of the condensed mercury-vapour temperature (above ambient temperature) in °C, with only the filament switched on. (Filament voltage is 2.37 V.)

LIMITING VALUES (absolute values)

Peak forward anode voltage	V_{ap}	= max.	2500 V
Peak inverse anode voltage	V_{ainvp}	= max.	5000 V
Grid voltage before conduction	$-V_g$	= max.	500 V
Grid voltage during conduction	$-V_g$	= max.	10 V
Peak cathode current below 25 c/s	I_{ap}	= max.	1 A
Peak cathode current at 25 c/s and higher	I_{ap}	= max.	2 A
Anode current ($T_{av} = \text{max. } 15 \text{ sec}$)	I_a	= max.	0.5 A
Grid current ($T_{av} = \text{max. } 15 \text{ sec}$)	I_g	= max.	0.05 A
External resistance between grid and cathode	R_g	= max.	100 kΩ
Recommended value	R_g	= max.	10 kΩ
Temperature range of condensed mercury	t_{Hg}	=	35–80 °C
Recommended temperature	t_{Hg}	=	50 °C
Surge anode current for max. 0.1 sec.	I_{surge}	= max.	40 A

PL 5559

mercury-vapour triode

The PL 5559 is a mercury-vapour filled triode with a negative control characteristic and indirectly heated cathode. It is designed for an average anode

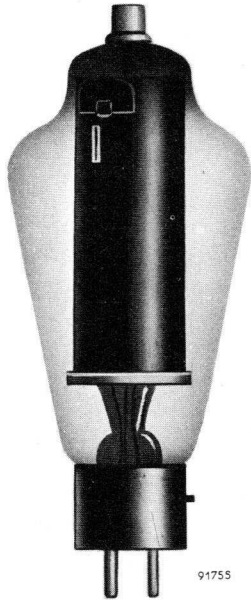


Fig. 7.21. The mercury-vapour triode PL 5559.

current of 2.5 A, whilst the maximum peak anode current is 15 A at frequencies of 25 c/s and above, and 5 A below 25 c/s. The peak inverse anode voltage and the peak forward anode voltage may become as high as 1000 V. The anode is brought out at the top of the bulb, thus ensuring safe operation at high anode voltages. Despite the absence of a screen grid the anode-to-grid capacitance has been kept low (3.6 pF), so that there is little risk of influence from anode voltage surges on the grid circuit.

In ignitron firing service a peak anode current of 40 A is allowed with a corresponding average current of 1 A.

The tube requires relatively little grid power and is suitable for use in relay circuits, for the control of d.c. motor speed, variable and stabilized d.c. output rectifiers and in automatically operated battery chargers. In anti-parallel circuits the tube can also be used for controlling and switching a.c. power and firing ignitrons.

For the PL 5559 tube socket type 40218/03 is recommended, this being made of highly insulating material. The tube fits the medium 4-pin socket with bayonet.

TECHNICAL DATA

HEATER DATA

Heating	indirect	
Heater voltage	$V_f = 5.0 \text{ V} \pm 5\%$	
Heater current	$I_f = 4.5 \text{ A}$	
Waiting time	$T_w = \text{min. } 5 \text{ min.}^1)$	
Mounting position	vertical, base down	
Base	medium 4-pin with bayonet	
Socket	type 40218/03	
Cap	type 40619	
Net weight	125 g	
Shipping weight (50 tubes)	8500 g	

TYPICAL CHARACTERISTICS

Arc voltage	$V_{\text{arc}} = 12 \text{ V}$
Ionization time	$T_{\text{ion}} = 10 \mu\text{sec}$
Deionization time	$T_{\text{dion}} = 1000 \mu\text{sec}$
Operating frequency	$f = \text{max. } 150 \text{ c/s}$

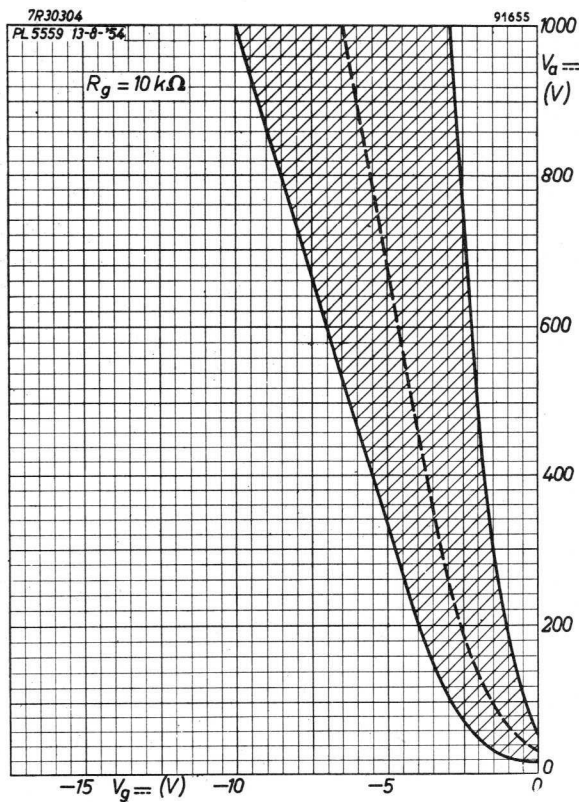


Fig. 7.22. Control characteristic of the PL5559.

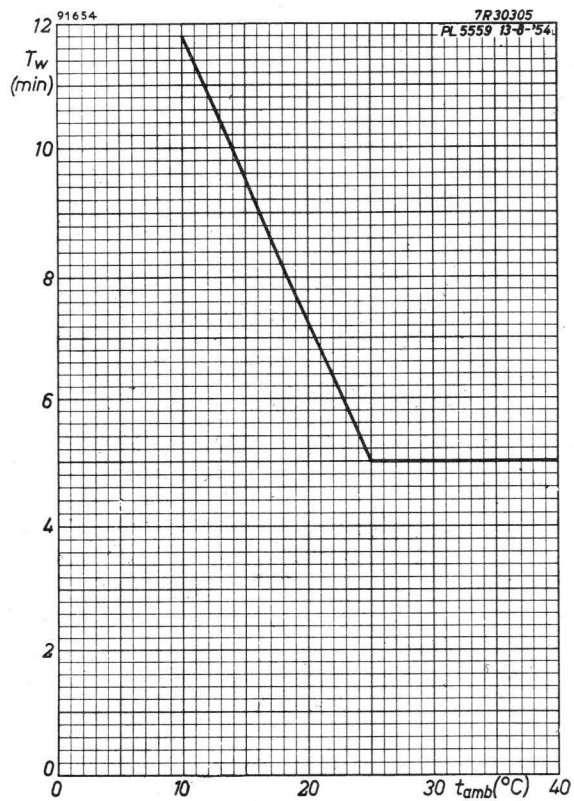
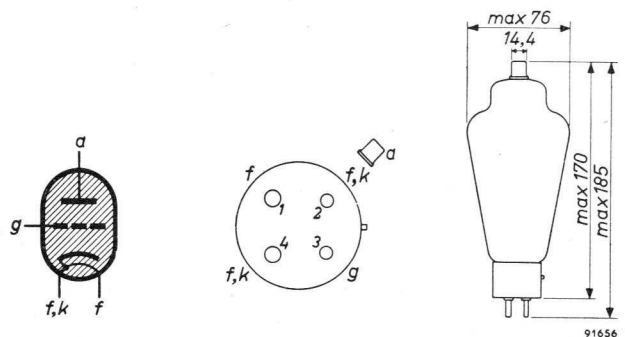


Fig. 7.23. Cathode preheating curve. The curve indicates the necessary preheating time as a function of the ambient temperature.

CAPACITANCES

Anode to grid	$C_{ag} = 3.6 \text{ pF}$
Grid to cathode	$C_{gk} = 7.8 \text{ pF}$

BASE CONNECTIONS²⁾ AND DIMENSIONS (in mm)



¹⁾ See Fig. 7.23.

²⁾ Pins 1 and 4 heater, pin 2 cathode return.

LIMITING VALUES (absolute values)

Peak forward anode voltage	V_{ap}	= max.	1000 V
Peak inverse anode voltage	V_{ainvp}	= max.	1000 V
Grid voltage before conduction	$-V_g$	= max.	500 V
Grid voltage during conduction	$-V_g$	= max.	10 V
Peak cathode current below 25 c/s	I_{kp}	= max.	5 A
Peak cathode current at 25 c/s and above	I_{kp}	= max.	15 A
Cathode current ($T_{av} = \text{max. 15 sec.}$)	I_k	= max.	2.5 A
Grid current ($T_{av} = \text{max. 15 sec.}$)	I_g	= max.	0.25 A
External resistance between grid and cathode	R_g	= max.	100 k Ω
Recommended value	R_g	=	10 k Ω
Temperature range of condensed mercury	t_{Hg}	=	40–80 °C
Recommended temperature	t_{Hg}	=	60 °C
Frequency	f	= max.	150 c/s
Peak cathode current for ignitron firing service	I_{kp}	= max.	40 A
Cathode current for ignitron firing service	I_k	= max.	1 A
Cathode fault current for 0.1 sec maximum	I_{surge}	= max.	200 A

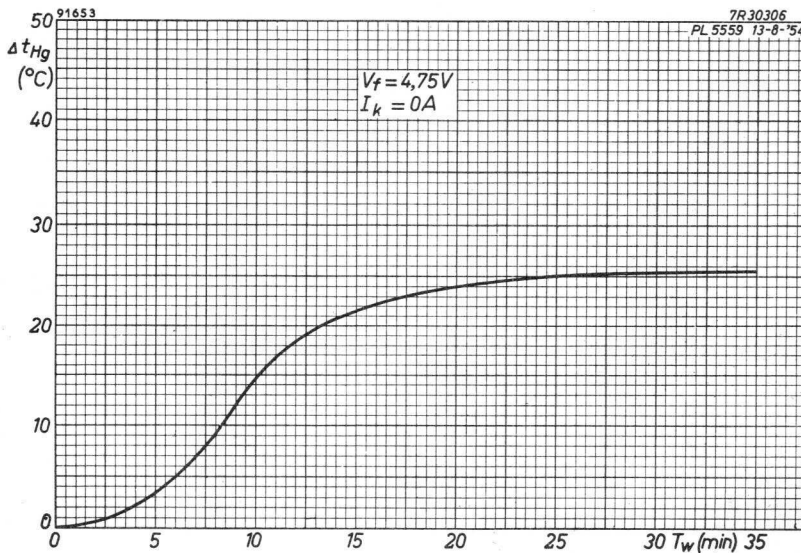


Fig. 7.24. Temperature rise characteristic indicating the rise of the condensed mercury-vapour temperature (above ambient temperature) in °C, with only the filament switched on. (Filament voltage is 4.75 V.)

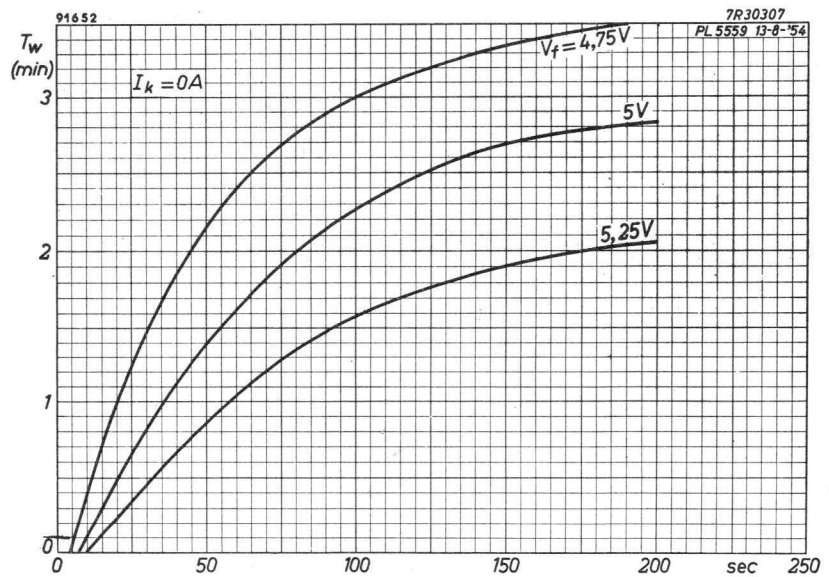


Fig. 7.25. Minimum required cathode preheating time before the anode voltage may be switched on indicated as a function of the time interval of heater current interruption.

PL 105

mercury-vapour tetrode

The PL 105 is a mercury-vapour filled tetrode with an indirectly heated cathode and a comparatively

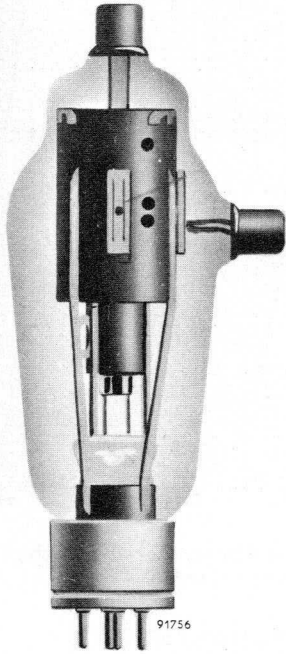


Fig. 7.26. The mercury-vapour filled tetrode PL 105.

low heater consumption. It is designed for an average anode current of 6.4 A whilst the maximum peak anode current is 40 A at frequencies of 25 c/s and above, and 12.8 A below 25 c/s. The permissible forward and inverse peak anode voltage are as high as 2500 V. The anode and control grid are brought out at the bulb thus ensuring safe operation at high voltages. Although the screen grid can be used to shift the characteristics of the tube, this electrode will normally be connected via a resistor to the cathode.

The PL 105 can be used for battery chargers, as electronic switch, for rectifiers with variable or stabilized d.c. output voltage and for d.c. motor speed control. It is also used for the control of ignitron circuits, whilst control of light intensity of discharge lamps is possible by employing two tubes in an inverse parallel circuit. A.c. power control can be effected by two tubes used as the load of a transformer connected in series with the supply circuit.

The PL 105 fits the super jumbo socket with bayonet. Tube socket type 40403/00 is recommended, this being made of highly insulating material.

TECHNICAL DATA

HEATER DATA

Heating		indirect
Heater voltage	$V_f = 5.0 \text{ V} \pm 5\%$	
Heater current	$I_f = 10 \text{ A}$	
Waiting time	$T_w = \text{min. } 5 \text{ min}^1)$	

Mounting position	vertical, base down
Base	Super Jumbo with bayonet
Socket	type 40403/00
Cap	type 40620
Net weight	510 g
Shipping weight	1400 g

CAPACITANCES

Anode to control grid	$C_{ag1} = 1.8 \text{ pF}$
Control grid to cathode	$C_{g1k} = 5.0 \text{ pF}$

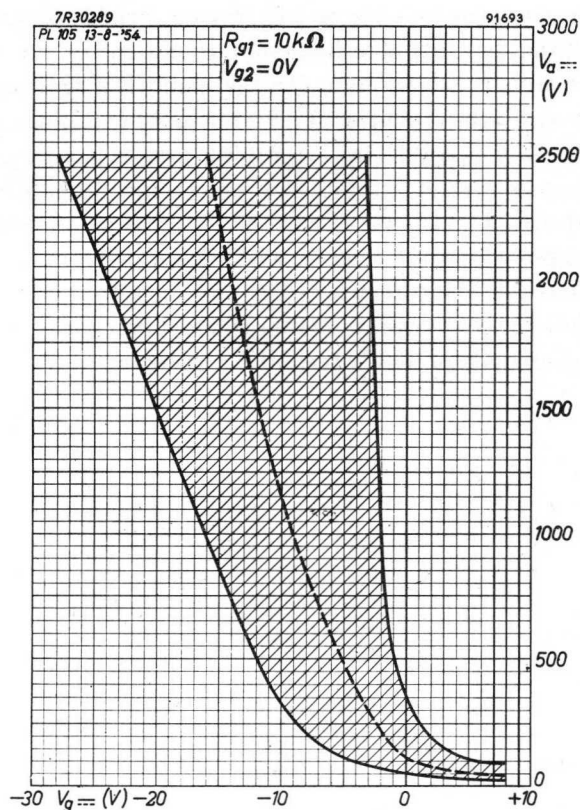


Fig. 7.27. Control characteristic of the PL 105 with screen grid connected to cathode via a resistor.

¹⁾ During long periods of interrupted service (e.g. during night) it is recommended to reduce the heater voltage to 60-80% of its nominal value instead of switching off the filament. In this way the waiting time can be reduced according to the dotted curve of fig. 7.29.

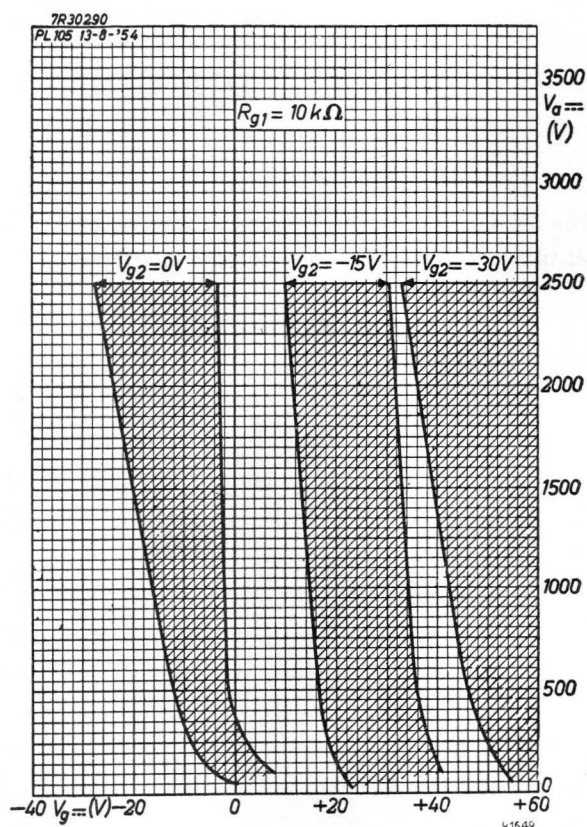
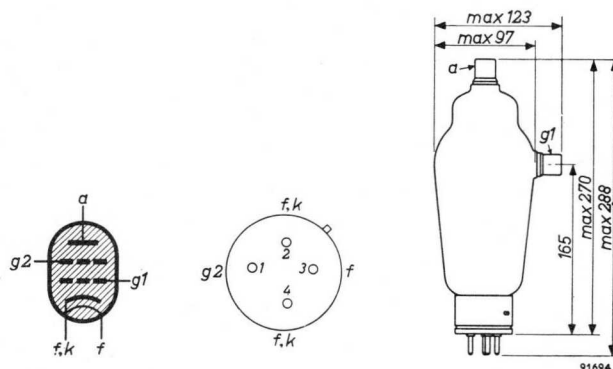


Fig. 7.28. Control characteristic of the PL 105 for indicated screen-grid voltages.

TYPICAL CHARACTERISTICS

Arc voltage	$V_{\text{arc}} = 12 \text{ V}$
Ionization time	$T_{\text{ion}} = 10 \text{ } \mu\text{sec}$
Deionization time	$T_{\text{dion}} = 1000 \text{ } \mu\text{sec}$
Operating frequency	$f = \text{max. } 150 \text{ c/s}$

BASE CONNECTIONS²⁾ AND DIMENSIONS (in mm)



²⁾ Pins 2 and 3 heater, pin 4 cathode return.

LIMITING VALUES (absolute values)

			continuous service	intermittent service
Peak forward anode voltage	V_{ap}	= max.	2500	750 V
Peak inverse anode voltage	V_{ainvp}	= max.	2500	750 V
Screen-grid voltage before conduction	$-V_{g2}$	= max.	500	500 V
Screen-grid voltage during conduction	$-V_{g2}$	= max.	10	10 V
Control-grid voltage before conduction	$-V_{g1}$	= max.	1000	1000 V
Control-grid voltage during conduction	$-V_{g1}$	= max.	10	10 V
Peak anode current below 25 c/s.	I_{ap}	= max.	12.8	5.0 A
Peak anode current at 25 c/s and higher	I_{ap}	= max.	40	77 A
Anode current ($T_{av} = \text{max. } 15 \text{ sec}$)	I_a	= max.	6.4	A
Anode current ($T_{av} = \text{max. } 5 \text{ sec}$)	I_a	= max.		2.5 A
Fault current (maximum duration = 0.1 sec)	I_{surge}	= max.	400	400 A
Peak screen-grid current	I_{g2p}	= max.	2.0	2.0 A
Screen-grid current ($T_{av} = \text{max. } 15 \text{ sec}$)	I_{g2}	= max.	0.5	A
Screen-grid current ($T_{av} = \text{max. } 5 \text{ sec}$)	I_{g2}	= max.		0.5 A
Peak control-grid current	I_{g1p}	= max.	1.0	1.0 A
Control-grid current ($T_{av} = \text{max. } 15 \text{ sec}$)	I_{g1}	= max.	0.25	A
Control-grid current ($T_{av} = \text{max. } 5 \text{ sec}$)	I_{g1}	= max.		0.25 A
External resistance between screen grid and cathode	R_{g2}	= max.	10	10 k Ω
Recommended value	R_{g2}	=	10	10 k Ω
External resistance between control grid and cathode	R_{g1}	= max.	100	100 k Ω
Recommended value	R_{g1}	=	10	10 k Ω
Temperature range of condensed mercury	t_{Hg}	=	40 - 80	40 - 80 $^{\circ}\text{C}$
Recommended temperature	t_{Hg}	=	60	60 $^{\circ}\text{C}$

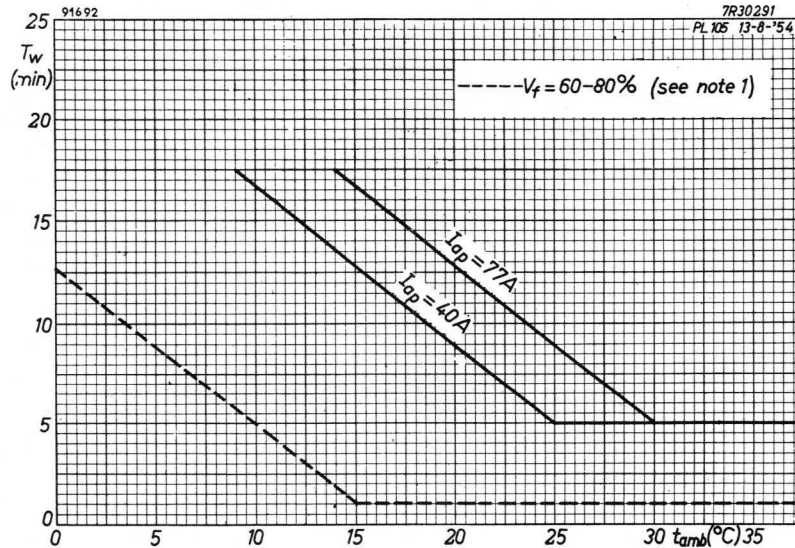


Fig. 7.29. Cathode preheating curve. The curve indicates the necessary preheating time as a function of the ambient temperature. The dashed line holds for the case the heater voltage is reduced to 60-80% during long periods of interruption of operation.

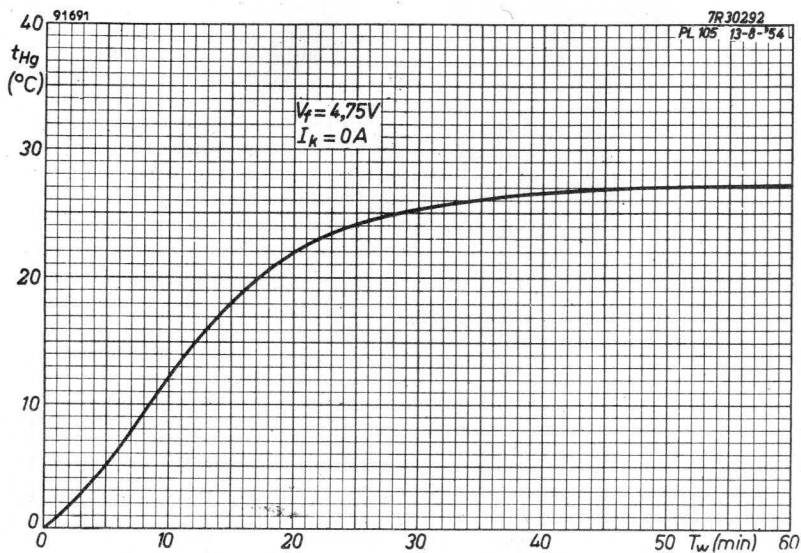


Fig. 7.30. Temperature rise of the condensed mercury (above ambient temperature) in °C, with only the filament switched on as a function of the minimum required waiting time.

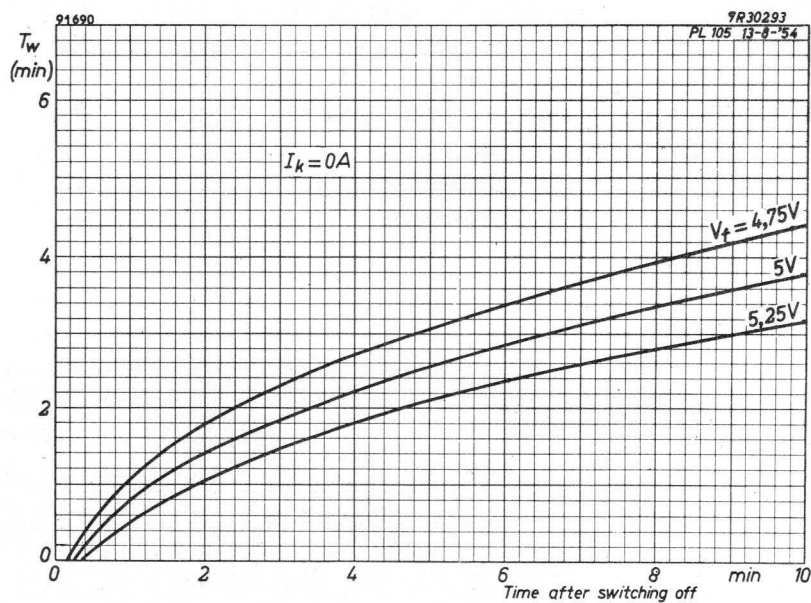


Fig. 7.31. Minimum required cathode preheating time before the anode voltage may be switched on as a function of the time interval of heater current interruption.

PL 255 mercury-vapour triode

The thyatron type PL 255, is specially designed for electronic motor control. It is a 12.5 ampere grid-controlled mercury-vapour filled rectifier made

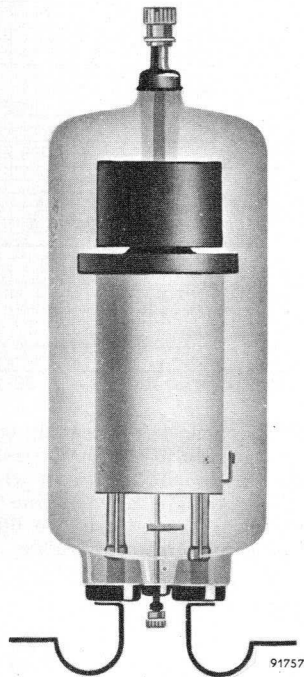


Fig. 7.32. The mercury-vapour filled triode PL 255.

for a maximum peak anode voltage of 1500 volts, the maximum peak inverse voltage being 2500 volts. When used in a normal three-phase circuit, three PL 255 tubes can deliver 16.5 kilowatts at 440 volts, which power will suffice for most machine tools.

When higher power is required, for production machines, for instance, the voltage can be increased or circuits with six tubes can be used.

The filament and cathode connections are heavy metal strips; the anode and grid terminals provide for firm connections of cable lugs.

The normal anode current rating is 12.5 A, average value. When in this case the r.m.s. value does not exceed 30 A, the peak current will not exceed 80 A, and the tube is operated within its ratings. When a motor is started, there is only little back e.m.f. Without current limiting devices the average and peak anode currents may reach intolerable values.

The PL 255 thyatron, however, has been specially designed to facilitate the construction of high-quality electronic motor control equipment. Therefore it is made to deliver an average current of 20 amperes with a peak current of 160 amperes during 5 seconds, once every 5 minutes. Owing to these improvements the motor can reach its rated speed more rapidly, resulting in higher production speed. When the motor reaches its maximum rated speed, the back-e.m.f. of the armature causes a decrease in average tube anode current with an associated increase in peak current. Therefore, another rating of the anode current is 10 amperes average value with a corresponding peak current of 100 A.

Apart from production machine control the PL 255 is a very attractive tube for use in many other applications, among others automatic elevator control, and resistance welding.

TECHNICAL DATA

HEATER DATA

Heating indirect
 Heater voltage $V_f = 5.0 \text{ V}$
 Heater current $I_f = 14 \text{ A}$
 Waiting time $T_w = \text{min } 5 \text{ min.}^1)$

Mounting position vertical, base down
 Net weight 820 g
 Shipping weight 1500 g

TYPICAL CHARACTERISTICS

Arc voltage $V_{\text{arc}} = 10 \text{ V}$
 Ionization time $T_{\text{ion}} = 10 \mu\text{sec}$
 Deionization time $T_{\text{dion}} = 1000 \mu\text{sec}$
 Operating frequency $f = \text{max. } 150 \text{ c/s}$

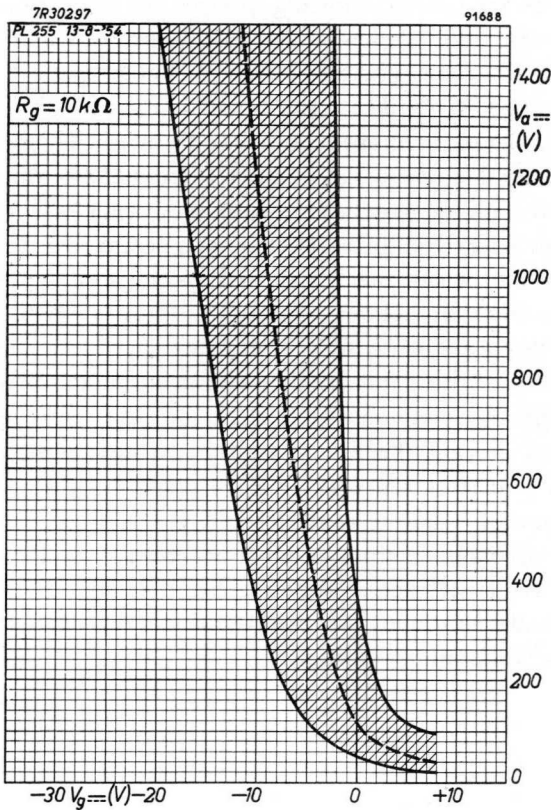


Fig. 7.33. Control characteristic of the PL 255.

¹⁾ During long periods of interrupted service (e.g. during night) it is recommended to reduce the heater voltage to 60-80% of its nominal value instead of switching off the filament. In this way the waiting time can be reduced according to the dotted curve of fig. 7.34.

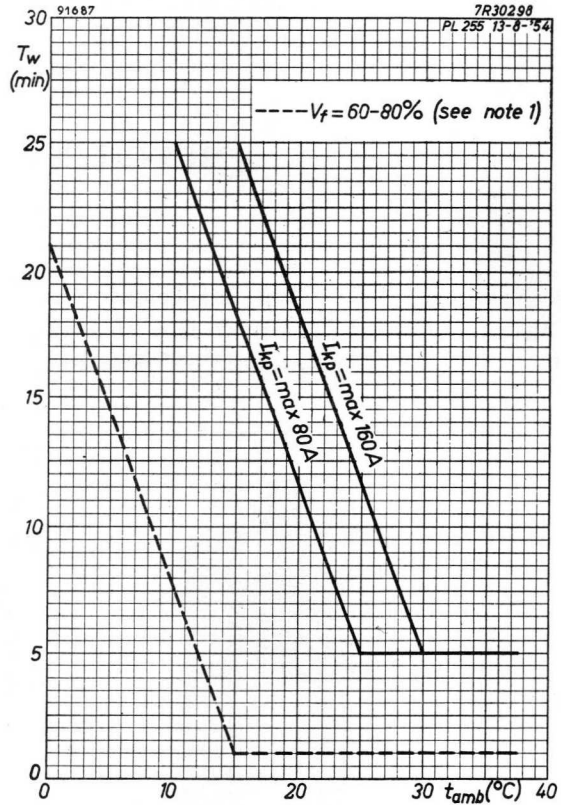
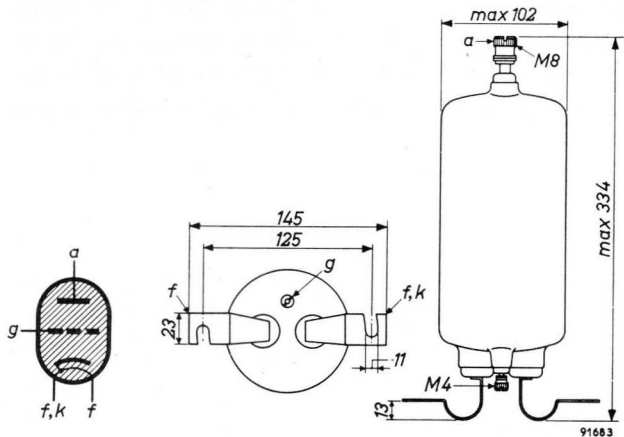


Fig. 7.34. Minimum cathode preheating time as a function of the ambient temperature for the indicated cathode peak currents which will be drawn when the anode voltage is switched on. The dashed line holds for the case the heater voltage is reduced to 60-80% during long periods of interruption of operation.

CAPACITANCES

Anode to grid $C_{ag} = 8 \text{ pF}$
 Grid to all other electrodes $C_g = 30 \text{ pF}$

BASE CONNECTIONS AND DIMENSIONS (in mm)



Electrode arrangement, electrode connections and maximum dimensions in mm.

LIMITING VALUES (absolute values)

CONTINUOUS SERVICE (motor control)

Peak forward anode voltage	V_{ap}	= max.	1500	V	
Peak inverse anode voltage	V_{ainvp}	= max.	2500	V	
Grid voltage before conduction	$-V_g$	= max.	300	V	
Grid voltage during conduction	$-V_g$	= max.	10	V	
Fault current (max. duration = 0.1 sec)	I_{surge}	= max.	1500	A	
Grid current (V_a positive)	I_g	= max.	0.25	A	
Peak grid current	I_{gp}	= min.	0.5	mA	
Peak grid current	I_{gp}	= max.	1	A	
External resistance between grid and cathode	R_g	= max.	50	k Ω	
Recommended value	R_g	=	10	k Ω	
Peak cathode current	I_{kp}	= max.	80	100	160 ¹⁾ A
Cathode current	I_k	= max.	12.5	10	20 ¹⁾ A
Effective value of cathode current	I_{krms}	= max.	30	30	50 ¹⁾ A _{rms}
Averaging time	T_{av}	= max.	15	15	²⁾ sec
Temperature of condensed mercury	H_g	=	35—75	35—75	40—75 °C
Recommended value	t_{Hg}	=	60	60	60 °C

AC AND WELDER OPERATION (two tubes in inverse parallel)

Peak forward anode voltage	V_{ap}	= max.	750	V	
Peak inverse anode voltage	V_{ainvp}	= max.	750	V	
Grid voltage before conduction	$-V_g$	= max.	300	V	
Grid voltage during conduction	$-V_g$	= max.	10	V	
Duty cycle	δ	=	10	50	100 %
Peak cathode current	I_{kp}	= max.	156	78	39 A
Average cathode current	I_k	= max.	5	12.5	12.5 A
Total a.c. current	I_{orms}	= max.	110	55	27.5 A _{rms}
Averaging time	T_{av}	= max.	5	5	15 sec
Fault current (max. duration = 0.1 sec)	I_{surge}	= max.	1500	A	
Grid current (V_a positive)	I_g	= max.	0.25	A	
External resistance between grid and cathode	R_g	= max.	50	k Ω	
Recommended value	R_g	=	10	k Ω	
Temperature range of condensed mercury	t_{Hg}	=	40—80	°C	
Recommended temperature	t_{Hg}	=	60	°C	

1) Overload during max. 5 sec in each 5 minutes operating period.

2) Max. 1 cycle.

PL 260

mercury-vapour triode

The thyatron PL 260 is especially designed for electronic motor control. It is a 25 A grid-controlled mercury-vapour filled rectifier made for a maximum peak anode voltage of 1500 volts; the maximum peak inverse voltage being 2500 volts.

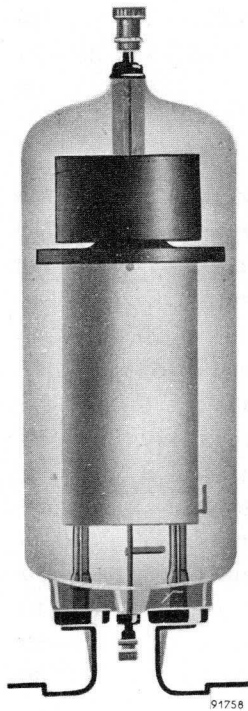


Fig. 7.35. The mercury-vapour filled triode PL 260.

The filament and cathode connections are heavy metal strips; the anode and grid terminals provide for firm connections of cable lugs.

The normal anode current rating is 25 A, average value. When in this case the r.m.s. value does not exceed 60 A, the peak current will not exceed 160 A and the tube is operated within its ratings.

When a motor is started, there is only little back-e.m.f. Without current limiting devices the average and peak anode currents may reach intolerable values. The PL 260, however, has been especially designed to facilitate the construction of high-quality electronic motor control equipment. Therefore it is made to deliver an average current of 40 A with a peak current of 300 A during 5 sec, once every 5 minutes of operation. Owing to these improvements the motor can reach its rated speed more rapidly, resulting in a higher production speed. When the motor reaches its maximum rated speed, the back-e.m.f. of the armature causes a decrease in average tube anode current with an associated increase in peak current. Therefore, another rating of the anode current is 20 A average value with a corresponding peak current of 200 A.

Apart from production machine control the PL 260 is a very attractive tube for use in many other applications, amongst others automatic elevator control and resistance welding.

TECHNICAL DATA

HEATER DATA

Heating		indirect
Heater voltage	$V_f =$	5.0 V
Heater current	$I_f =$	25 A
	$I_f =$	max. 27.5 A
Waiting time	$T_w =$	min. 10 min. ¹⁾

Mounting position	vertical, base down
Net weight	1600 g
Shipping weight	5600 g

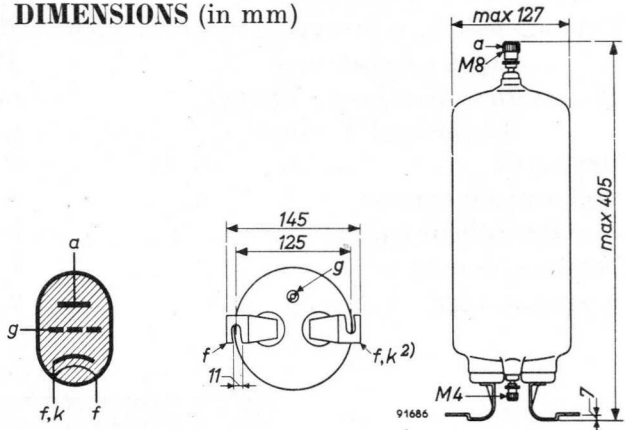
TYPICAL CHARACTERISTICS

Arc voltage	$V_{arc} =$	10 V
Ionization time	$T_{ion} =$	10 μ sec
Deionization time	$T_{dion} =$	1000 μ sec
Operating frequency	$f =$	max. 150 c/s

CAPACITANCES

Anode to grid	$C_{ag} =$	15 pF
Grid to all other electrodes	$C_g =$	60 pF

BASE CONNECTIONS AND DIMENSIONS (in mm)



LIMITING VALUES (absolute limits)

CONTINUOUS SERVICE (motor control)

Peak forward anode voltage	$V_a =$ max.	1500	V
Peak inverse anode voltage	$V_{ainvp} =$ max.	2500	V
Grid voltage before conduction	$-V_g =$ max.	300	V
Grid voltage during conduction	$-V_g =$ max.	10	V
Fault current (max. duration = 0.1 sec)	$I_{surge} =$ max.	2500	A ³⁾
Grid current (V_a positive)	$I_g =$ max.	0.25	A ⁴⁾
Peak grid current	$I_{gp} =$ max.	1	A
Peak grid current	$I_{gp} =$ min.	3	mA
External resistance between grid and cathode	$R_g =$ max.	20	k Ω
Recommended value	$R_g =$	10	k Ω
Peak cathode current	$I_{kp} =$ max.	160	200
Cathode current	$I_k =$ max.	25	20
Effective value of cathode current	$I_{krms} =$ max.	60	60
Averaging time	$T_{av} =$ max.	15	15
Temperature of condensed mercury	$t_{Hg} =$	35—75	35—75
Recommended value	$t_{Hg} =$	60	60

Remark: Under normal operating conditions ($V_f = 5$ V; $I_k = 25$ A): $t_{Hg} - t_{amb} = 35 - 40$ °C.
 When $t_{amb} > 35$ °C a low-velocity air flow may be necessary.

¹⁾ See fig. 7.37. During long periods of interrupted service (e.g. during night hours) it is recommended to reduce the heater voltage to 60-80% of its nominal value instead of swichting off the heater. In this way the value of T_w can be decreased according to the dotted curve.
 When the heater voltage has been switched off during less than 5 minutes, T_w should be at least twice the "off"-time. After a longer switching-off time the normal waiting time of 10 minutes can be applied.
²⁾ Marked red.
³⁾ Anode fuse max. 80 A (recommended 60 A).
⁴⁾ In order to facilitate the ignition of the tube a positive grid current of at least 3 mA is necessary. The use of a fixed negative grid bias (30-50 V for d.c. output voltages of 200-600 V) and a sharp grid pulse (100-130 V) is recommended ($R_g = 10$ k Ω , impedance of pulse transformer max. 10 k Ω).
 If a sinusoidal grid voltage is used for control, this voltage should be at least 60 V_{rms}. The impedance of the source for the negative bias should be low compared to the total grid series impedance.
⁵⁾ Overload, during max. 5 sec in each 5 minutes operating period.
⁶⁾ Max. 1 cycle.

AC AND WELDER OPERATION (two tubes in antiparallel)

Peak forward anode voltage	V_a	= max.	750	V
Peak inverse anode voltage	V_{ainvp}	= max.	750	V
Grid voltage before conduction	$-V_g$	= max.	300	V
Grid voltage during conduction	$-V_g$	= max.	10	V
Fault current (max. duration = 0.1 sec)	I_{surge}	= max.	2500	A
Grid current (V_a positive)	I_g	= max.	0.25	A ¹⁾
External resistance between grid and cathode	R_g	= max.	20	k Ω
Recommended value	R_g	=	10	k Ω
Temperature of condensed mercury	t_{Hg}	=	40—80	°C
Recommended value	t_{Hg}	=	60	°C
Duty cycle	δ	=	10 50	100 %
Peak cathode current	I_{kp}	= max.	285 156	78 A
Average cathode current	I_k	= max.	9 25	25 A
Total a.c. current	I_{orms}	= max.	200 110	55 A
Averaging time	T_{av}	= max.	5 5	15 sec

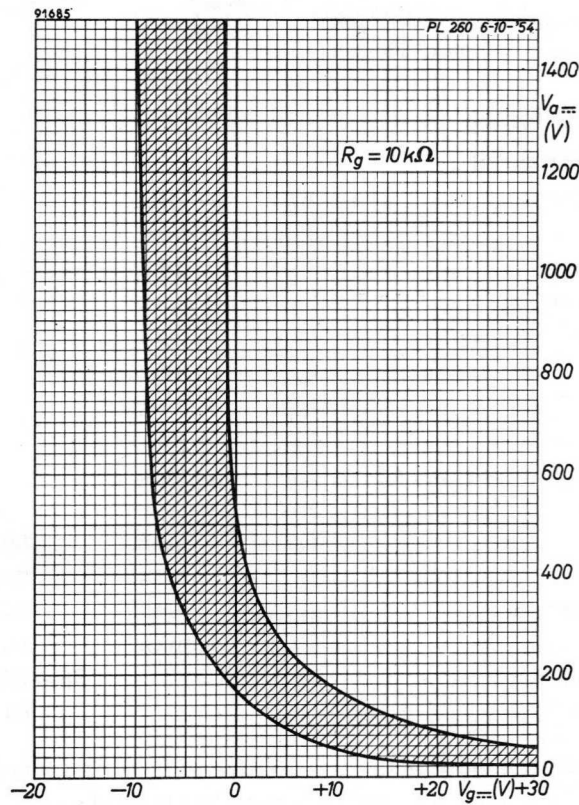


Fig. 7.36. Control characteristic of the PL 260 for $R_g = 10 \text{ k}\Omega$.

¹⁾ See note 4 on page 61.

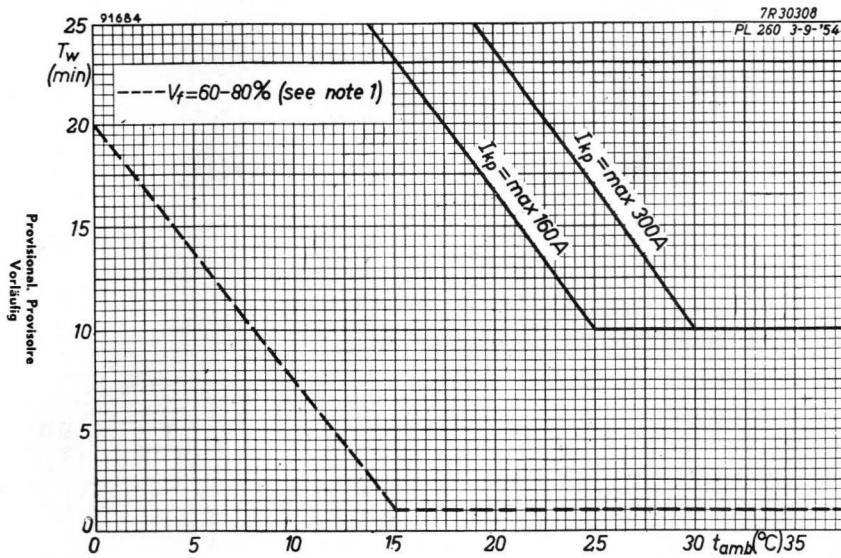


Fig. 7.37. Minimum cathode pre-heating time as a function of the ambient temperature for the indicated cathode peak currents which will be drawn when the anode voltage is switched on. The dashed line holds for the case the heater voltage is reduced to 60-80% during long periods of interruption of operation.

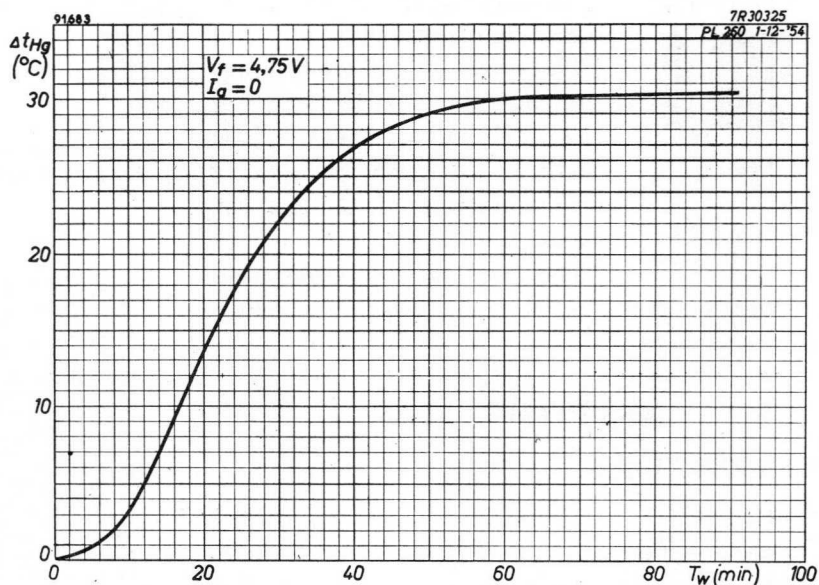


Fig. 7.38. Temperature rise of the condensed mercury (above ambient temperature) in °C, with only the filament switched on as function of the minimum required waiting time.

1) See page 61.

PL 3C23

mercury-vapour and gas-filled triode

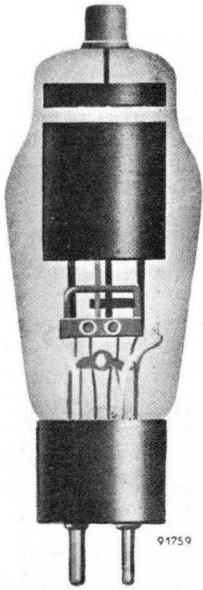


Fig. 7.39.
The PL 3C23.

The PL 3C23 is a mercury-vapour and rare-gas filled triode with an oxide-coated directly heated cathode. It is designed for an average anode current of 1.6 A, the permissible peak anode current being 6.4 A. The mixture of rare gas and mercury vapour makes for constancy of characteristics and for use of the tube under widely divergent temperatures.

The anode-to-grid capacitance of this tube is particularly low (3.8 pF) so that there is little risk of influence from anode voltage surges on the grid circuit.

The main field of application of this thyatron is in electronic relays and motor control circuits.

TENTATIVE DATA

FILAMENT DATA

Heating		direct
Filament voltage	$V_f =$	2.5 V
Filament current	$I_f =$	7 A
Waiting time	$T_w =$	30 sec ¹⁾
Mounting position		vertical, base down
Base		Medium 4-pins with bayonet
Socket		40218/03
Anode cap		40619

CAPACITANCE

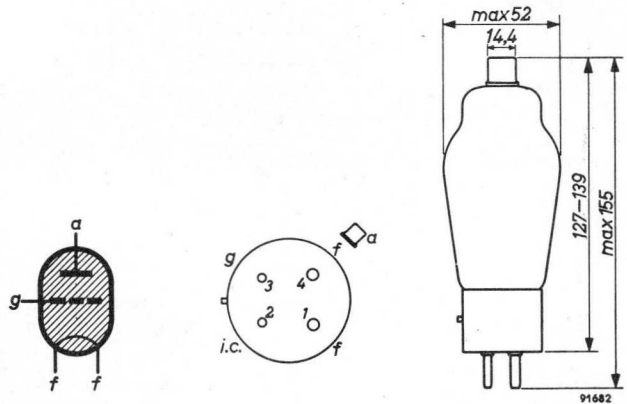
Anode to grid	$C_{ag} =$	3.8 pF
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TYPICAL CHARACTERISTICS

Arc voltage	$V_{arc} =$	12 V
Ionization time	$T_{ion} =$	10 μ sec
Deionization time	$T_{dion} =$	1000 μ sec

¹⁾ If urgently wanted T_w may be decreased to min. 15 sec.

BASE CONNECTIONS AND DIMENSIONS (in mm)



Electrode arrangement, electrode connections and maximum dimensions in mm.

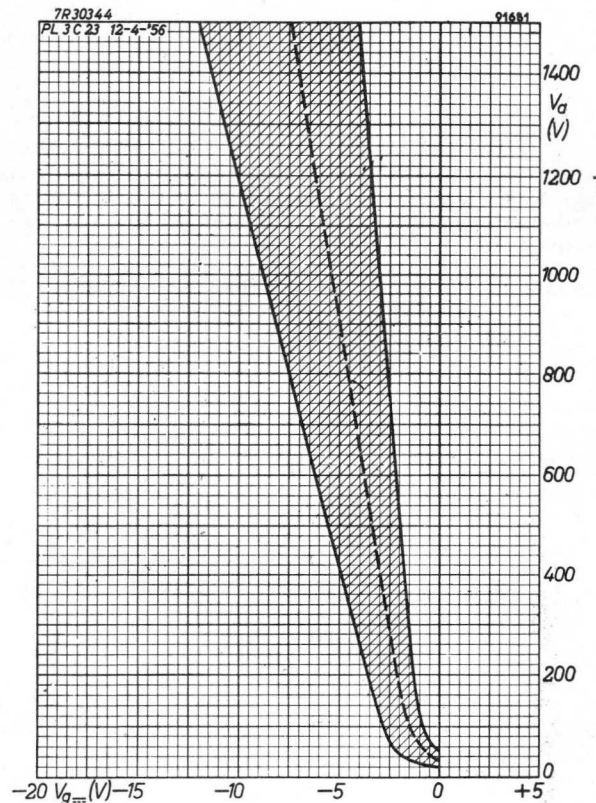


Fig. 7.40. Control characteristic of the PL 3C23.



The cathode assembly is spot-welded to the tube base



The tube base is sealed to the envelope

LIMITING VALUES (absolute limits)

Peak forward anode voltage	V_{ap}	= max.	1500 V
Peak inverse anode voltage	V_{ainvp}	= max.	1500 V
Grid voltage before conduction	$-V_g$	= max.	500 V
Grid voltage during conduction	$-V_g$	= max.	10 V
Peak cathode current	I_{kp}	= max.	6.4 A
Cathode current ($T_{av} = 5$ sec)	I_k	= max.	1.6 A
Fault current (max. duration = 0.1 sec)	I_{surge}	= max.	120 A
Grid current (V_a positive; $T_{av} = 5$ sec)	I_g	= max.	10 mA
Peak grid current	I_{gp}	= max.	50 mA
External resistance between grid and cathode	R_g	=	5 - 100 k Ω
Recommended value	R_g	=	50 k Ω
Ambient temperature	t_{amb}	=	-40 to +50 °C
Temperature of condensed mercury	t_{Hg}	=	-40 to +80 °C
Recommended value	t_{Hg}	=	40 °C

PL 6755

mercury-vapour and gas-filled triode

The PL 6755 is a mercury-vapour and rare-gas filled triode with a negative control characteristic and

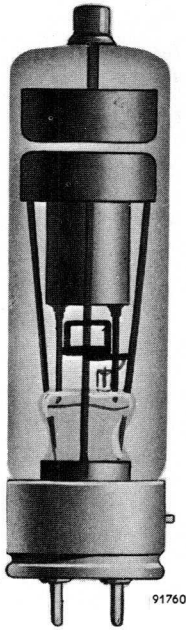


Fig. 7.41. The rare gas and mercury-vapour filled triode PL 6755.

directly heated cathode. At continuous service the average cathode current is 3.6 A and the peak forward anode voltage 1000 V.

The tube can be used in many applications, amongst others for:

- (a) Dimming installations for stage-lighting, fluorescent lamps, etc.
- (b) Motor control and rectifiers with variable and stabilized output.
- (c) Ignitron firing.
- (d) A.c. control (small resistance welders, furnace control, etc).

Below extensive data are given of this thyatron for use in each of the four applications.

The PL 6755 fits the super jumbo with bayonet. The tube socket 40403/00 is recommended, this being made of highly insulating material.

TENTATIVE DATA

FILAMENT DATA

Heating		direct
Filament voltage	$V_f =$	2.5 V
Filament current	$I_f =$	11 A
Waiting time	$T_w =$	min. 60 sec

Mounting position	vertical, base down	
Net weight	345 g	
Shipping weight	1350 g	

Base	Super Jumbo with bayonet	
Socket	40403/00	
Anode cap	40619	

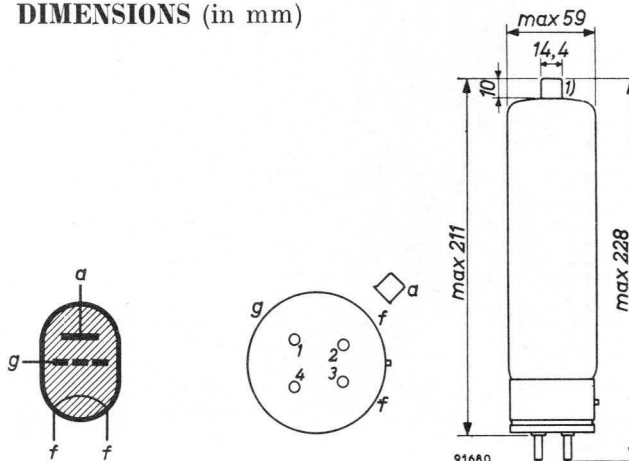
TYPICAL CHARACTERISTICS

Arc voltage	$V_{arc} =$	12 V
Ionization time	$T_{ion} =$	10 μ sec
Deionization time	$T_{dion} =$	500 μ sec

CAPACITANCES

Anode to grid	$C_{ag} =$	7 pF
Grid to cathode	$C_{gk} =$	10 pF

BASE CONNECTIONS AND DIMENSIONS (in mm)



LIMITING VALUES (absolute limits)

		Application A	Application B	Application C	Application D			
Peak forward anode voltage . . .	$V_{ap} = \text{max.}$	1000	1500	1500	1000			V
Peak inverse anode voltage . . .	$V_{ainvp} = \text{max.}$	1000	1500	1500	1000			V
Grid voltage before conduction . .	$-V_g = \text{max.}$	500	300	300	300			V
Grid voltage during conduction . .	$-V_g = \text{max.}$	10	10	10	10			V
Duty cycle	$\delta = \text{max.}$				10	50	100	%
Cathode current ($T_{av} = \text{max.}$ 15 sec)	$I_k = \text{max.}$	3.6	3.2	0.5	1.25	3.2	3.6	A
Peak cathode current	$I_{kp} = \text{max.}$	15	20	40				A
Cathode current (r.m.s. value of two tubes in inverse-parallel) . .	$I_k = \text{max.}$				28	14	8	$A_{rms}^2)$
Grid current	$I_g = \text{max.}$	0.25	0.25	0.25	0.25			A
Fault current ($T_{av} = \text{max.}$ 0.1 sec)	$I_{surge} = \text{max.}$	200	200	200	200			A ³⁾
External resistance between grid and cathode	$R_g = \text{max.}$	0.3 ⁴⁾	0.1	0.1	0.1			M Ω
Recommended value . . .	$R_g =$	0.1	0.03	0.03	0.03			M Ω
Temperature of condensed mercury	$t_{Hg} =$	20-85	25-80	25-80	25-85			$^{\circ}$ C
Ambient temperature	$t_{amb} =$	0-45	0-40	0-40	0-45			$^{\circ}$ C
Operating frequency	$f = \text{max.}$	150	150	150	150			c/s

¹⁾ Cross section of flexible anode lead $\geq 4 \text{ mm}^2$.

²⁾ Total r.m.s. current for two tubes in inverse parallel.

³⁾ Fuse in anode circuit max. 10 A.

⁴⁾ High values of R_g are only recommended for grid-controlled circuits which are insensitive to grid current.

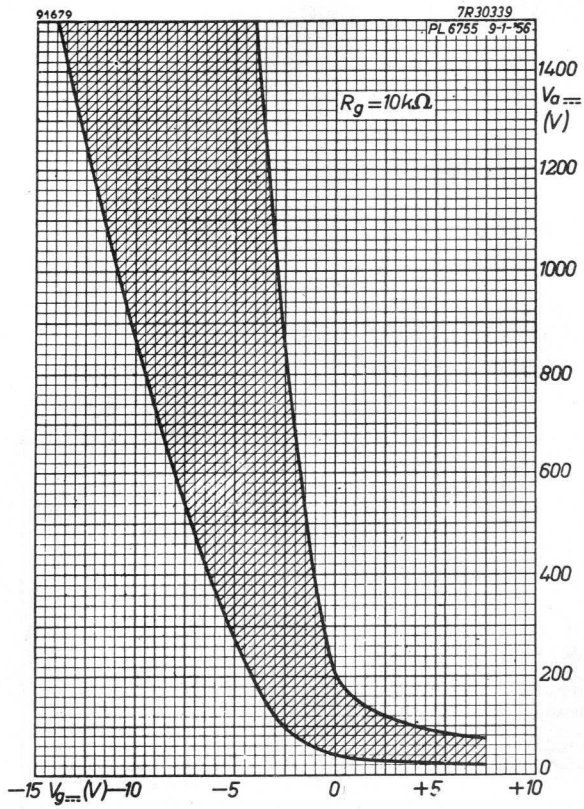


Fig. 7.42. Control characteristic of the PL 6755 for $R_g = 10\text{ k}\Omega$.

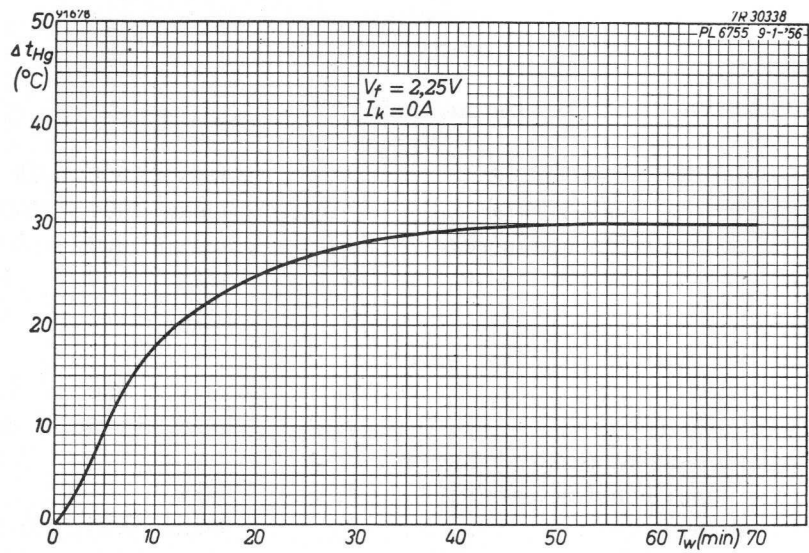


Fig. 7.43. Temperature rise of the condensed mercury (above ambient temperature) in $^{\circ}\text{C}$, with only the filament switched on as function of the minimum required waiting time.

PL 106

mercury-vapour and gas-filled triode

The PL 106 is a mercury-vapour and inert-gas filled thyatron with a negative control character-

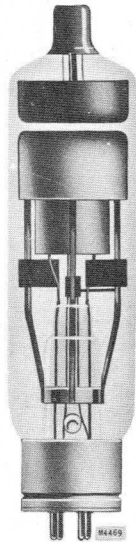


Fig. 7.44. The mercury-vapour and gas-filled triode PL 106.

istic and a directly heated cathode. At continuous service the permissible average anode current is 6.4 A, the permissible peak anode current being 80 A.

The filament has been centre-tapped, so that the filament base pins carry reduced currents because the anode current is returned via its own base pins. The mixture of inert gas and mercury vapour ensures constancy of characteristics and enables the tube to be used under widely divergent temperatures. The maximum peak anode forward and inverse voltages of the PL 106 are 2000 V.

The various features make this tube an attractive proposition for dimming installations, motor control service and other industrial applications.

The PL 106 fits the super jumbo base with bayonet; the tube socket type 40403 is recommended.

TECHNICAL DATA

FILAMENT DATA

Heating		direct
Filament voltage	$V_f =$	2.5 V
Filament current	$I_f =$	22 A
Waiting time	$T_w =$	min. 30 sec ¹⁾

Mounting position	base down
Net weight	480 g
Shipping weight	2135 g

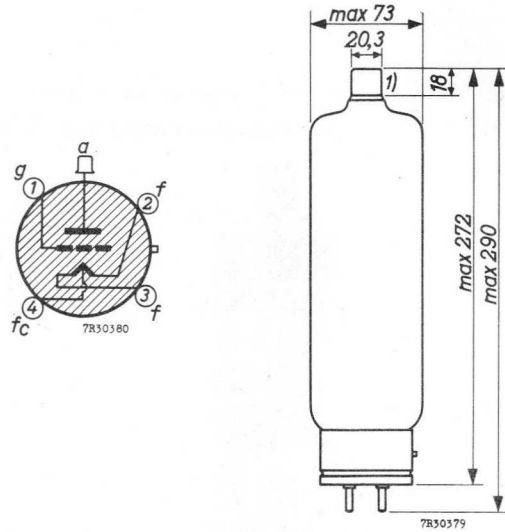
TYPICAL CHARACTERISTICS

Arc voltage	$V_{arc} =$	12 V
Ionization time	$T_{ion} =$	10 μ sec
Deionization time	$T_{dion} =$	500 μ sec

CAPACITANCES

Anode to grid	$C_{ag} =$	9 pF
Grid to cathode	$C_{gk} =$	19 pF

BASE CONNECTIONS AND DIMENSIONS (in mm)



¹⁾ Cross section of flexible anode lead at least 10 mm².

LIMITING VALUES (absolute limits)

Peak forward anode voltage	$V_{ap} =$	max. 2000 V
Peak inverse anode voltage	$V_{ainvp} =$	max. 2000 V
Grid voltage before conduction	$-V_g =$	max. 500 V
Grid voltage during conduction	$-V_g =$	max. 10 V
Cathode current ($T_{av} =$ max. 15 sec)	$I_k =$	max. 6.4 A
Peak cathode current	$I_{kp} =$	max. 80 A
Surge current (maximum duration 0.1 sec)	$I_{surge} =$	max. 800 A
Grid current	$I_g =$	max. 0.25 A
Temperature of condensed mercury	$t_{Hg} =$	min. 25 °C
		max. 80 °C
Ambient temperature	$t_{amb} =$	min. -40 °C
		max. +50 °C

¹⁾ Recommended value 60 sec.

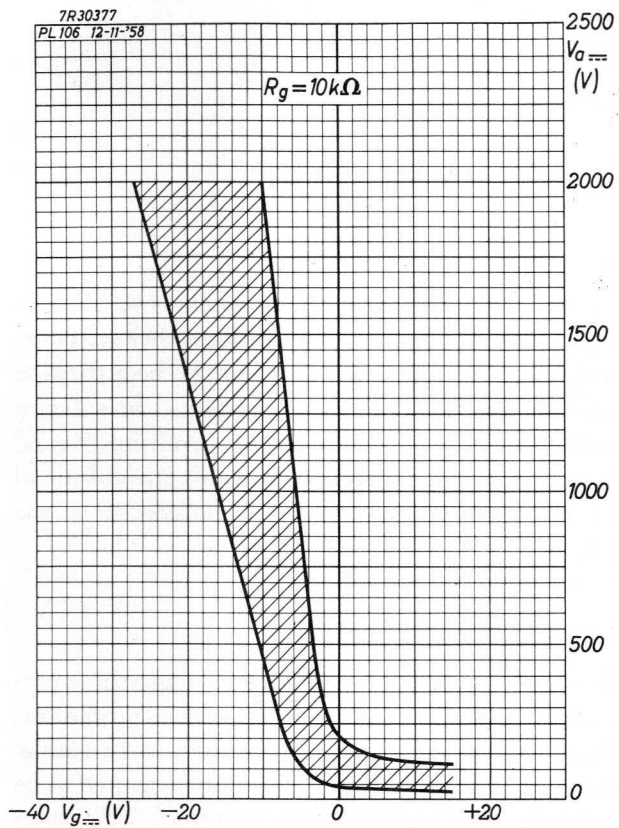


Fig. 7.45. Control characteristic of the PL 106.

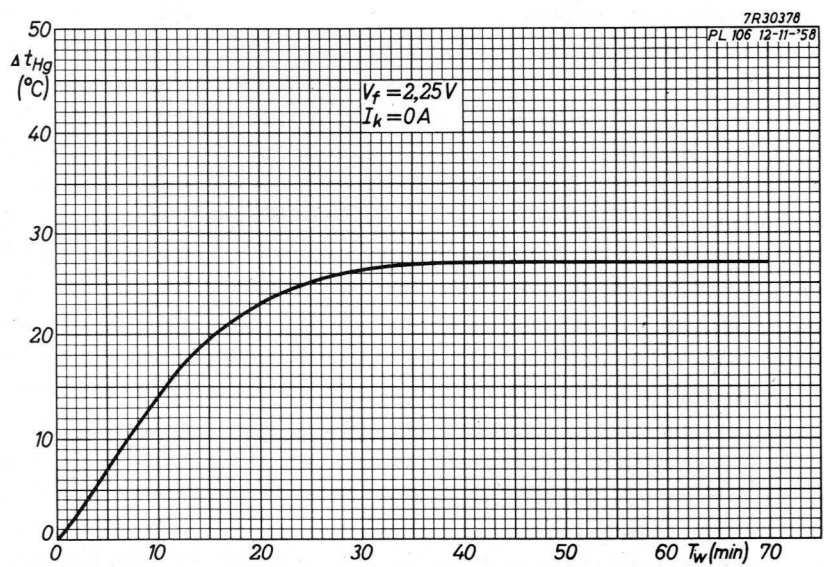


Fig. 7.46. Temperature rise of the condensed mercury (above ambient temperature) in $^{\circ}C$.

VIII. Applications of thyratrons

The particular properties of thyratrons render these types of tube suitable for an almost unlimited number of applications.

The fact that an anode current up to many ampères can be initiated by applying a small signal to the grid of a thyatron makes this tube a very useful electronic switch.

The application of thyratrons as timers is already widely spread. Since many thyratrons can operate at frequencies up to about 500 c/s, electronic timers offer the best solution for timing very short intervals, such as required with resistance welding, photographic work, etc.

For control and regulation of power supplies often use is made of a thyatron operating as a rectifier, the output of which can be very accurately controlled, so that a high efficiency is maintained even at greatly decreased outputs.

Previously variable resistors or variable-ratio transformers were used instead of thyratrons. With variable resistors efficiency must obviously be poor. Moreover, difficulties may be encountered in dissipating the heat developed. A tapped transformer, on the other hand, has the disadvantage of requiring auxiliary switch gear. Both methods have the additional draw-back that they cannot be remote-controlled and are extremely cumbersome.

Below a survey is given of four main applications of thyratrons, viz.

- a. Thyratrons used as electronic switches.
- b. Timers equipped with thyratrons
- c. Thyratrons in controlled rectifiers.
- d. Inversion of d.c. into a.c.

After a general discussion is given on these applications, a large number of practical circuits will be described.

A. THYRATRONS USED AS ELECTRONIC SWITCHES

The pulse required for operating a thyatron switching device may be supplied by any suitable pick-up acted upon by light, sound, mechanical vi-

brations, or temperature or pressure variations. A few of the many applications are given below. These examples have for the sake of clearness been divided into two groups, viz. "alarm systems" in which a mere alarm is given when a certain condition occurs, and "intervention systems" in which the output of the electronic switch is used to intervene in the process.

Alarm systems

Various non-electronic circuits for safeguarding personnel and equipment are in operation nowadays. These devices are not always simple and reliable, and electronic protection is generally accepted to be a simpler and more reliable solution. The main task set for these devices is to give a warning of an improper condition. Generally, a pilot lamp or a horn is used for this purpose.

For *intrusion alarms* numerous photoelectric devices have been designed which give warning of intrusion inside a guarded area. Preference is given to an infrared beam when atmospheric conditions such as fog, fumes, etc. must be taken into account. It has been proved possible to construct such a device by which a distance of 50 m could be supervised by means of an infra-red beam, an ordinary 25 W car-lamp being used as the light source. Such an installation can be operated under any light or atmospheric condition.

Only a few applications where electronic switches are used to control *traffic signals* will be mentioned here, e.g. the photoelectric control of traffic in vehicular tunnels, photo-electrically operated warning signs placed on secondary roads where these roads cross the main roads, photoelectrically operated warning signs on railway crossings, photoelectric switching of warning lights for boats approaching lockgates or bridges.

For *supervision of combustion* in furnaces heated by means of oil, gas or pulverized coal an electronic switch may be used to operate an alarm device. For this purpose the phototube may be controlled direct-

ly by the light of the flame. Furthermore incorrect combustion can be detected by controlling a phototube placed in a chimney by the density of smoke; excessive density of smoke actuates the alarm. For *liquid overflow protection* an alarm may be given when the fluid level exceeds a given limit. An example of such a device is given in Fig. 8.1.

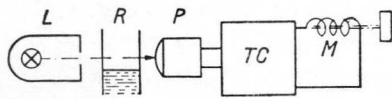


Fig. 8.1. Liquid overflow protection. The light beam emitted from the source *L* may be intercepted by the level of the fluid in the reservoir *R*, thereby interrupting the excitation of the phototube *P*. The thyatron-controlled circuit *TC* and thus the magnet *M* are thereby activated.

Electronic control has been successfully applied to *textile machines* in which a length of fabric is printed with a pattern. At the places where the lengths are stitched together a rather thick seam results, which must not be passed between the rollers without supervision, since damage might result. In order to announce the approach of the seam, a contact is mounted which closes the primary circuit of an electronic relay, thereby causing a horn to sound so that the operator, who can now serve several machines simultaneously, is warned and may take the necessary measures to lead the seam past the rollers. The alarm keeps sounding until switched off by means of a push-button.

Intervention systems

Several of the "alarm systems" mentioned in the previous section can, with slight alterations, be transformed into an intervention system. A few typical intervention systems are described below. In the case of gas-, oil- or pulverized coal-fired furnaces an electronic switch may be provided to *switch off the fuel supply* if the flame fails. It is also possible to carry out the device so that at excessive smoke densities in the chimney or too high furnace temperatures, a *servo motor* which adjusts the fuel supply is set into operation; in this way considerable savings of fuel can be obtained. In the case of a *liquid overflow protection*, the pumping of the fluid can be stopped by means of the electronic switch as soon as the level exceeds a certain value. Excessive *temperature* or *pressure* can also be avoided in a similar manner if the light beam

is interrupted by a rising mercury column or by the fluid level of a manometer gauge, thus operating a control device.

Machines can be automatically stopped when improper operation conditions occur. The phototube can stop the manufacturing process, say, when in an assembling machine certain components are missing or when a roll of paper in a printing press or wrapping machine is broken. A small switch or a light beam can supervise the continuity of the wire or yarn fed into a machine, so that in case of breakage the supply will be switched off.

Similar installations have been built in which a light beam is used to *control the knife of a machine* for cutting veneer or a roll of paper into strips or sheets. *Switching on and off lights*, such as street lights, flood lights, electric signs, navigational or airport lights, lighting of factories, schoolrooms, etc. can also be effected by an electronic relay. The energy savings obtained in this way are quite considerable; the efficiency of working personnel can be kept constant since the lighting can be adjusted to the best conditions.

Electronic sorting and grading can be applied for almost any purpose. Sorting can be carried out according to size, colour, electrical or physical qualities or standards. A few examples of this wide field of application include sorting cigarettes, rejection of defective electric lamps, grading fruit according to colour, etc.

A survey of a number of applications of thyratrons used as electronic switches and the type of pick-up to be used is given below:

<i>Application</i>	<i>Pick-up</i>
Automatic light switching	phototube
Switching display lighting on and off	phototube
Cutting opaque material into given lengths	phototube
Switching off a winding or spinning machine when the yarn breaks	running roller
Stopping a machine for winding enamelled wire when the coating is damaged	conductive rubber rollers
Cutting off the oil feed when the flame of a burner extinguishes	phototube
Accurate time recording at races	phototube

<i>Application</i>	<i>Pick-up</i>
Regulating the level of liquids	two electrodes or an <i>NTC</i> resistor
Limiting minimum or maximum temperatures	<i>NTC</i> resistor
Regulating humidity	contact hygrometer
Signalling overvoltages of 20% and more	transformer + capacitor or two capacitors
Signalling failure of the ventilator in drying plants	vane
Testing ventilators manufactured in series	vane
Testing the varnish films of preserving tins	two electrodes
Signalling the filling of bunkers to maximum capacity	phototube, capacitor or strain gauge
Smoke signalling	phototube
Checking the viscosity of a substance	contact arm
Burglar alarm	phototube
Fire alarm	bi-metal or <i>NTC</i> resistor
Signalling excessive vibration of machinery	vibration pick-up
Signalling mechanical overload	two strain gauges
Signalling a break in conduits for transporting sand, cement, etc.	phototube
Switching off the drive of printing rollers in the textile industry when seams or knots occur in the material	two rollers
Counting objects on a moving belt	phototube
Counting drops of a liquid	two bare wires
Sorting goods to size	phototube
Automatic stopping of the supply when filling boxes, etc., to a certain weight	pointer of weighing machine

B. TIMERS EQUIPPED WITH THYRATRONS

A timer is a device which permits a given operation to start at a given moment and to stop after a pre-selected period. A timer may be either of the automatic and continuous-action type, or be operated by hand. Electronic timers are widely applied. They are used, for instance, for the automatic control of electric welding machines, for the control of che-

mical processes in laboratories, for regulating the radiation quantities of X-ray apparatus, and for the control of exposure times in photographic studios.

C. THYRATRONS IN CONTROLLED RECTIFIERS

Rectifiers with controlled output are used for many purposes, including the following:

- speed control of d.c. motors;
- voltage regulation of generators;
- control of the charging rate of batteries;
- control of electric welding apparatus;
- control of electrochemical processes;
- intensity control of illumination;
- temperature control.

A few examples demonstrating some of the various possibilities are given below.

For **controlling the speed of d.c. motors** the principle shown in Figs 8.2 and 8.3 may be applied.

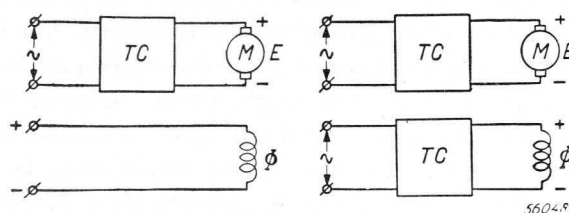


Fig. 8.2. (left) Basic diagram for controlling the speed of a d.c. motor *M* by feeding the armature from a thyatron rectifier *TC*.

Fig. 8.3. (right) Diagram similar to that of Fig. 8.2. in which both the armature and the field winding are fed from a thyatron rectifier *TC*.

The motor speed is determined by the well-known equation $n = E/k\Phi$, in which n is the number of revolutions per minute, E the back e.m.f., k the motor constant and Φ the magnetic flux. The speed of the motor can thus be controlled by varying E (see Fig. 8.2), by varying Φ or by varying both E and Φ (see Fig. 8.3). When control is applied by means of a thyatron rectifier it is possible to vary the speed of the motor smoothly and efficiently over a range exceeding 1:100.

Similar circuits have been developed to **keep the motor speed constant** and independent of load and supply voltage variations. This may be achieved either entirely electrically by means of the voltage at the input terminals of the motor or by means of the voltage delivered by a tachometer driven by the motor. This voltage which in the latter case may be amplified by a d.c. amplifier, is compared with a reference voltage and the difference be-

tween these voltages is applied to the grid of a thyatron the output of which governs the motor. **The output voltage of d.c. or a.c. generators can be kept constant** automatically by exciting the generator field by means of a thyatron rectifier *TC* (see Figs. 8.4 and 8.5).

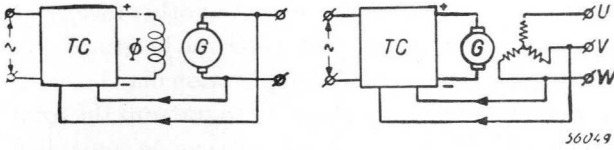


Fig. 8.4. (left) Basic diagram for maintaining the output voltage of a d.c. generator *G* constant by controlling the generator field by means of a thyatron rectifier *TC*.

Fig. 8.5. (right) Circuit similar to that of Fig. 8.4. for maintaining the output voltage of an a.c. generator *G* constant.

The output voltage of the generator is then compared with a reference voltage and the difference between these voltages is applied to the grid circuit of the thyratrons. In this way the output voltage may be kept constant independent of electrical load and mechanical speed variations.

Battery chargers may also be equipped with thyratrons so as to keep the output voltage or current constant with the aid of a reference voltage. In the first example (see Fig. 8.6) the output voltage will

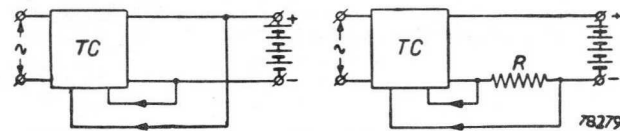


Fig. 8.6. (left) Basic diagram for stabilizing the output voltage of a thyatron rectifier *TC* used as a battery charger.

Fig. 8.7. (right) Circuit similar to that of Fig. 8.6. in which the output current of the thyatron rectifier *TC* is kept constant.

remain constant throughout the charging period, and in the second example (see Fig. 8.7) the charging current will be maintained at the desired value. The values of the voltage or current which are to be kept constant can obviously be adjusted to any predetermined level by variation of the reference voltage.

Thyratrons also play a predominant role in **resistance welding** apparatus. Large seam welders (Fig. 8.8) are fed by ignitrons the ignition circuit *IC* of which is governed by a thyatron circuit *TC*, also known as a timer. The time during which the

objects to be welded are under pressure, pre-heated, heated or cooled down can thus be adjusted accurately.

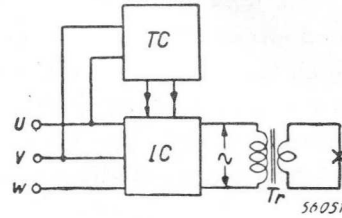


Fig. 8.8. Basic circuit diagram of a resistance welding apparatus in which the welding transformer *Tr* is fed by an ignitron contactor *IC* which is controlled by a thyatron rectifier *TC*.

In **energy storage welders** which are generally used for spot welding, a thyatron rectifier may be used to control the amount of energy transferred to the work. These welders may be based on the discharge of a capacitor or on the amount of energy stored in the inductance of the primary of the welding transformer (see Fig. 8.9a and b).

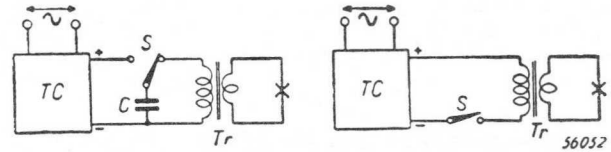


Fig. 8.9a. (left) Energy storage welder in which the amount of energy stored in the condenser *C* is governed by the thyatron rectifier *TC*.

Fig. 8.9b. (right) Energy storage welder in which the thyatron rectifier *TC* supplies a definite amount of energy which is stored in the inductance of the primary of the welding transformer *Tr*.

In arc-welding apparatus in which the **welding rod is fed automatically** it is necessary to control the speed of the d.c. motor used for the purpose. This control may be performed by means of a thyatron circuit *TC* similar to that used for d.c. motor control. The speed of the motor is governed by the voltage drop across the arc, i.e. when the rod is advanced too slowly the length of the arc increases, this causing the motor to accelerate so that the rod is fed more rapidly.

For controlling the density and duration of current flow in **electrolytic processes**, thyatron rectifiers have been used to advantage. In the basic diagram given in Fig. 8.10 the output voltage of the rectifier *RS*, which may for instance be of the selenium type and delivers the power required, is fed back to a thyatron rectifier *TC*₁ which controls

the reactance of the transductor S^1): the input voltage and consequently the output voltage of the rectifier RS is thus kept constant and independent of load variations. Moreover, a second thyatron-controlled circuit TC_2 may be provided, by means of which the current is switched off at a remote point r as soon as the deposit has reached the desired thickness. The process can thus be controlled quickly and most efficiently.

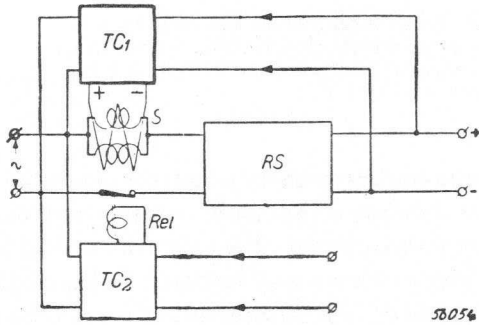


Fig. 8.10. Circuit for maintaining the output voltage of a selenium rectifier RS constant by means of a thyatron rectifier TC_1 , the output of which feeds the d.c. winding of the transductor S . A second thyatron-controlled circuit TC_2 operating a relay Rel makes it possible to switch off the current from a remote point r .

An important field of application for thyatron circuits is that of **lighting control**. Accurate control of the intensity of illumination is required for the stage, for large halls, such as theatres, picture houses, music halls and so on. By simultaneous control of light sources of different colours, various decorative effects may be obtained.

A basic circuit for controlling the light of incandescent lamps is given in Fig. 8.11. The transductor S is adjusted by means of the thyatron rectifier TC ,

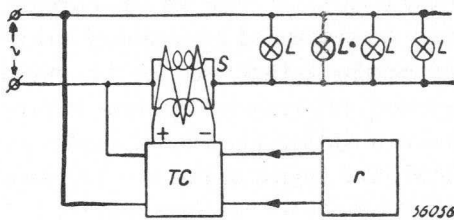


Fig. 8.11. Basic circuit diagram for controlling the luminous intensity of the incandescent lamps L ; the thyatron rectifier TC , to which a remote control unit r may be connected, feeds the d.c. winding of the transductor S connected in series with the lamps.

1) A transductor or saturated core reactor consists of two windings on a core: an a.c. winding and a d.c. winding. When the d.c. current varies the saturation of the core and thus the reactance of the a.c. winding is also varied.

which may, in turn, be controlled by a remote control unit r , so that great flexibility of control may be obtained. By means of pre-set controls any particular light intensity and mixture of colours can be exactly produced at any time.

Although the use of thyatrons for controlling the luminous intensity of fluorescent or other discharge lamps does not, in fact, fall under the heading "rectification", this important application may be briefly mentioned here. By means of thyatrons the total output of light of discharge lamps can be controlled over the full range. This cannot be achieved by any other means owing to the fact that discharge lamps have a fixed ignition voltage below which they will remain extinguished. With thyatron control the time interval of current flow during each period is varied, the amplitude of the supply voltage remaining unaltered.

The method used in this case is based on the application of two thyatrons in anti-parallel connection as shown in Fig. 8.12.

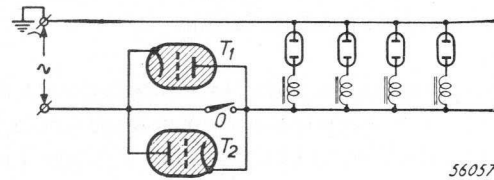


Fig. 8.12. Basic circuit diagram for controlling the light of discharge lamps; the switch O has been provided to short out the thyatrons T_1 and T_2 at full light intensity so as to prolong their useful life.

In many industrial processes an accurate **temperature regulation** is essential. A few examples in this field where thyatrons have been successfully used are melting furnaces, baking ovens, heat treatment ovens, plastic preheaters and oil baths for annealing. A control circuit operating with the aid of a thyatron will render it possible to keep the temperature automatically constant within very narrow pre-set limits.

Another application of thyatron circuits consists in keeping the room temperature constant, as may be required for instance in wool manufacturing industries and chemical works.

The principle of operation of a temperature control circuit is given in Fig. 8.13, R being a resistor the resistance of which depends on the temperature. This resistor is one arm of an a.c. bridge circuit controlling the thyatron rectifier TC , the output of

which controls the saturation of the transducer S connected in series with the heater H of the electric furnace F .

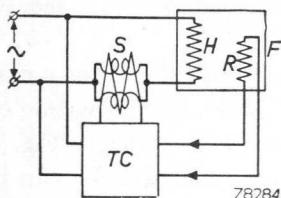


Fig. 8.13. Basic circuit diagram for maintaining constant temperature in an electric furnace F . The voltage drop across the transducer S connected in series with the heater H is governed by the thyatron rectifier TC , the output of which depends on the resistance of the temperature-sensitive resistor R .

The number of applications of thyratrons for controlling purposes is practically unlimited. Further examples are circuits for regulating the pressure of fluids and gases, the level of fluids or materials, etc. Furthermore these circuits may be used for regulating voltages, currents, phase angles or frequencies. Generally speaking, practically any quantity, quality or condition can be controlled and regulated by means of thyratrons.

D. THYRATRONS FOR INVERSION (d.c. into a.c.)

The inversion of d.c. into a.c. was in the past accomplished by means of rotating machinery, that is to say by a.c. generators mechanically coupled to a d.c. motor, or by converters.

Compared with the mechanical methods, the electronic method has the advantage of containing no moving parts, thus operating silently and requiring no foundations. No auxiliary starting gear is required, and since no sparks occur due to brush commutation, the installation can be safely operated in surroundings where the hazard of an explosive atmosphere exists. Finally, high efficiency of operation is maintained at all loads.

Technique of operation

An inverter being fed by a d.c. source, the generation of a.c. power necessitates periodical extinction of the tube. For this reason the circuit of an inverter must be based upon principles similar to those of the d.c.-operated thyatron relay circuits, as explained in an earlier part of this section.

Various circuits have been developed, two of which are discussed below — one for an externally excited

parallel inverter and one for a self-excited relaxation inverter.

In an *externally excited* parallel inverter (see Fig. 8.14) the constancy of the output frequency depends upon the stability of the excitation frequency v_i . The capacitor C is an essential part of the circuit, since it extinguishes the working tube when the second tube is ignited. For satisfactory operation of the circuit, careful selection of the value of this capacitor is of paramount importance. The wave form of the a.c. voltage V_o also depends on the value of this capacitor and, moreover, on the magnitude of

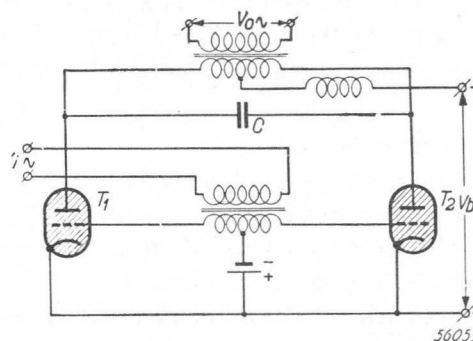


Fig. 8.14. Simplified circuit diagram of an externally excited parallel inverter.

the output current and on the type of load. The best wave form will be obtained with an inductive load, as the time then available for deionization is longer than when the load is non-inductive.

In a *self-excited* relaxation inverter as shown in Fig. 8.15 the excitation is obtained by means of the capacitor C_2 and the resistor R .

The circuit operates as follows. The voltage V_b causes the thyatron T to ignite, as a result of which the anode assumes practically the same potential as the cathode, so that the capacitor C_1 discharges. Owing to the oscillatory tendency of the series circuit constituted by the capacitor C_1 and the inductor L , this capacitor then starts to charge in a direction opposite to that indicated in Fig. 8.15. The in-

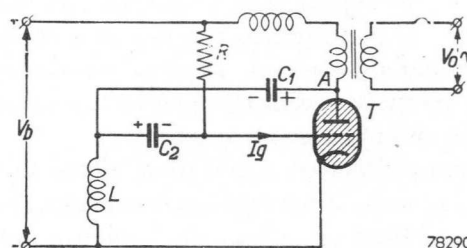


Fig. 8.15. Simplified circuit diagram for a self-excited relaxation inverter.

stant the potential of point A is reduced below the extinction voltage of the tube, conduction ceases and, since the flow of unidirectional grid current during the period of conduction has caused the capacitor C_2 to assume a charge as indicated, the grid has become highly negative with respect to the cathode, so that the thyatron does not re-ignite. During this non-conducting period the capacitor C_2 discharges slowly through the resistor R , so that the negative grid voltage gradually decreases. In the meanwhile the capacitor C_1 resumes its original polarity as indicated, and at a certain moment the tube re-ignites, after which a new cycle starts. The principle of these inverter circuits can easily be extended to a three-phase output circuit.

Fields of application

Among the main applications the use of invertors for feeding a.c.-operated appliances from a d.c. supply has the great advantage of offering freedom to select the most economic frequency.

Industries, such as the textile or woodworking industries, will welcome this solution to the problem of high speed drive; the same applies to driving tools, such as grinders, polishers, etc., at high speeds. When the frequency is for instance raised to 500 c/s the speed attainable will be 30 000 revolutions per minute. It should also be noted that in this case the size and therefore the cost of the a.c. motor will be considerably reduced.

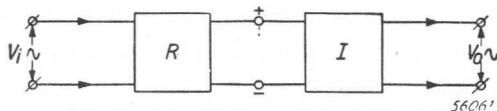


Fig. 8.16. Principle of an electronic frequency changing device. The a.c. input V_i is changed into d.c. by the rectifier R and then changed back to a.c. of the required frequency by the inverter I .

A further interesting possibility consists in the application of an inverter in combination with a comparatively cheap asynchronous motor for variable speed drive, whereby the speed is controlled by variation of the supply frequency. This solution will generally be preferred to the use of a controlled rectifier and a d.c. motor. Electronic invertors are also successfully used for delivering the a.c. power required for induction heating.

An entirely different application of the inverter consists in using it for regenerative braking of d.c. motors fed from a.c. mains. The inverter normally works as a rectifier, i.e. the a.c. energy from the mains is applied as d.c. energy to the motor, but

during the period of braking a.c. energy is returned to the mains, the electronic equipment being used as a true inverter. Such equipments are of particular value in railway installations, steel mills, elevators, etc.

To change the frequency of the a.c. supply electronically (conversion), a combination of a rectifier R and an inverter I is used (see Fig. 8.16). The frequency of the a.c. output V_o can in this way be adjusted to the required value, so that the driven appliance can be operated in the most efficient way. The output frequency can also be made variable and used for variable speed drive of a.c. motors.

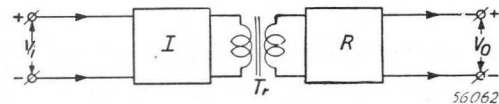


Fig. 8.17. Principle of an electronic device for d.c. transformation.

In the established method of transformation of d.c. a rotary machinery has previously been employed with all the disadvantages that this entails compared with electronic methods. In the electronic method (see Fig. 8.17) use is made of apparatus in which the d.c. supply voltage V_i is inverted into a.c. by the inverter I , then stepped up (or down) by a transformer Tr and finally rectified to the required d.c. output level V_o by the rectifier R . As an example, the 220 V d.c. mains voltage may be transformed into 10 kV d.c.

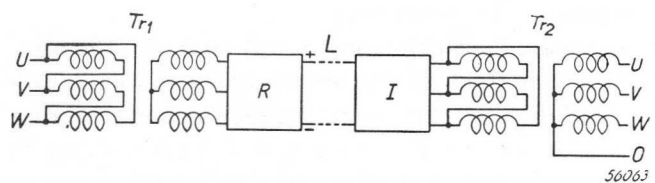


Fig. 8.18. Principle of d.c. power transmission.

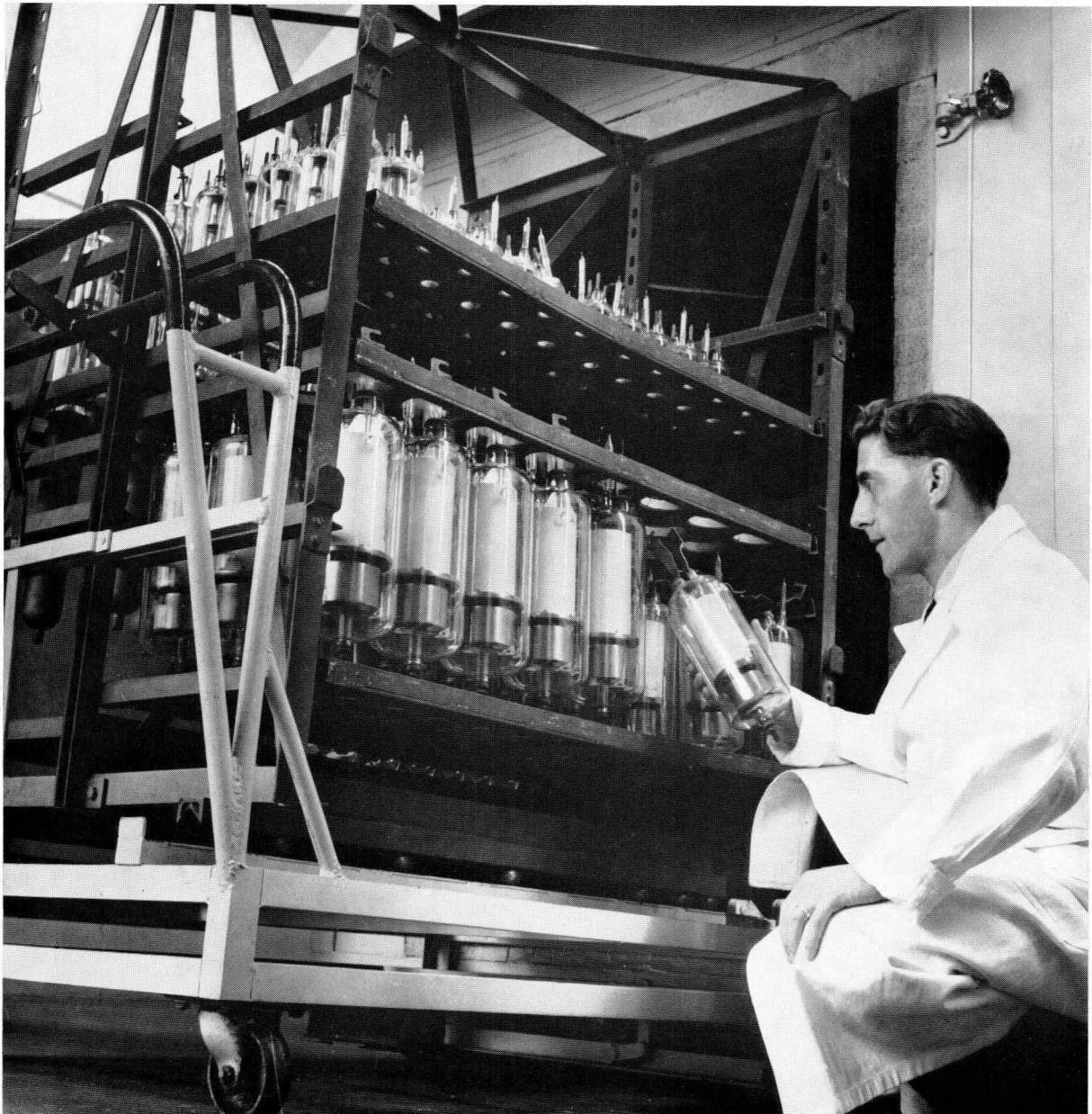
A similar solution may be used for power transmission (see Fig. 8.18). The generated a.c. power is stepped up by the transformer Tr_1 , rectified by the rectifier R , transmitted over a long high-tension d.c. line L , inverted to the most economical frequency by the inverter I and finally stepped down to the required voltage level by the transformer Tr_2 . This allows full realization of the advantages of d.c. transmission, namely the absence of wattless power and of skin effect. This permits the use of thinner conductors, and in addition the insulation of d.c. lines is easier than that of a.c. lines for the same voltage.

Part 2

Practical Applications
and
Circuit Descriptions



Before being evacuated the thyratrons are prepumped



Rack with thyatrons before final heat treatment

Electronic contactors

INTRODUCTION

In many industrial apparatus current must be switched on and off several hundred times per hour. Until recently electromechanical contactors were as a rule used for this purpose. These contactors are capable of handling the power to be switched; however, in many cases they prove to be mechanically inadequate at high switching frequencies. After a few hours' use it may be necessary to replace the switch contacts, and after a few weeks the entire contactor often must be replaced.

The continually recurring breakdowns in service, which occur at unpredictable moments, cause interruptions in the production process with consequent economic loss.

With electro-mechanical contactors alternating currents will not usually be switched at the moment when the instantaneous value of the current happens to be zero, so that additional safety measures must be taken. Moreover, electro-mechanical contactors produce objectionable noise during switching.

By means of thyratrons it is possible to construct contactors without any of these disadvantages. Such electronic contactors are not subjected to wear, and reliable service is guaranteed over thousands of hours without interruption of the working process.

I. D.C. CONTACTOR

Fig. 1.1. shows the circuit of a d.c. contactor equipped with three thyratrons PL 5557. The grid circuits of the tubes are fed from the RC-networks $R_4 C_4$, $R_5 C_5$, $R_6 C_6$ and C_6 which provide three a.c. grid voltages approximately 90° out of phase with the anode voltages of the corresponding tubes. In addition to this a.c. signal, a d.c. voltage which is developed across R_{10} and R_{11} keeps the grids sufficiently negative to prevent the tubes from firing.

When the switch S is momentarily opened the d.c. bias is reduced so that the tubes fire. The value of

the rectified current through the load can be regulated by means of R_{10} , which determines the firing angle of the tubes.

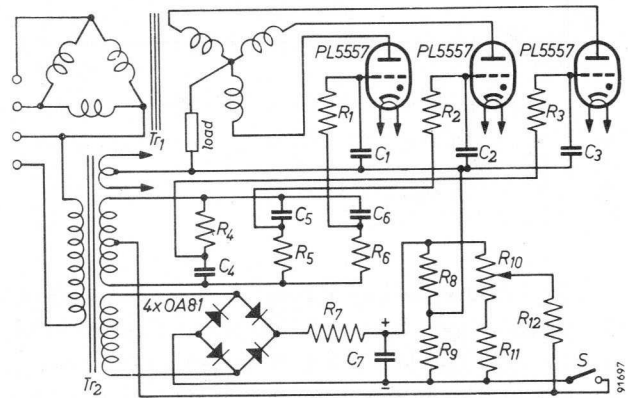


Fig. 1.1. D.c. contactor.

$R_1 = R_2 = R_3 = 50 \text{ k}\Omega$	$C_1 = C_2 = C_3 = 250 \text{ pF}$
$R_4 = 50 \text{ k}\Omega$	$C_4 = C_5 = 0.1 \mu\text{F}$
$R_5 = 11 \text{ k}\Omega$	$C_6 = 0.25 \mu\text{F}$
$R_6 = 60 \text{ k}\Omega$	$C_7 = 10 \mu\text{F}$
$R_7 = 5 \text{ k}\Omega$	
$R_8 = 10 \text{ k}\Omega$	$Tr_1 = \text{mains transformer}$
$R_9 = 25 \text{ k}\Omega$	380/240 V_{rms}
$R_{10} = 25 \text{ k}\Omega$ variable	$Tr_2 = \text{transformer}$
$R_{11} = 5 \text{ k}\Omega$	220/2 \times 50 V_{rms}
$R_{12} = 50 \text{ k}\Omega$	

II. A.C. CONTACTOR

Description

Fig. 1.2 shows the circuit of an a.c. contactor with two thyratrons PL 5559 in anti-parallel connection with which an alternating current of $5.5 A_{\text{rms}}$ can be switched. The thyratrons can be controlled by means of the switch S_1 which can be operated by the apparatus that has to be switched on and off. Since the current flowing through this switch during operation is only in the order of 10 mA, the load on the operating contacts is practically negligible.

The two grids of the thyratrons are connected to the direct voltage units A_1 and A_2 (type 1289). Part of the available voltage of 45 V from these units is

used as negative grid bias for the thyratrons by applying the voltage to the voltage dividers R_3-R_7 and R_4-R_8 . When the switch S_1 is closed the circuit which runs from one pole of the a.c. mains via $R_6-R_4-R_3-R_5$ to the other pole of the mains is established,

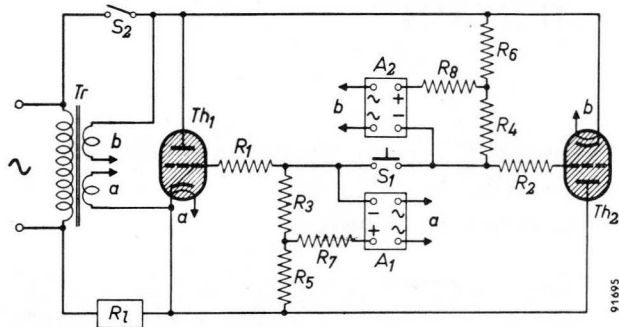


Fig. 1.2. Electronic a.c. contactor

$R_1 = R_2 = 10 \text{ k}\Omega, 1 \text{ W}$ $A_1 = A_2 = \text{control units}$
 $R_3 = R_4 = 3.3 \text{ k}\Omega, 1 \text{ W}$ type 1289
 $R_5 = R_6 = 10 \text{ k}\Omega, 1 \text{ W}$
 $R_7 = R_8 = 1.5 \text{ k}\Omega, 1 \text{ W}$

so that an alternating voltage is superimposed on the negative grid bias and the thyratrons are fired alternately. The load R_l is included in the circuit formed by the mains, the switch S_2 and the two thyratrons connected in anti-parallel.

The primary of transformer Tr is also connected to

the mains and has two secondary windings a and b for feeding the heaters of the thyratrons Th_1 and Th_2 and the direct voltage units A_1 and A_2 .

Operation

The operation of this circuit may be explained as follows. It will be assumed that the switch S_1 is closed at the instant at which the anode of Th_1 is positive. As a result this thyatron fires and the current will flow through the tube until the mains voltage passes through zero. During the next half cycle this tube remains extinguished, but thyatron Th_2 will then be fired. The load R_l is thus fed, via the switch S_2 , by the two thyratrons.

When switch S_1 is opened at an arbitrary moment one of the thyratrons will as a rule continue to supply current until the instantaneous value of the anode voltage has dropped to zero notwithstanding its grid is biased negatively. Current thus continues to flow through the load during this half cycle. In the next half cycle, however, the other thyatron does not fire anew and thus the load is switched off. Switch S_2 serves to protect the thyratrons when the contactor is put into use. The load should not be connected to the thyratrons before they have been warmed up; switch S_2 must therefore not be closed before the prescribed heating time has elapsed.

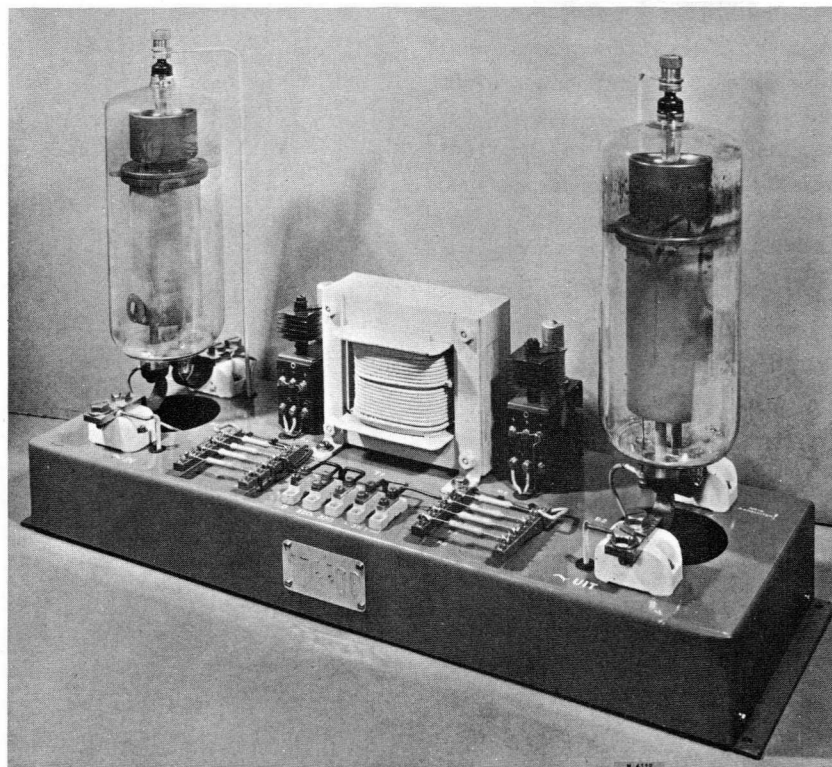


Fig. 1.3. Electronic a.c. contactor for 27 A_{r.m.s.}

The current which is fed to the load by means of this contactor depends upon the type of thyratrons used. With two PL 5559, which can deliver a mean current of 2.5 A, a current of $2.2 \times 2.5 = 5.5 A_{rms}$ and with two thyratrons PL 255 a current of $2.2 \times 12.5 = 27 A_{rms}$ can be supplied to the load. Fig. 1.3 shows a contactor equipped with two thyratrons PL 255.

By using a timer for operating the switch S_1 the circuit shown in Fig. 1.2 can be used for feeding welding transformers directly or for controlling resistance welding machines. In the former case the welding transformer forms the load R_l in Fig. 1.2. Below a table is given of the currents through the primary of the transformer when different types of thyatron are used ¹⁾.

A simplified diagram of the contactor controlling a resistance welding machine is given in Fig. 1.4. The circuit is almost equal to that represented in Fig. 1.2 but in the former circuit two ignitrons, connected in anti-parallel and controlling the welding transformer Tr_2 , form the load of the a.c. contactor.

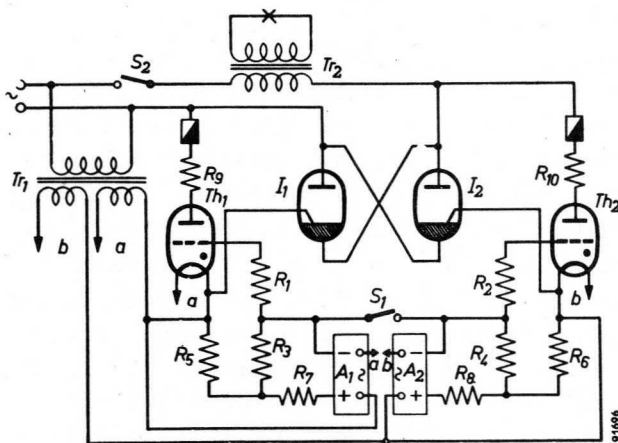


Fig. 1.4. Electronic a.c. contactor for firing two ignitrons in a welding apparatus. The values of the components are equal to those in Fig. 1.2.

The welding contactor is of the non-synchronous type, i.e. the current through the ignitrons may start to flow at any instant during the positive half cycle of the mains voltage. Since the current can start to flow only when the anode voltage of the ignitrons has reached the ignition voltage, it is recommended that the mains voltage amounts to 380 V at least to obtain a sufficiently large firing range.

The cathodes of the thyratrons PL 5632/C3J are connected to the ignitors of the ignitrons. When the thyratrons are fired a current will flow via the thyatron cathodes and the ignitors of the ignitrons so that

¹⁾ Cf. fig. 5.3, page 92.

these tubes are also fired. As long as S_1 remains closed the thyratrons—and consequently the ignitrons—are fired in turn each half cycle of the mains voltage. The welding time depends, therefore, on the period of S_1 being closed. When S_1 is energized by a timer the duration of the weld can be determined within very narrow limits.

In the anode circuits of the thyratrons a fuse and a resistor have been inserted. The resistors must be so large that the current peaks occurring when the thyratrons are fired, do not exceed the permissible value required for firing the ignitrons. The value of the resistors can be determined easiest by choosing their value in ohms equal to one hundredth of the r.m.s. value of the supply voltage:

$$\begin{aligned} V = 220 V_{rms} & R = 2 \Omega \\ V = 380 V_{rms} & R = 4 \Omega \\ V = 500 V_{rms} & R = 5 \Omega \end{aligned}$$

The value of the fuses should be chosen in accordance to the r.m.s. current flowing through the thyratrons. Below a table is given of different values of the current through the primary of the welding transformer when this is connected in the circuit of Fig. 1.2 or Fig. 1.4. The types of thyatron, resp. ignitron, which can deliver these currents are indicated in the centre column, whilst in the last column the r.m.s. value is given which can be delivered by these tubes in continuous service, e.g. temperature control of furnaces or dimming installations of fluorescent lamps. It is clear that the currents delivered in welding are considerably higher, since the tubes are then extinguished for the major part of the time. The figures given in the table hold for two tubes in anti-parallel connection.

Current through primary of transformer (A_{rms})	Type of thyatron resp. ignitron	Current delivered with continuous service (A_{rms})
28	PL2D21	0.22
	PL 5557	1.1
	PL 5559	5.5
	PL 5544	7
54	PL 105	14
110	PL 255	27
200	PL 260	55
2400 ²⁾	PL 5551 ³⁾	124
4800 ²⁾	PL 5552 ³⁾	308
9600 ²⁾	PL 5553 ³⁾	
1000 ⁴⁾	PL 5555 ³⁾	455

²⁾ At a mains voltage of 250 V.

³⁾ In this type of circuit for all types of ignitron the thyatron PL 5632/C3J may be used for firing.

⁴⁾ At a mains voltage up to 2400 V.

Electronic switch with the PL2D21

Fig. 2.1 shows the circuit diagram of an electronic switch. In the anode circuit of the PL2D21, which is a.c. fed, a relay *Rel*, shunted by a capacitor C_2 , and a current-limiting series resistor R_4 are included. To limit the grid current, a resistor R_3 is incorporated in the control-grid circuit.

The grid voltage is obtained from a germanium rectifier OA 81 and can be varied by the potentiometer

R_1 from 0 to approx. —30 V. One side of the pick-up is always connected to earth, and must also be connected either to the cathode of the PL2D21 or to a tap of the secondary winding of the mains transformer Tr_1 (dashed lines), depending on the type of pick-up used.

In the case of a make contact, for example, one side must be connected to earth and to the cathode, and R_1 must be so adjusted that with open contact the thyatron is non-conductive. When the contact is closed the grid is connected to the cathode via the resistor R_3 . The grid voltage then becomes zero, so that the tube ignites, and the relay *Rel* is energized as long as the contact remains in the closed position. When a phototube is employed, however, its anode must be connected to earth and to the tap of the transformer instead of to the cathode of the PL2D21. The voltage applied to the phototube, i.e. the voltage derived from $w_3 + w_4$, depends on the type of phototube used; in the case of the 3546, for example, it amounts to $45 V_{rms}$. When light impinges on the phototube the latter becomes conductive and current starts to flow through the resistor R_2 . The voltage thus produced across R_2 is applied to the grid of the thyatron and is superimposed on the grid bias derived from R_1 . This bias should be adjusted in such a way that the PL2D21 will ignite as soon as the phototube is exposed to light. At the same time the grid should be kept as highly negative as is compatible with faultless operation of the relay.

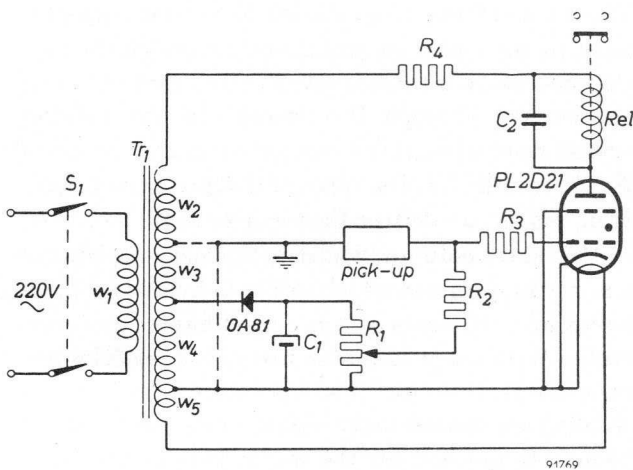


Fig. 2.1. Electronic switch

$R_1 = 2 \text{ k}\Omega, 1 \text{ W}$	$Tr_1 = \text{mains transformer}$
$R_2 = 5.6 \text{ M}\Omega, 0.5 \text{ W}$	$w_1 = 220 \text{ V}, 50 \text{ c/s}$
$R_3 = 0.1 \text{ M}\Omega, 0.5 \text{ W}$	$w_2 + w_3 + w_4 = 195 \text{ V}$
$R_4 = 1.2 \text{ k}\Omega, 1 \text{ W}$	$w_3 + w_4 = \text{see text}$
$C_1 = 25 \mu\text{F}, 500 \text{ V}$	$w_4 = 25 \text{ V}, 0.1 \text{ A}$
$C_2 = 0.5 \mu\text{F}, 500 \text{ V}$	$w_5 = 6.3 \text{ V}, 0.6 \text{ A}$
	<i>Rel</i> : relay, d.c. resistance $15 \text{ k}\Omega$

Thyratron timers

Thyratrons have made it possible to construct timers which are much simpler and more reliable than the commonly used mechanical timers. Since, moreover, thyatrons can deliver large currents, a thyatron timer can operate simultaneously as an electronic switch for high powers. These properties are of paramount importance in many industrial processes, especially in welding.

The essential requirement for good welding is to reduce the volume of the material heated up to the welding temperature to a minimum. To achieve this it was found necessary to pass an extremely high current of very short duration through the joint, say 30 000 A for 1 cycle of the mains frequency (0.02 sec). The electronic method of control offers the best solution for timing such short intervals with the highest possible exactness.

The introduction of the electronic welding timer immediately extended the range of welding and made it possible to weld light metals and their alloys together.

discharges via R_1 . The duration of the discharge depends on the value of R_1 and determines the length of the welding time, because as soon as C_1 is almost fully discharged the thyatron fires and energizes the relay so that the welding transformer circuit is interrupted.

INTERVAL TIMER FOR A SMALL BENCH-WELDER

A simplified diagram of an interval timer is shown in Fig. 3.1; the operation of it can be explained as follows.

When the main switch S_1 is closed, a small current will flow via a resistor (1.2 k Ω), the contacts of the relay Rel , the primary of the welding transformer Tr , the selenium rectifier Sel and the resistor R_1 . The capacitor C_1 will be charged by this current in the polarity as indicated in the figure. The potential of the grid of the thyatron PL 1607 will, therefore, become negative so that the tube is prevented from firing.

The welding current can be switched on by closing the footswitch S_2 , which short-circuits at the same time the selenium rectifier Sel and R_1 . The charging of C_1 will consequently be stopped and the capacitor

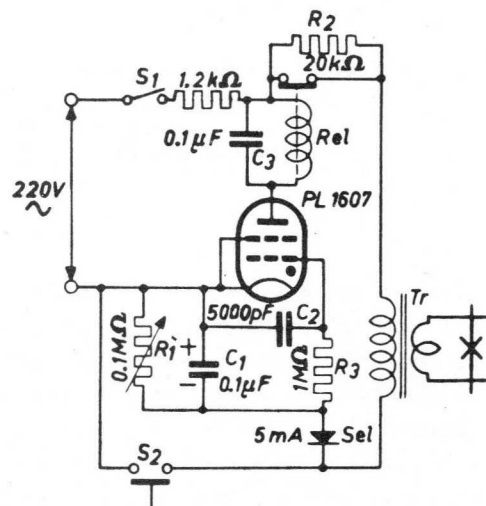


Fig. 3.1. Electronic weld timer with the PL1607.

If S_2 is reopened, C_1 will be charged again and the thyatron is extinguished so that the circuit returns to its initial stage.

Theoretically the welding current might be interrupted by premature opening of S_2 . In practice, however, this is impossible since the welding period is so small that a mechanical switch can generally not be closed and opened in such a short time.

TIMER FOR APPLICATION IN PHOTOGRAPHY

Fig. 3.2 shows a circuit for the control of the exposure times in photographic studios.

After the mains voltage has been switched on and the cathode of the indirectly heated rectifying tube V_1 is heated up, the PL2D21 receives a positive

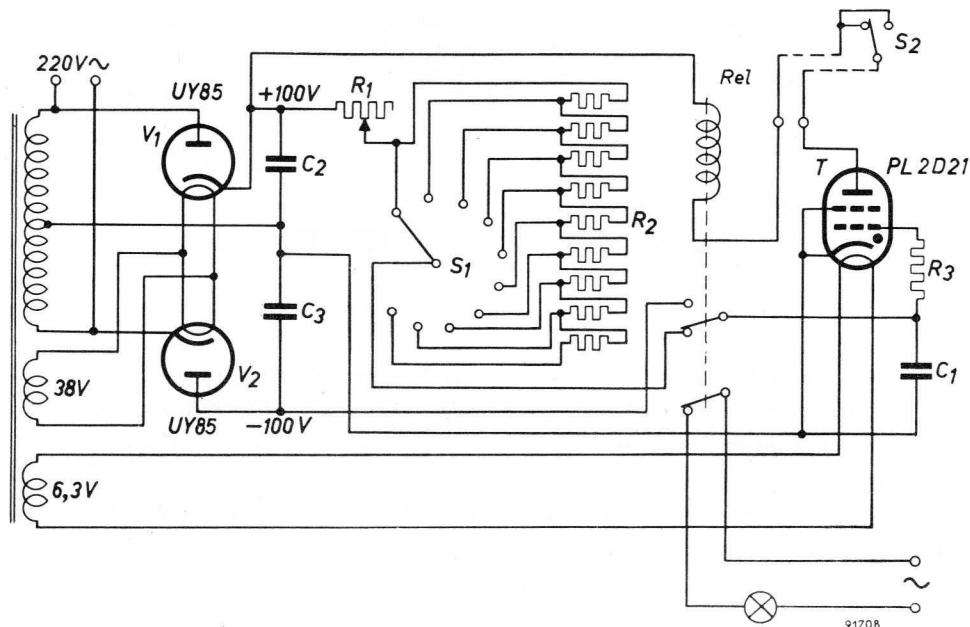


Fig. 3.2. Circuit diagram of a timer for enlarging apparatus in photography.

$$\begin{aligned}
 R_1 &= 1.5 \text{ M}\Omega & C_1 &= 2 \mu\text{F} \\
 R_2 &= 9 \times 1 \text{ M}\Omega & C_2 &= 8 \mu\text{F} \\
 R_3 &= 0.1 \text{ M}\Omega & C_3 &= 8 \mu\text{F} \\
 \text{Rel} &= \text{relay } 7600 \Omega
 \end{aligned}$$

control-grid and anode voltage. The thyatron ignites and the relay *Rel* is energized so that the circuit containing the lamp is interrupted and a capacitor C_1 is connected to the rectifying tube V_2 , so that it is then charged to -100 V. Although the control grid of the PL2D21 now becomes negative, this tube will not be extinguished because the anode voltage has not been interrupted. If, however, switch S_2 is turned from one position to the other, the anode voltage is interrupted for a few milliseconds, and, owing to the extremely short de-ionization time of the thyatron, the tube will remain extinguished as a result of the negative control-grid voltage caused by the charge of C_1 . Consequently, the relay cuts out and closes the circuit which contains the lamp. At the same time C_1 is connected to a voltage source of opposite polarity ($+100$ V) via the resistors R_1 and R_2 . R_2 consists of nine resistors, from which a choice can be made by means of the tapping switch S_1 , for adjusting the discharge time. After the capacitor has been discharged down to approx. -2 V, the thyatron is ignited again; the relay is energized and the circuit containing the

lamp is interrupted. Now the timer has returned to its initial state, and the lamp remains switched off until switch S_2 is operated again.



Fig. 3.3. Experimental unit using the circuit of Fig. 3.2.

The interval can be adjusted by means of the resistors R_1 and R_2 .

Fig. 3.3 shows an experimental timer working on the principle described above.

Stabilizing circuits

Below a number of circuits is described for stabilizing the mains voltage. Fluctuations in this voltage may be reduced to about $\frac{1}{2}\%$; the efficiency of the circuits is approximately 90% and almost any power up to many kilowatts can be stabilized.

The circuits have been specially designed for stabilization of the heater voltage and current of large tubes, e.g. transmitting tubes. In practice, however, many other applications will be possible, such as stabilization of the mains voltage for supply units, for high-precision measuring instruments, for projector lamps etc. A limitation of the applications is, however, that the output voltage is not sinusoidal as will be clear from the description below. This description is based on stabilization of the heater power of large tubes but the circuits can be modified for other applications as indicated above.

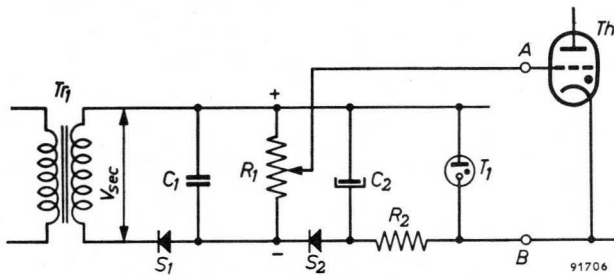


Fig. 4.1. Control unit for a mains stabilizing circuit.

The regulation is effectuated by two thyristors connected in antiparallel in one of the feeder lines of the mains. The control voltage for these thyristors is derived from the mains voltage so that a fluctuation of the latter results in a variation of the moment of ignition of the thyristors. In general such a grid control requires an amplifier to obtain sufficient driving effect. The need for a simpler and cheaper method has led to the development of the circuit given in Fig. 4.1.

The left part of the diagram consists of a rectifying circuit in which R_1 and C_1 have such low values that the voltage at R_1 is almost sawtooth-shaped. During the intervals of conduction of S_1 the full

secondary voltage of the mains transformer stands across R_1 . The capacitor C_2 will, therefore, be charged via S_2 to the peak value of V_{sec} . Part of the voltage at C_2 is kept constant by the reference tube T_1 . Since the polarity of the sawtooth voltage at R_1 is such that the upper side of the resistor is positive with respect to the lower side, the a.c. voltage at the tapping is negative with respect to point B. It can further easily be seen from the figure that the d.c. potential at the tapping of R_1 is positive with respect to B. The output voltage between A and B is therefore the sum of a positive d.c. voltage and a negative-going sawtooth voltage (see Fig. 4.2). Variation of the tapping ratio of R_1 does not influence the d.c. voltage between A and B but it does influence the amplitude of the sawtooth voltage at the output terminals A-B.

The controlling action of the circuit can be seen from Fig. 4.2. In this figure the anode voltage of the controlled thyatron (Th in fig. 4.1) is indicated by V_a . The d.c. component of the output voltage of the control circuit is represented by $V_{g=}$ and the sawtooth-shaped component by $V_{g\sim}$.

The intersection P of $V_{g\sim}$ with the critical control characteristic determines the moment of ignition of the thyatron. When the mains voltage increases the amplitude of the sawtooth voltage increases e.g. to $V_{g'\sim}$, whereas $V_{g=}$ is kept constant by T_1 . Consequently the moment of ignition is delayed from P to Q , so that the average value of the

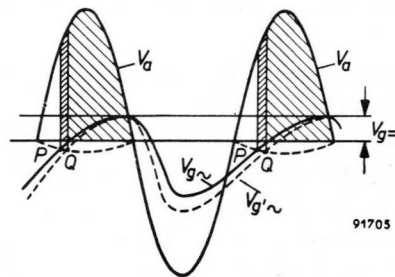


Fig. 4.2. Control voltage produced by the circuit given in Fig. 4.1.

output voltage and current decreases. Variations in the mains voltage are thus counteracted by the stabilization circuit. The moment of ignition can be adjusted by means of the potentiometer R_1 .

An even better stabilization can be obtained by feeding back the output voltage of the controlled thyatron to the input of the control unit. A simplified diagram of such a circuit is shown in Fig. 4.3. If it is supposed that the thyatron Th_1 is conducting, almost the entire mains voltage is across the primary of the transformer Tr_1 . In the control unit a sawtooth and a d.c. voltage are produced as described above. The intersection of the sawtooth voltage and the critical control voltage of the thyatron Th_2 determines the moment of ignition:

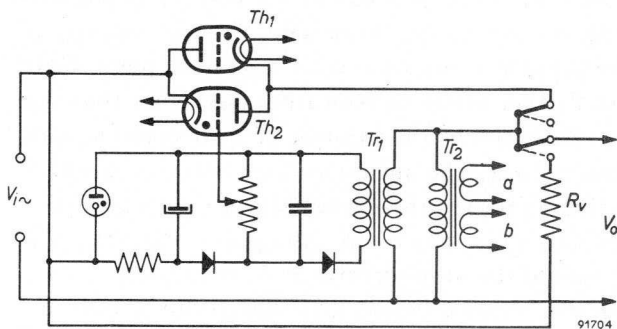


Fig. 4.3. Circuit in which stabilized output voltage is fed back to the input of the control unit.

For the operation of the circuit it is necessary that the primary of Tr_1 is connected directly to the mains prior to the thyatrons being put into operation. Across the output of the control circuit a suitable control voltage will then be present, so that the thyatrons will be controlled from the very moment of switching-on. The switch which must provide the change over of the primary of Tr_1 may be combined with the switch which takes care of a suitable pre-heating time of the cathodes of the thyatron (transformer Tr_2). The circuitry is represented in Fig. 4.3 for one control unit. A resistor R_v must be provided between the switch and the mains to compensate the voltage difference between the mains and V_o .

Fig. 4.4 shows a circuit which actually has been tested. The primary of the transformer has been connected to the mains (method A) and the control voltages of both identical circuits have been applied to two PL 105 thyatrons in anti-parallel. In Fig. 4.5 the output voltage V_o of this circuit has been plotted at three different settings of R_1 and various values of the mains voltage (drawn lines). The same measurements have been carried out with the same control

circuit the input of which was, however, connected between the output of the thyatrons and one feeder of the mains (cf. Fig. 4.3, method B). With these measurements the potentiometer has been so adjusted that the output voltage V_o which was ob-

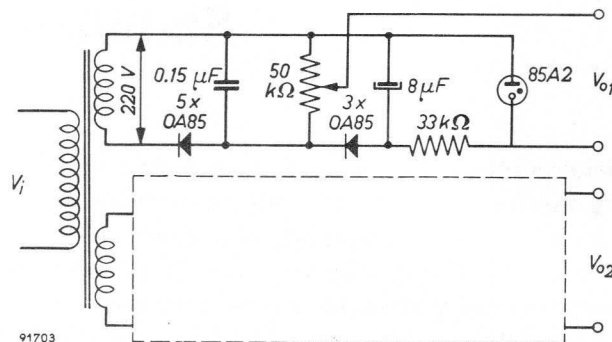


Fig. 4.4. Measuring circuit.

tained at a mains voltage of about 220 V, was equal to that measured with method A. The results of the measurements with method B are represented by the dashed lines in Fig. 4.5. The curves reveal that the stabilization obtained with method B is considerably better than with method A. With the former method a particularly good stabilization is obtained

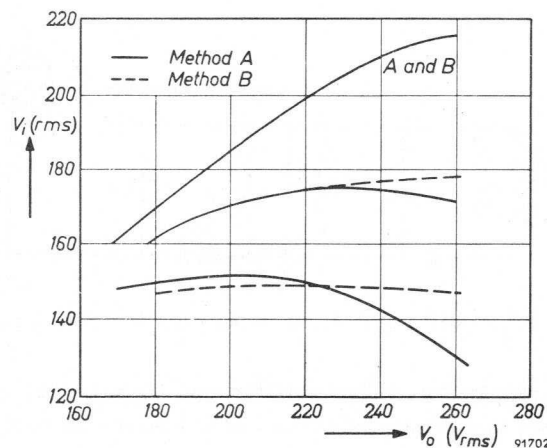


Fig. 4.5. Output V_o of measuring circuit as function of the input voltage V_i . For explanation of curves: see text.

when R_1 is so adjusted that at a mains voltage of 220 V the output V_o amounts to 150 V; a fluctuation of $\pm 20\%$ in the mains voltage is reduced to $< 2\%$ in the output voltage.

The circuits may be used in combination with almost every type of thyatron. Below a table is given of a number of thyatrons and the power which can be stabilized by two tubes connected in anti-parallel.

Thyratron type	Maximum stabilized power in kVA	
	with 220 V \sim supply	with 380 V \sim supply
PL2D21	0.042	0.075
PL 5557	0.21	0.4
PL 5559	1.1	2.0
PL 5544	1.4	2.5
PL 5545	2.8	5.0
PL 105	2.8	5.0
PL 255	5.6	10.0
PL 260	11.2	20.0
PL 6755	1.6	2.8

Practical circuit

A circuit will be described for stabilization of the heater voltage and current of a large transmitting tube (TBL 12/25; $V_f = 8\text{ V}$, $I_f = 100\text{ A}$).

When the filament of such a large tube is cold, its resistance is so low that an inadmissibly large current would flow when the full heater voltage was applied at once. The high current peak might then cause mechanical damage to the filament. The heater voltage is therefore gradually increased to its full value; the increase may extend over a period of 25–50 cycles of the heater voltage with the TBL 12/25.

Fig. 4.6 shows the stabilizing circuit in which provisions have been made for delaying the warming up period of the filament. For that purpose the voltage reference tubes T_1 and T_2 have been shunted by an RC-filter. When the mains is applied to the circuit the relay Rel_1 is in the position as drawn in the diagram, so that the capacitors C_1 and C_2 are short-circuited by the low resistances of R_3 and R_4 . The d.c. component of the control voltage being equal to the voltage at C_1 and C_2 , the thyratrons cannot ignite due to the low value of the d.c. voltage at their grids. When the relay Rel_1 is opened the voltage at C_1 and C_2 gradually increases to the operating voltage of T_1 resp. T_2 ; the increase depends on the RC-constant RC_1 resp. RC_2 . The thyratrons start to ignite at a large ignition angle, after which this angle becomes gradually smaller as the d.c. voltages at C_1 and C_2 become larger. The heater voltage and current of the tubes which are stabilized by the thyratrons will consequently also gradually increase until the full heating power is applied when the voltages at C_1 and C_2 are equal to the operating voltage of T_1 and T_2 .

The operation of the entire stabilization circuit is as follows. When the mains switch is closed the filaments of the thyratrons are heated up via the transformer Tr_2 . In series with the primary of Tr_2 a relay tube T_5 has been inserted. This tube provides a heating time of about 1 min for the thyatron heaters. After this period the relays Rel_1 and Rel_2 come into action. The relay Rel_2 disconnects the relay tube from the mains and the filament transformer Tr_2 is connected directly to the mains. The relay Rel_1 in-

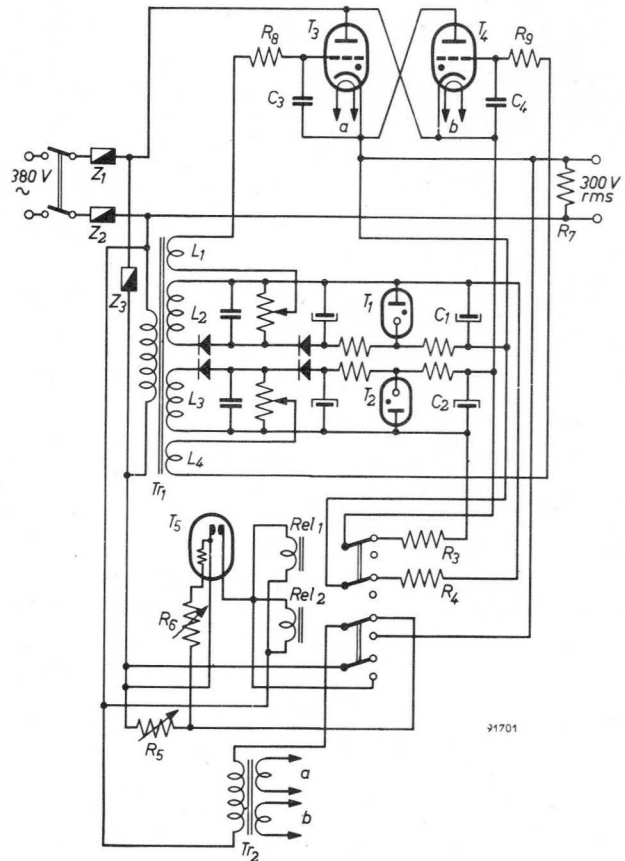


Fig. 4.6. Complete stabilizing circuit for feeding the filament of a large transmitting tube.

- $R_1 = R_2 = 33\text{ k}\Omega, 1\text{ W}$
- $R_3 = R_4 = 100\ \Omega, 1\text{ W}$
- $R_5 = 500\ \Omega, 40\text{ W, variable}$
- $R_6 = 1000\ \Omega, 10\text{ W, variable}$
- $R_7 = 10\text{ k}\Omega, 10\text{ W}$
- $R_8 = R_9 = 47\text{ k}\Omega, 1\text{ W}$
- $C_1 = C_2 = 25\ \mu\text{F}$
- $C_3 = C_4 = 22000\ \text{pF}$
- $Z_1 = Z_2 = \text{fuse } 6\text{ A}$
- $Z_3 = \text{fuse } 2\text{ A}$
- $T_1 = T_3 = 85\text{A2}$
- $T_2 = T_4 = \text{PL } 6755$
- $T_5 = \text{bimetal relay } 4152.$
- $Tr_1 = \text{mains transformer } 380/2 \times 220/2 \times 5\text{ V}_{\text{rms}}$
- $Tr_2 = \text{heater current transformer } 300/2 \times 2.5\text{ V}_{\text{rms}}.$

For the remaining parts: see Fig. 4.4.

interrupts the shunts of the capacitors C_1 and C_2 so that the output voltage of the circuit will gradually increase as described above. When the mains is switched on, control voltages are produced in the control circuits after one or more cycles. Since, however, the mains voltage is applied instantaneously to the thyratrons full anode current would flow in these tubes until a control voltage was built up. Therefore

an additional small negative bias is applied to the tubes by means of a sinusoidal voltage of about $5 V_{\text{rms}}$, which has an opposed phase compared to the anode voltage of the thyratrons. These voltages are derived from the windings L_1 and L_4 of the transformer Tr_1 . The presence of this bias influences the stabilizing action of the thyratrons to a negligible extent only.

Electronic control of small spot welders

Fig. 5.1 shows the circuit of an apparatus for controlling small spot welders. Two thyratrons T_1 and T_2 connected in anti-parallel are incorporated in the primary circuit of the welding transformer Tr_1 . Thyratrons type PL 105 are used for this purpose; when they are connected in anti-parallel, they can supply a current with an r.m.s. value of 55 A at a duty cycle of less than 10%.

In the control grid circuit of these tubes the secondary windings of a peaking transformer Tr_3 (type No. 84590) and two direct voltage sources for providing the negative grid bias are included. The primary of Tr_3 is connected to the output of a push-pull amplifier equipped with two tubes E80L. The control voltage for these tubes is taken from the resistors R_5 and R_6 shunted across the output of a phase-shifting network. Tr_4 is a normal push-pull output transformer for a power of 4 W, having a primary impedance of $2 \times 7 \text{ k}\Omega$ at 50 c/s and a transformer ratio of $2 \times 2 : 1.5$. The variable resistor R_{17} of the phase-shifting network renders it possible to shift the control voltage with respect to the mains voltage almost from 10° to 170° . The phase angles of the pulses at the secondaries of Tr_3 vary accordingly, so that the point at which the thyratrons are ignited each half cycle can be delayed. In this way it is possible to adjust the welding current as shown in the diagram of Fig. 5.2.

For adjusting the welding time a special timer equipped with the thyatron T_3 (PL2D21) has been provided. During the off time this tube is conducting, so that a voltage drop of 50 to 70 V is produced across R_{13} ; this voltage drop is used for biasing the grids of V_1 and V_2 , so that these tubes are completely cut off. A voltage drop is, moreover, produced across $R_{15} + R_{16}$, so that C_{10} is charged, and a nega-

tive control-grid voltage is applied to the thyatron T_3 ; this tube is, however, not extinguished, since it is d.c. fed. For extinguishing this tube its anode circuit must be interrupted during a few milliseconds by means of the pedal switch FS , after which C_{10} will be discharged via R_{15} and R_{16} . When the voltage across C_{10} has dropped to approximately 2 V, T_3 will re-ignite, the welding time thus being termin-

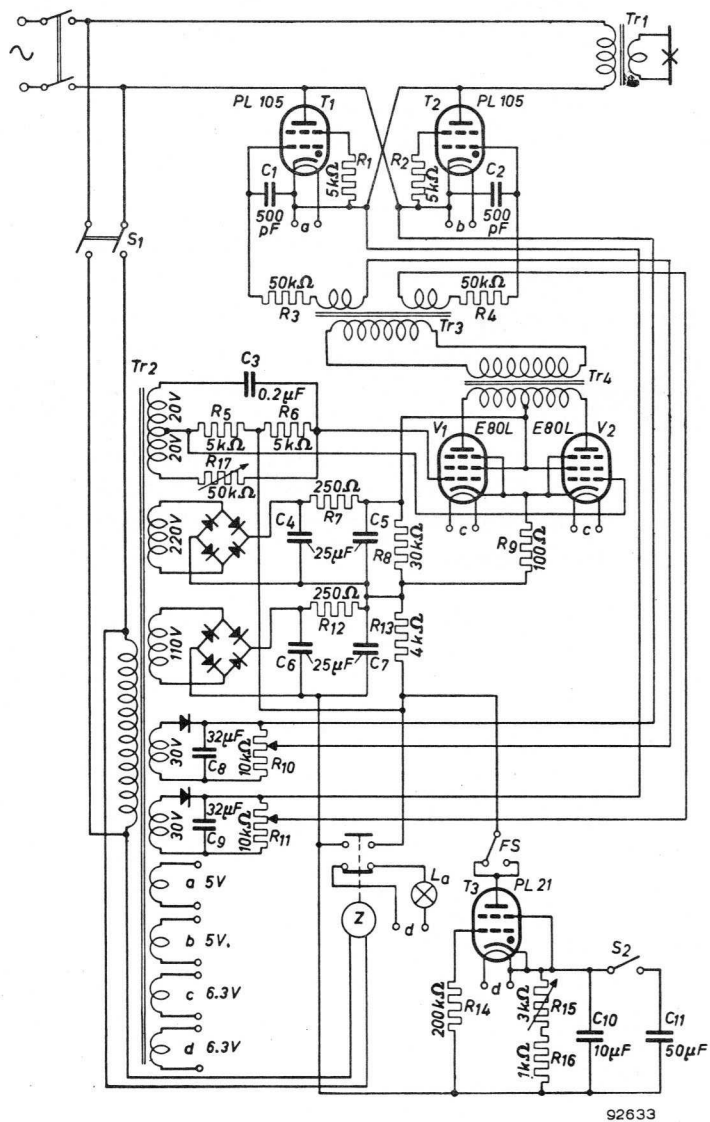


Fig. 5.1. Electronic control device for small spot welders.

ated. The duration of this time can be varied within certain limits by means of R_{15} . With the component values indicated in the circuit diagram, welding times ranging from 0.02 sec to 0.12 sec can be obtained. By means of S_2 the capacitor C_{11} can be shunted across C_{10} to extend the range from approximately 0.12 sec to 0.75 sec.

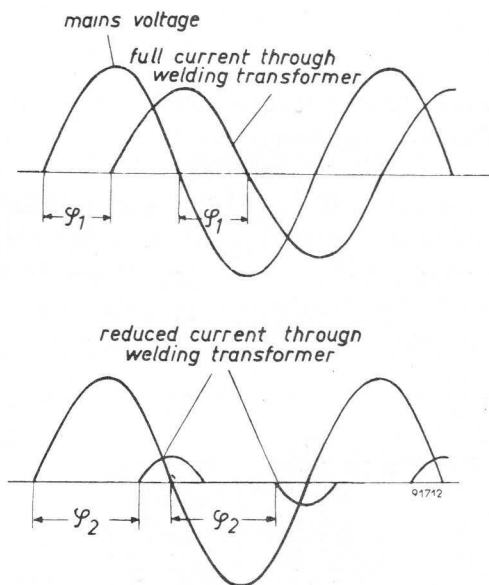


Fig. 5.2. Controlling the current by varying the firing angle of the thyratrons.

The apparatus can be rendered suitable for large powers by using thyratrons PL 260 instead of thyratrons PL 105. The maximum permissible current flowing through the tubes connected in anti-parallel then has an r.m.s. value of 200 A at a maximum duty cycle of 10%, as shown by the characteristics of Fig. 5.3. For a given adjustment the duty cycle is given by the relation:

$$\text{duty cycle} = \frac{T}{t_o} \cdot 100\%$$

in which T represents the duration of the welding time and t_o the averaging time of the tubes employed. For the tubes PL 5559, PL 105 and PL 255 this time is 5 sec at a duty cycle from 0 to 50%, and 15 sec at a duty cycle from 50 to 100%.

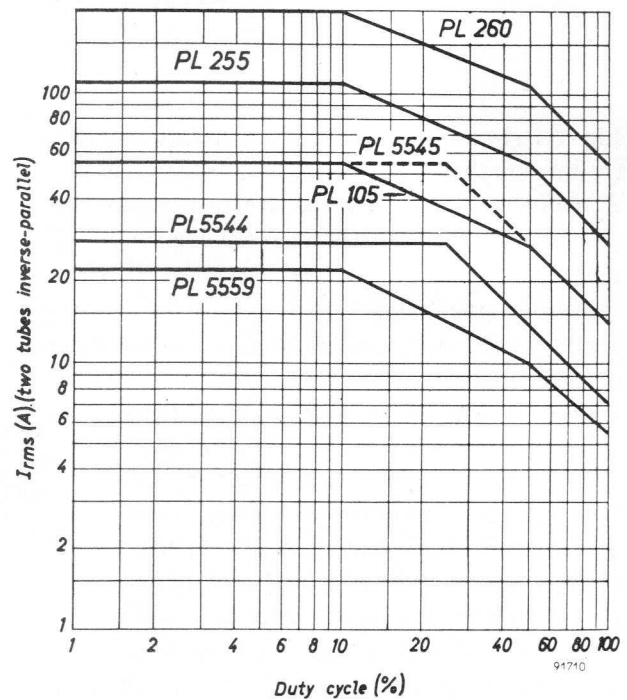


Fig. 5.3. Power characteristics (welding current as function of the duty cycle) of different types of thyatron in anti-parallel (two tubes).

Consequently, a current with an r.m.s. value, for example 110 A, can be supplied by two tubes PL 255 at a maximum welding time of 0.5 sec followed by an off time of at least 4.5 sec. With PL 105 thyratrons a current with an r.m.s. value of 55 A is permissible during only 0.5 sec at a maximum duty cycle of 10%.

Electronic dimming of fluorescent lamps

Another example of the growing use of electronic tubes in a wide field of applications is the dimming of lamps. For example in stage lighting and the illumination of auditoriums in theatres, cinemas and the like. Hitherto, variable series resistors have usually been employed for dimming incandescent lamps, as shown in Fig. 6.1. However, this method is

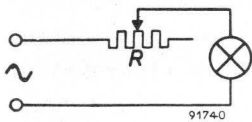


Fig. 6.1. Dimming an incandescent lamp by means of a variable resistor.

uneconomic if heavy loads have to be controlled, because of the losses in the resistor; saturable-core reactors are therefore often preferred (see Fig. 6.2).

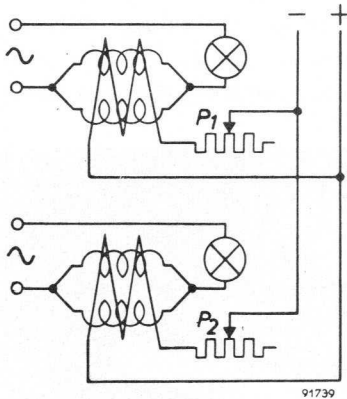


Fig. 6.2. Dimming by means of saturable core reactors.

By adjusting the premagnetisation the permeability and thus the a.c. resistance of the reactor may be varied. The range of adjustment is not very large, however, and furthermore a rather poor power factor has to be accepted. Another method of dimming is to use a variable voltage transformer (Fig. 6.3) which will be preferred when large loads have to be

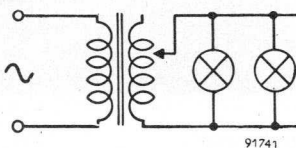


Fig. 6.3. Dimming by means of a variable voltage transformer.

controlled; but the controlling process then requires complex mechanical equipment or a special servo motor.

For dimming incandescent lamps one of the methods described above may be used, but they are all quite unsuitable for controlling fluorescent lamps. Fluorescent lighting makes use of a gas discharge, the ignition voltage of which is comparatively high, so that dimming over a wide range by varying the

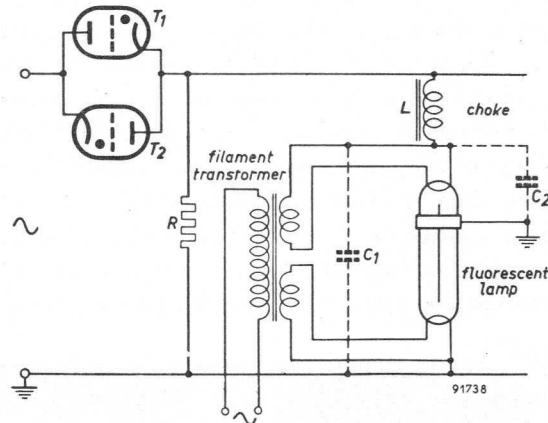


Fig. 6.4. Dimming a fluorescent lamp by means of two inverse-parallel connected thyratrons.

supply voltage becomes difficult. However, a solution is found by using two thyratrons connected in inverse parallel, the ignition points of which are shifted in phase.

A typical circuit is shown in Fig. 6.4. In this arrangement an alternating current, the value of which can be varied by grid control flows through the tubes and the load. The latter consists of the fluorescent lamp in series with a choke. The presence of the choke is essential for the correct operation of the circuit, since its inductance causes a certain delay of the lamp current, and thus of the voltage across the lamp, with respect to the mains voltage. Since the power factor of the choke is approximately 0.5, the voltage across the lamp is phase-shifted by about 60 degrees with respect to the mains voltage.

As will be seen from Fig. 6.5, in these circumstances

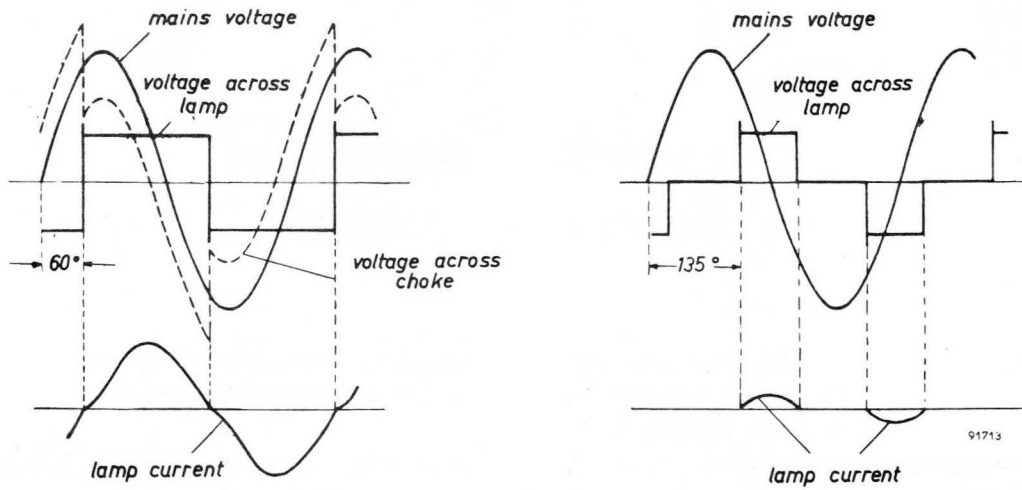


Fig. 6.5. Voltages and currents in the circuit of Fig. 6.4. for different firing angles.

the ignition voltage of the lamp is smaller than the instantaneous value of the mains voltage, so that ignition can take place without difficulty. When the thyristors are ignited with a firing angle of 60 degrees, the full current will still flow through the lamp. When the firing angle is increased by means of grid control up to 135 degrees, the lamp current falls almost to zero (see Fig. 6.5). Nevertheless, ignition of the lamp can still occur under this condition, since the instantaneous value of the mains supply voltage for $\varphi = 135^\circ$ is still about 220 volts if a mains voltage of 220 volts r.m.s. is assumed. Moreover, the voltage $V_{\max} \cdot \sin \varphi$ which, after igni-

tion of a thyristor, is suddenly applied to the series connection of lamp and choke, excites an oscillating circuit consisting of the choke L and the capacitance C_1 appearing between the ignition electrodes and between the filament transformer windings connected thereto. Thus a momentary voltage surge appears across the lamp, and facilitates ignition. Finally, the ignition voltage of the lamp can be reduced by applying a longitudinal metallic strip, painted along the glass tube but not reaching to the ignition electrodes. A voltage difference occurring between these electrodes will now be concentrated at the small gaps between the ignition electrodes and

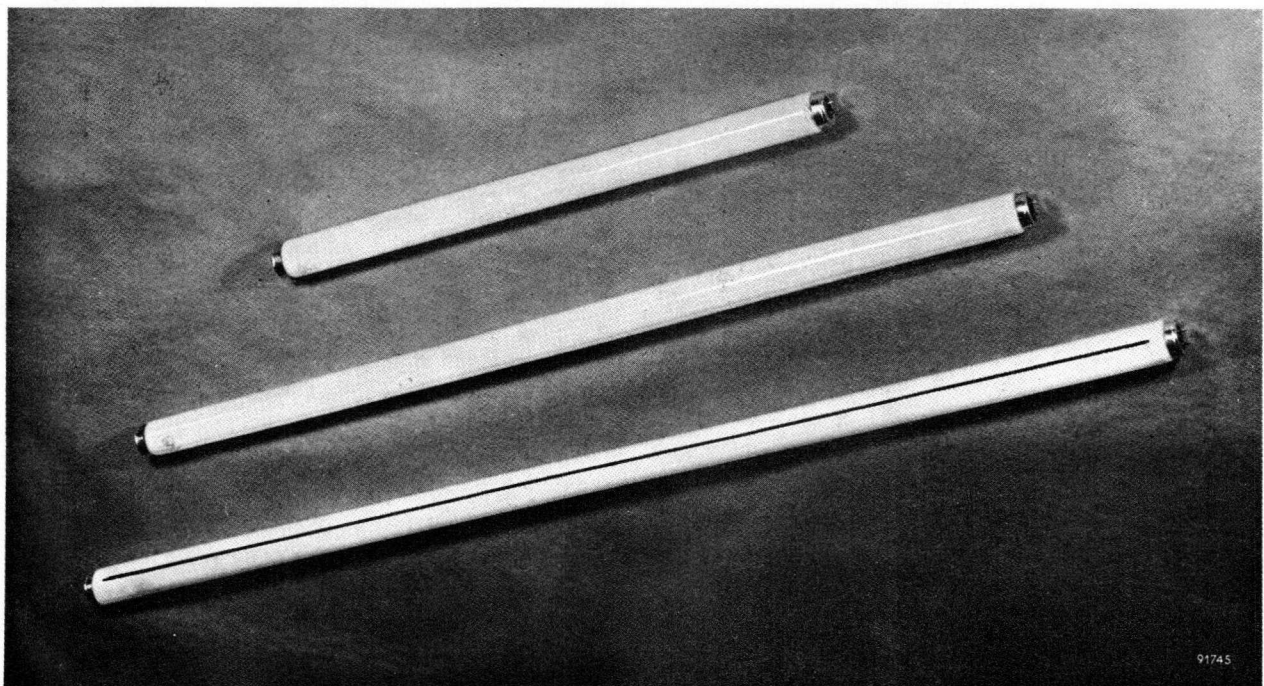


Fig. 6.6. Fluorescent lamps, one of them equipped with a longitudinal strip.

the ends of the strip. The field strength near the electrodes is thereby increased, and the ignition voltage is consequently reduced.

Fig. 6.6 shows several fluorescent lamps, one of them being provided with a longitudinal strip. If the strip is earthed by a thin metal band some 3 mm wide and placed round the glass tube at the non-earthed side of the lamp (see Fig. 6.4), the ignition voltage now appears across the capacitance C_2 formed by the strip and the non-earthed electrode and the gap

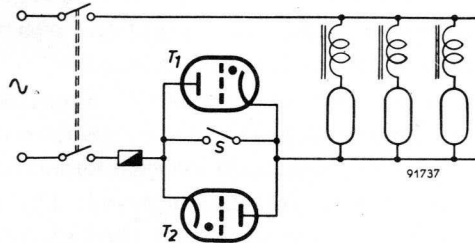


Fig. 6.7. Simultaneous dimming of several fluorescent lamps.

between them. By this method ignition of the lamp is facilitated so that the lamp will operate at currents down to about one milliamperes without flickering. Thus very gradual dimming is possible over the whole range down to the point at which the current may be interrupted without the spectators being aware.

Simultaneous control of several fluorescent lamps is possible by connecting them in parallel, a separate choke being provided for each lamp as shown in Fig. 6.7. The thermal starter switch normally used is omitted, but the filaments of both electrodes of each lamp are fed from separate filament transformers in

order to maintain the necessary temperature of the electrodes at reduced lamp current. Since the electrodes are self-heated by ionic bombardment at full current, it is recommended that the filament heating is reduced as the lamp current is increased.

It should be pointed out that a dimming device using two thyratrons connected in inverse parallel is suitable not only for fluorescent lamps, but also for high-voltage neon illumination. In this case, however, the device must be connected in the primary circuit of the high-voltage transformer.

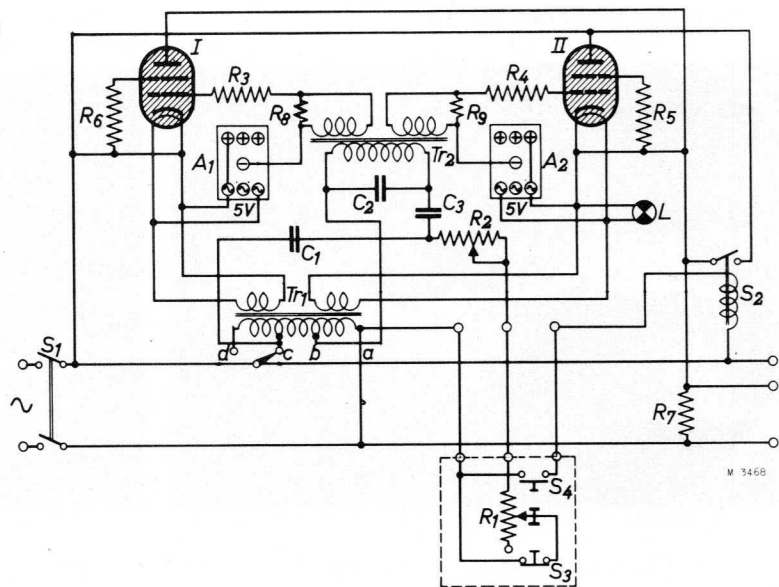
Electronic circuit for dimming fluorescent lamps

In the dimming installation according to the circuit diagram given in Fig. 6.8 the negative biases for the control grids of the thyratrons are derived from auxiliary ignition units type 1289/03. These units are fed from the filament voltage windings for the corresponding thyratrons. Only one transformer Tr_1 is required, this being provided with primary taps for the phase-shifting network.

In the circuit diagram two microswitches S_3 and S_4 are indicated, by means of which it is possible either to interrupt (S_3) the primary of the peaking transformer Tr_2 so that the tubes remain extinguished (black-out) or to operate (S_4) an electromagnetic contactor S_2 , which short-circuits the thyratrons so that the illumination can be switched on immediately after the master switch S_1 has been closed. With S_4 the thyratrons can also be short-circuited after the luminous intensity has been increased to the maximum, in which case the thyratrons are obviously no longer required. The

Fig. 6.8. Complete circuit of an electronic dimming device.

- $R_1 = 2 \text{ k}\Omega$, 100 W variable
- $R_2 = 470 \Omega$, 10 W semi-variable
- $R_3 = R_4 = 18 \text{ k}\Omega$, 1 W
- $R_5 = R_6 = 10 \text{ k}\Omega$, 1 W
- $R_7 = 10 \text{ k}\Omega$, 10 W
- $R_8 = 150 \text{ k}\Omega$, 1 W
- $R_9 = 150 \text{ k}\Omega$, 1 W
- $C_1 = 2 \mu\text{F}$, 5000 V
- $C_2 = C_3 = 0.5 \mu\text{F}$, 1000 V
- $I = II = \text{PL } 105$
- $L =$ pilot lamp, type 6913 N
- $Tr_1 =$ filament transformer
prim: 110 V, 110 V, 160 V
sec.: $2 \times 5 \text{ V}$, 11 A.
- $Tr_2 =$ peaking transformer, type 84590
- $A_1 = A_2 =$ control units, type 1289/03
- $S_1 =$ double pole switch
- $S_2 =$ electromagnetic contactor
15 A, 220 V coil
- $S_3 = S_4 =$ microswitch, single-pole
double-throw.



microswitches may be operated by means of a notch on the spindle of the potentiometer.

For remote control it is possible to mount the potentiometer in a separate control unit connected to the dimming installation by means of a three-core cable.

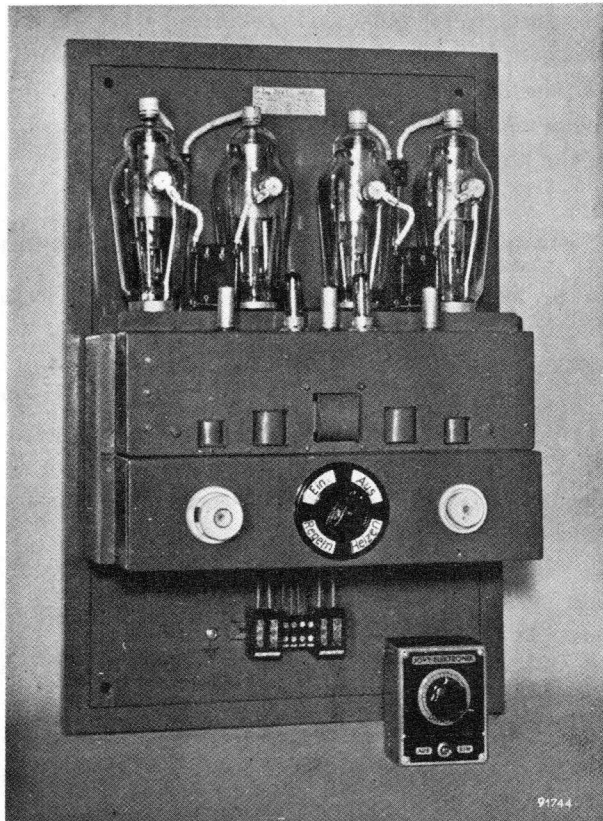
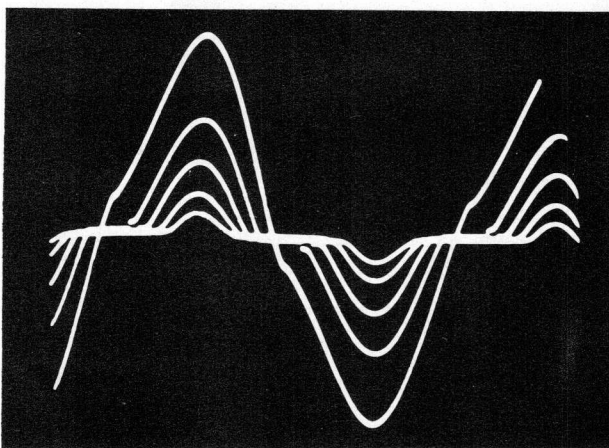
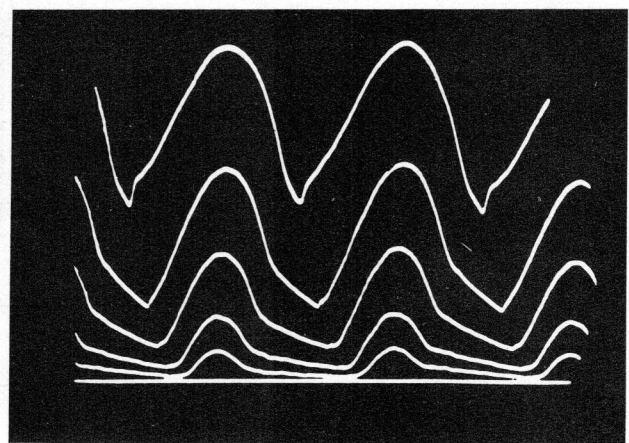


Fig. 6.9. Electronic dimming device for 6.4 kVA output. (Courtesy of Dr. Ing. Jovy, Leer, Ost-Friesland, Germany.)

It is clear that instead of a RC -network for controlling the thyratrons, also a combination of a resistor and a transductor can be used.



a



b

Fig. 6.10. Lamp current (a) and light intensity (b) plotted with the firing angle as parameter.

An example of a typical dimming equipment is illustrated in Fig. 6.9 which shows an apparatus for a load of 6.4 kVA.

The oscillograms reproduced in Fig. 6.10 show the curves of lamp current and light intensity of four fluorescent lamps. The lamp current was adjusted to 1200, 600, 300, 150 and 75 milliamperes by an electronic dimming device.

Not only fluorescent lamps but also incandescent lamps may be dimmed by the method described above. However, because of the low cold resistance of incandescent lamps, due precautions with regard to current limitation must be taken.

The maximum number of lamps which may be connected to a dimming device of the type described is governed by the maximum average anode current rating I_a of the thyratrons employed. The r.m.s. value of the alternating current through a pair of inverse-parallel connected thyratrons is:

$$I = \frac{\pi}{\sqrt{2}} \cdot I_a,$$

and the apparent output power:

$$P = \frac{\pi I_a V}{\sqrt{2}},$$

where V is the supply voltage. The power losses caused by the arc voltage drop of the tubes are neglected.

The useful output power is then:

$$P = \frac{\pi I_a V}{\sqrt{2}} \cdot \cos \varphi$$

If the power consumption of one fluorescent lamp is p , and the power losses in the choke q , the number of lamps which may be connected is:

$$n = \frac{\pi I_a V}{(p+q)\sqrt{2}} \cdot \cos \varphi$$

For example, if:

$$\begin{aligned} I_a &= 6.4 \text{ amperes,} \\ V &= 220 \text{ volts,} \\ \cos \varphi &= 0.5, \\ p &= 40 \text{ watts,} \\ q &= 9 \text{ watts,} \end{aligned}$$

then the number of lamps which may be connected is:

$$n = \frac{3.14 \times 6.4 \times 220 \times 0.5}{49 \times 1.41} = 32 \text{ lamps}$$

Radio-interference

As might be expected in view of the greatly distorted wave-form of the current flowing through the lamps, there is some risk of interference with radio-reception in the neighbourhood of the dimming apparatus. This interference can reach the receiver in two ways, namely:

- (1) via the mains,
- (2) by radiation from the wiring and lamps.

The first mentioned interference is the more serious one, especially in the case of a.c./d.c. receivers. It can, however, easily be suppressed by means of the mains filter shown in Fig. 6.11 which is suitable for dimming devices of the type illustrated in Fig. 6.8. In addition to this filter, a capacitor should be

shunted across the thyratrons. In general it will be advisable to mount the filter in the same enclosure as the dimming apparatus. The enclosure must be efficiently earthed by some other earth connection than that for the radio set.

Interference radiated from the wiring and the lamps must be suppressed by screening the whole of the

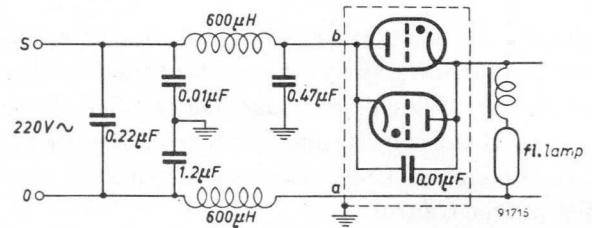


Fig. 6.11. Radio-interference suppression circuit.

wiring by running it in metal conduit. It is not advisable to install the radio set in the same room as the dimming apparatus. A screened aerial lead-in wire should be used in all cases.

The dimming installation described above is also suitable for controlling the temperature of electric ovens, furnaces etc., the temperature of which can then be adjusted by means of the potentiometer. It may further prove to be useful as a weld timer with heat control by varying the ignition point of the thyratrons. In that case the electromagnetic contactor can be left out.

Controlled three-phase rectifier

Below a rectifier will be described which combines a simple circuitry and a very constant output voltage with a negligible ripple voltage. The rectifier is shown in Fig. 7.1 and consists mainly of three tubes PL5557 in a three-phase single-wave rectifier and a circuit for voltage control.

The filter section consists of two LC-circuits. These circuits are so designed that the output voltage is independent of the load as much as possible even when the control circuit is inoperative. Therefore, a low-ohmic choke is required the inductance of which increases when the current through it decreases. Consequently an increase of the voltage at the following filter capacitor due to a lowering output current is prevented. The dependency of the the choke inductance of the current flowing through it is obtained by mounting the first choke without an air gap. The mains voltage stabilization is produced by vertical control of the three thyratrons. The required d.c. grid voltage is formed by the volt-

age difference between the output voltage and a reference voltage that is kept constant by means of stabilizing tubes. The transformers Tr_1 provide the required a.c. grid voltage and the heater voltage for each of the thyratrons. The primaries of these transformers are designed for 380 V to achieve the required phase shift of 90° between the anode voltages of the thyratrons and their grid voltages.

The output voltage of the rectifier can be varied by means of the potentiometer of $10\text{ k}\Omega$. To prevent hunting special filters have been provided in the feed back circuit of the output voltage and in the connecting circuit between the grids of the thyratrons and the reference circuit.

The control characteristics of the rectifier are represented in Fig. 7.2. It appears that in the range of the output current from 0.3 A to 1.5 A a very effective stabilization of the voltage is obtained.

Fig. 7.3 reveals that the ripple voltage at the maximum output current of 1.5 A is yet smaller than 1%.

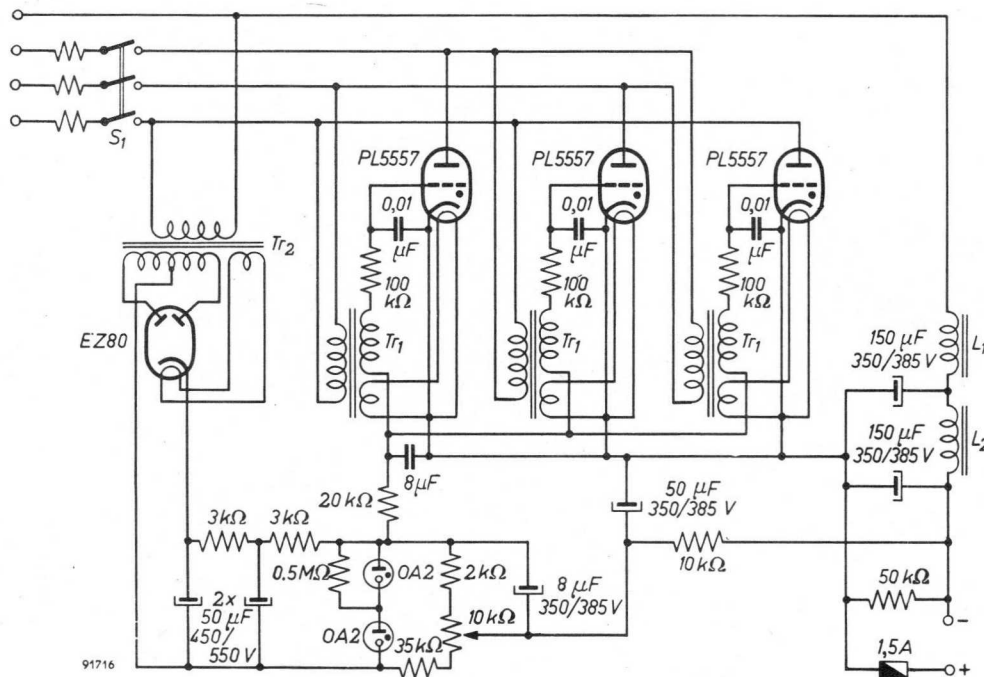


Fig. 7.1. Controlled three-phase rectifier (220 V — 1.5 A).

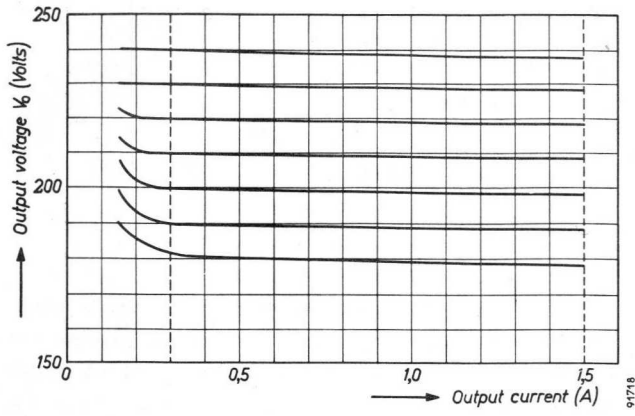
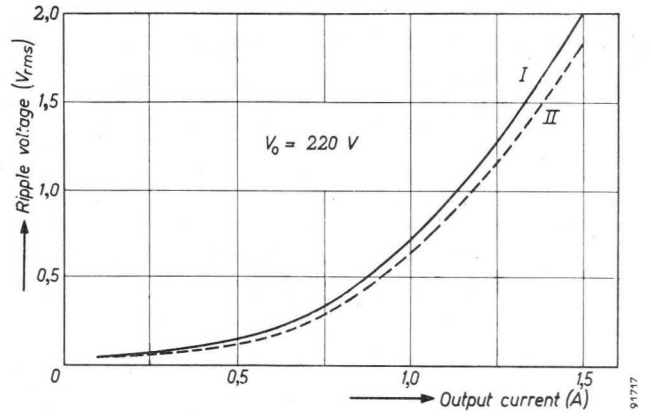


Fig. 7.2. Control characteristics of the rectifier.

Fig. 7.3. Ripple voltage of the rectifier as function of the output current, measured at $V_o = 220$ V.



A simplified electronic motor control system

Electronic control systems for d.c. motors consist basically of a grid-controlled rectifier to supply power to the armature, a smaller rectifier to supply field excitation, and a control circuit to control the power rectifier and sometimes the field rectifier also.

In the rectifiers, thyratrons are generally used for powers up to at least 20 h.p. The cost of such rectifiers varies according to the power output required and is therefore also roughly proportional to the cost of the motor. The power required to control the thyratrons is extremely small, and does not vary with their size. The cost of the control circuit thus becomes a progressively larger proportion of the total cost of the equipment towards the lower end of the power range.

It follows that the saving in cost due to a simplification of the control circuit will be more marked in low-powered equipment, and extends downwards the power range in which this type of equipment can be used economically. It is just in the lower range that the largest field of application for such equipment can be expected, so that simplification of the control circuit may help considerably to extend the use of electronic motor control.

Simplified control circuit

The simplified control circuit which is the basis of the control system described in this article, is shown in Fig. 8.1. It is designed to secure the greatest possible economy in tubes and circuit components, without sacrificing performance. A single amplifying tube is used working with a.c. on its anode, thus eliminating the need for a separate H.T. supply.

The circuit shown in Fig. 8.1 is arranged for controlling a bi-phase thyatron rectifier such as would generally be used for driving motors up to about 2 h.p. It can, however, be used equally well for multi-phase rectifiers as will be shown later.

The 90° lagging a.c. potentials for both thyratrons are derived from a phase-splitting bridge circuit

C_1, R_1, C_2, R_2 , which is supplied through a transformer winding from the same a.c. source as the thyatron anodes. By making $R = 1/\omega C$, a phase shift of 90° is obtained as shown in the vector diagram of Fig. 8.2. The points g_I and g_{II} (Fig. 8.1) are connected to the thyatron grids.

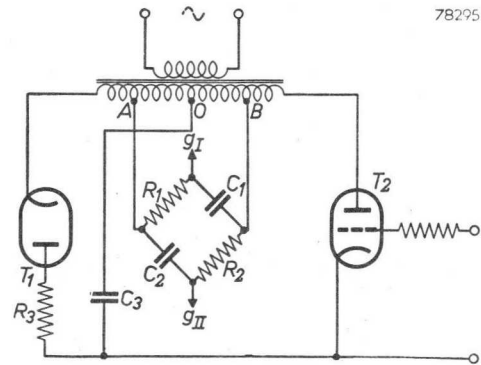


Fig. 8.1. Simplified control circuit for a two-phase thyatron rectifier. The points g_I and g_{II} are connected to the grids of the thyratrons, the anodes of which are supplied from the same a.c. source as the transformer.

The thyratrons are vertically controlled; the variable d.c. bias is developed across the capacitor C_3 and is controlled by the tube T_2 . When T_2 is non-conductive C_3 becomes charged via the diode T_1 and resistor R_3 , so that the upper end of C_3 becomes positive with respect to the lower end, and the firing angle of the thyratrons is reduced. As T_2 is made more conductive, the potential drop across R_3 increases and the d.c. potential across C_3 falls and re-

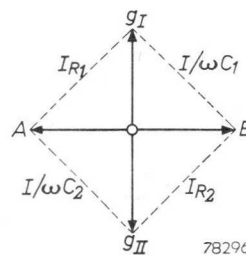


Fig. 8.2. Vector analysis of the phase-splitting bridge shown in Fig. 8.1.

verses, so that the firing angles of the thyratrons increase. In practice a large variation of the firing angles can be obtained with a variation of 1 V only on the grid of the control tube T_2 .

Speed regulating circuit

The complete motorspeed regulating circuit is shown in Fig. 8.5, in which the control circuit of Fig. 8.1 is incorporated. The voltage across the armature is taken as a measure for the motor speed, thus dispensing with the necessity of using a special tachometer.

The armature A of the motor is supplied via the thyratrons T_1 and T_4 and its field winding F via the rectifying tube T_5 . Part of the field voltage is derived from the potentiometer R_9 and applied to the cathode of the control tube T_3 . The grid of T_3 is connected to the positive side of the armature via a smooth-

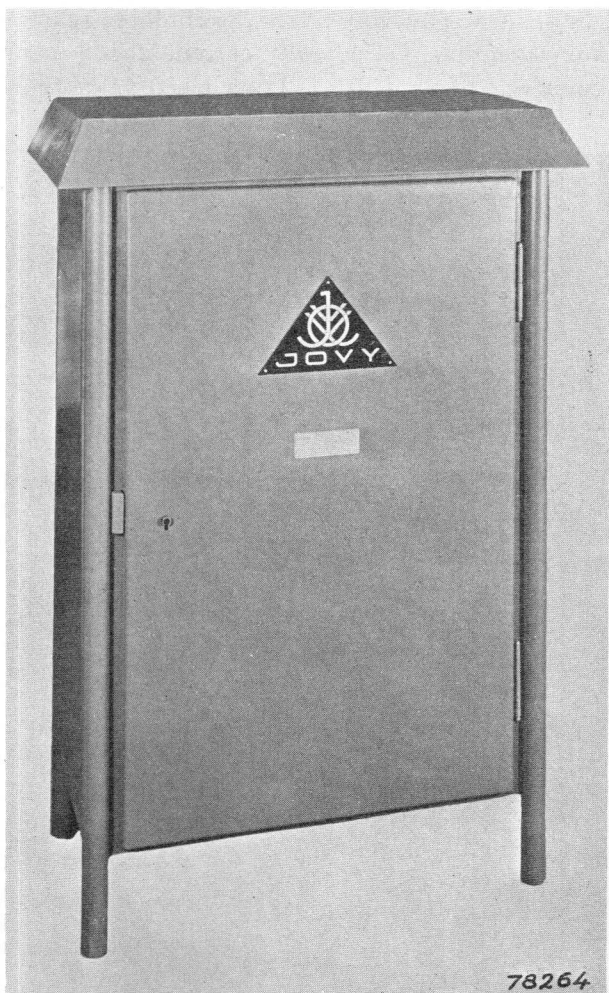


Fig. 8.3. Example of a motor control unit mounted in a cabinet. (Courtesy of Dr. Ing. Jovy, Leer, Ost-Friesland, Germany.)

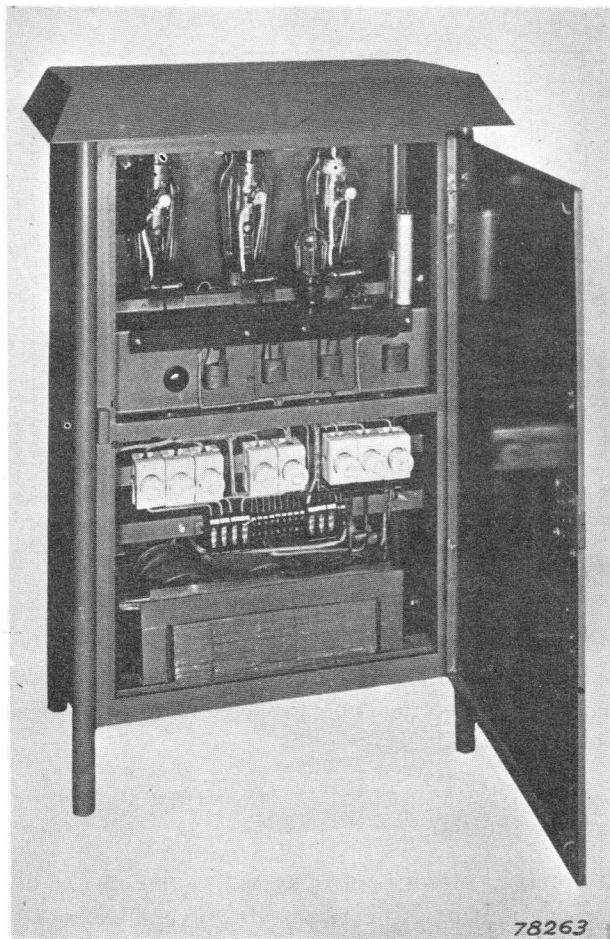


Fig. 8.4. Inside view of the cabinet of Fig. 8.3. (Courtesy of Dr. Ing. Jovy, Leer, Ost-Friesland, Germany.)

ing filter R_7, C_4 . When, therefore, the setting of R_9 is varied, the d.c. bias of T_3 varies accordingly. Consequently, the firing angles of the thyratrons and the speed of the motor will also be changed.

The mode of operation can be more clearly understood by considering the effects of variations of speed. If the motor is running at too low a speed, the armature voltage will be less than the portion of the field voltage that is derived from R_9 , thus applying negative bias to the control tube T_3 , and rendering it non-conductive. As described in the previous section, this "turns up" the thyratrons and the motor therefore tends to speed up.

If the motor is running too fast the opposite occurs; the tube T_3 receives a positive bias and "turns off" the thyratrons, causing the motor to slow down.

As previously mentioned, a smoothing filter is used in the grid circuit of T_3 to reduce the voltage fluctuations imposed on the grid. The capacitor C_3 must also be made sufficiently large to ensure balanced

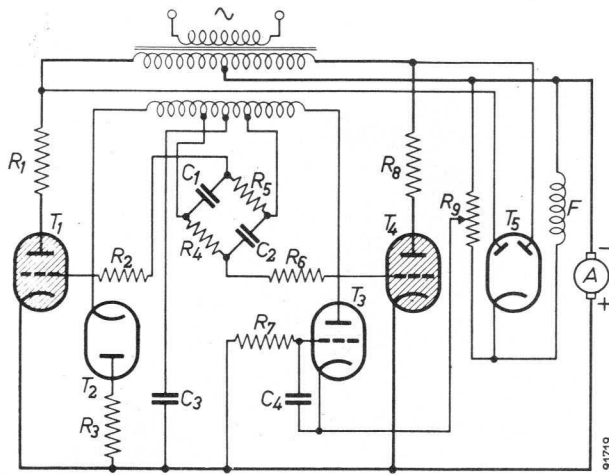


Fig. 8.5. Motor speed regulating circuit in which the control circuit of Fig. 8.1 is incorporated. T_1 and T_4 are thyratrons supplying the armature A , while the field coil F is fed by the rectifying tube T_5 .

working of the two thyratrons. The time delay thus introduced is in practice sufficient to prevent hunting or overshooting, and the system is in fact remarkably stable.

Current limiting

In practical motor control systems some means of current limiting is necessary to prevent excessive currents at starting, and to protect the thyratrons and the motor against overloads. A control circuit for this purpose is shown in Fig. 8.6. The current transformer precedes the rectifying tubes, this offering practical advantages.

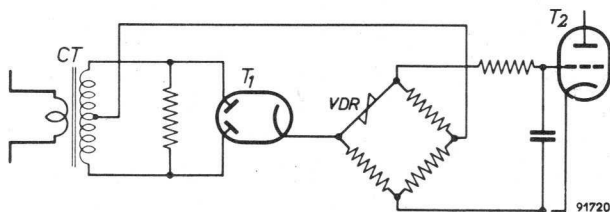


Fig. 8.6. Current-limiting control circuit. The voltage supplied by the current transformer CT is rectified by tube T_1 and applied to the bridge circuit one arm of which is formed by the non-linear resistor V.D.R.

The current transformer CT and rectifying tube T_1 generate a direct voltage proportional to the d.c. line current. This voltage is applied across a non-linear bridge to control a triode tube. Within the normal current range the bridge applies a negative bias to the tube which is thus held non-conductive, but when the maximum permissible current is reach-

ed the bias applied by the bridge tends to go positive and the tube becomes conductive.

By shunting the current control circuit of Fig. 8.6 across the speed control circuit of Fig. 8.5 so that the two control tubes work in parallel, the current-limiting circuit will take over control whenever the current flowing rises to a pre-set value, and it will prevent the current from exceeding this value.

In Fig. 8.6 the non-linear element of the bridge circuit is formed by a V.D.R. resistor. Other non-linear devices such as tungsten filament lamps or neon tubes can be considered. A V.D.R. resistor was chosen as having stable characteristics, a high degree of non-linearity, and no time lag in operation.

The rectified voltage applied to the bridge is not smoothed and therefore has the same waveform as the current flowing in the main circuit. A filter is provided in the grid circuit of the tube to reduce the a.c. component appearing at the grid. Because of the high conductivity of a V.D.R. resistor at peak voltages this arrangement tends to discriminate against bad waveforms, i.e. a peaky current in the main circuit will be limited to a lower mean value than

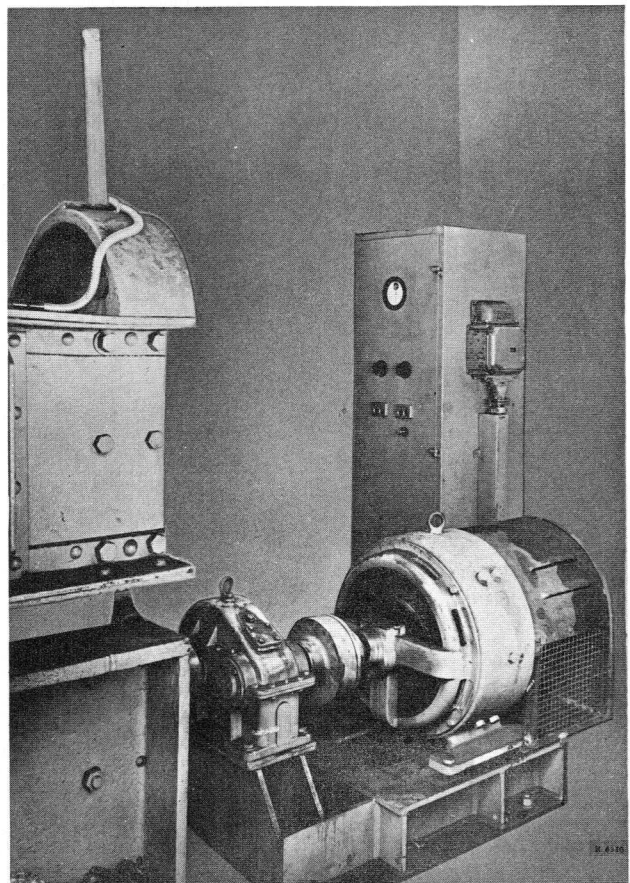


Fig. 8.7. D.c. motor with electronic control cabinet. (By courtesy of Degersfors, Järnverk, Sweden.)

a flat topped current. The current waveform tends to become worse, i.e. more peaky, at lower speeds when the thyratrons are working with a large firing angle, so that the above effect is desirable to protect the motor windings against overheating due to bad waveform.

IR-drop compensation

It has been assumed above, that the armature voltage is proportional to the motor speed. This is of course an approximation because of the IR -drop in the armature when under load. The control circuit in Fig. 8.5 is arranged to hold the armature voltage constant, and the speed of the motor therefore would tend to fall on load due to the increasing IR -drop. While this fall in speed is not generally enough to be a disadvantage at high speeds, it becomes progressively greater at lower speeds where the IR -drop becomes comparable with the total armature voltage. To obtain a reasonably level speed characteristic at low speeds it is therefore necessary to introduce IR -drop compensation by means of which

the armature voltage on load is increased by an amount equal to the internal IR -drop. This results in constant speed being held right up to the point at which the current limit comes in. A simple method of IR -drop compensation is described in the next section.

Complete motor control circuit

By adding the current limiting circuit of Fig. 8.6 to the speed control circuit of Fig. 8.5 and introducing IR -drop compensation and some other practical additions, the complete circuit of the simplified system is obtained as shown in Fig. 8.9.

The double-diode T_1 and the double triode T_2 performs the functions of speed and current control, as is described in the previous sections. A difference with the circuit of Fig. 8.5 is that the grid of the left-hand triode of T_2 is not connected directly to one side of the armature, but via a filter C_3R_6 and a potentiometer R_{10} . This circuit arrangement serves for the IR -drop compensation mentioned above.

The voltage across R_{10} is determined by the d.c. current flowing through the primary of the current transformer CT . This transformer has two primary windings, one connected in each thyatron anode circuit. This is preferred to a single primary winding in the a.c. line since it is not affected by changes in the primary tapping of Tr_2 (not shown). The secondary voltage is rectified by T_3 and used for current limiting and IR -drop compensation. The upper end of R_{10} is positive with respect to the slider, but the voltage between these two points varies with the armature current. When the armature current increases due to the motor being loaded, the voltage drop across R_{10} increases and the grid of the left-hand triode of T_2 becomes more negative. Consequently, the armature voltage increases so that the reduction of the speed, which would result from the increased load, is compensated. The slider of R_{10} is adjusted to obtain a level speed characteristic at low speeds and the compensation remains correct over the whole speed range. The delay circuit C_3R_6 serves to prevent instability which might otherwise result due to too rapid compensation action.

The field current also flows through the current transformer and thus serves to provide an initial current through the bridge. If no such provision was made the bridge would not produce any bias so long as the thyratrons are not fired. The current-limiting triode (right-hand section of T_2) would then be conducting, keeping the thyratrons extinguished. This

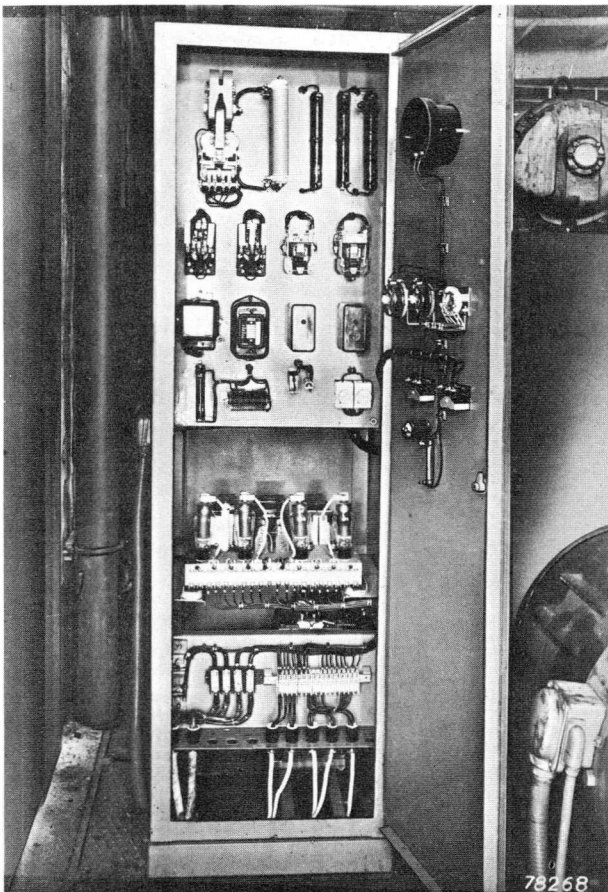


Fig. 8.8. Inside view of the cabinet of Fig. 8.7. (By courtesy of Degersfors, Järnverk, Sweden.)

arrangement moreover prevents the motor from starting until the field has built up. It serves as a protection against a fault in the field circuit, and also in preventing overshoot on starting motors whose field windings have a long time constant.

A relay *Rel* is used to open the armature and field circuits when the motor is stopped. On small motors it might be permissible to leave the field excited while stopped, but on larger machines this practice is liable to cause overheating. No difficulties have been experienced in switching the field circuit provided a suitable surge absorber such as a non-linear resistor

(*VDR*₂) or a neon tube is connected in the circuit to discharge the stored energy.

For small motors the tube *T*₆ can be an indirectly heated vacuum diode such as type GZ 34. The heating-up time of this tube is about the same as that of small thyratrons, and it will therefore serve to protect the thyratrons during the heating-up period since the relay *Rel* is energized through *T*₆, and cannot close until *T*₆ passes current.

On larger equipments *T*₆ must be a mercury-vapour tube and separate protection during the heating-up period must be provided by a time delay device.

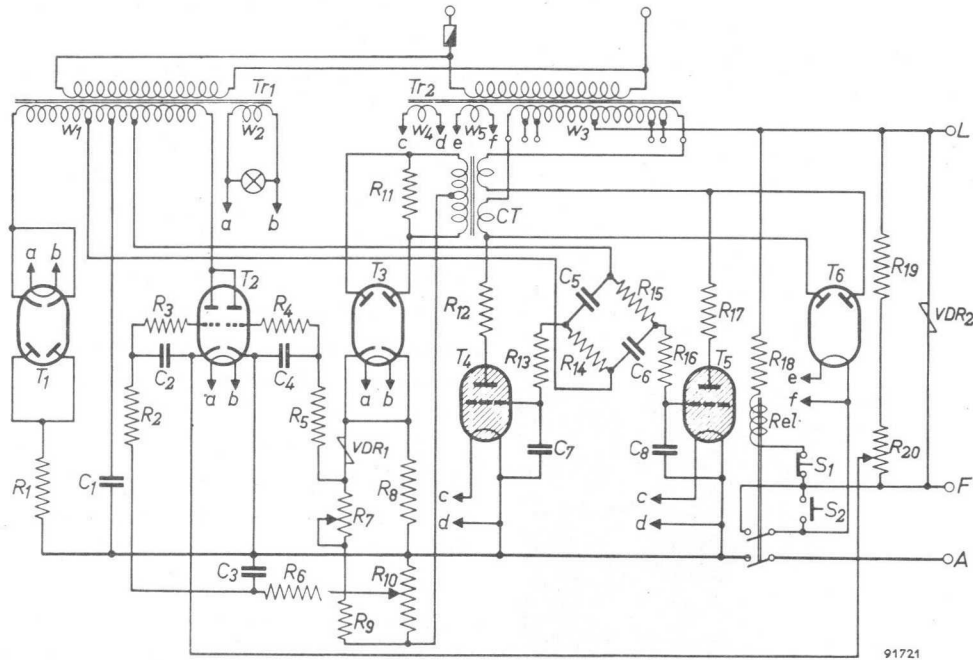


Fig. 8.9. Complete motor control circuit incorporating current limiting and *IR*-drop compensation. The armature is connected to terminals *A* and *L* and the field coil to terminals *F* and *L*. The motor is switched off by means of push button switch *S*₁ and switched on by means of switch *S*₂. The motor speed is controlled by means of potentiometer *R*₂₀ and the *IR*-drop compensation adjusted once and for all by means of potentiometer *R*₁₀.

COMPONENT VALUES

$R_1 = 47 \text{ k}\Omega, 1 \text{ W}$	$R_{19} = 560 \Omega, 1 \text{ W}$	$Tr_1 =$ auxiliary transformer with secondary windings w_1 for 150-30-0-30-150 V, 10 mA and w_2 for 6.3 V, 2 A;
$R_2 = 0.47 \text{ M}\Omega, 0.5 \text{ W}$	$R_{20} = 20 \text{ k}\Omega, 5 \text{ W}$	$Tr_2 =$ mains transformer with secondary windings w_3 for 325-300-275-0-275-300-325 V, 815 VA for rectified output of 1.25 A, w_4 for 2.5 V, 10 A and w_5 for 5 V, 2 A;
$R_3 = 100 \Omega, 0.5 \text{ W}$	$C_1 = 2 \mu\text{F}$	$CT =$ current transformer with two primary windings each to carry 1 A_{rms} and each having a ratio of 20:1 with the secondary designed for 150-0-150 V, 50 mA_{rms} ;
$R_4 = 100 \Omega, 0.5 \text{ W}$	$C_2 = 0.1 \mu\text{F}$	$Rel =$ telephone type relay with coil resistance of 2000 Ω and make contacts for 5 A and 1 A.
$R_5 = 0.47 \text{ M}\Omega, 0.5 \text{ W}$	$C_3 = 0.47 \mu\text{F}$	
$R_6 = 0.47 \text{ M}\Omega, 0.5 \text{ W}$	$C_4 = 0.1 \mu\text{F}$	
$R_7 = 10 \text{ k}\Omega, 1 \text{ W}$	$C_5 = 0.1 \mu\text{F}, 5\%$	
$R_8 = 10 \text{ k}\Omega, 1 \text{ W}$	$C_6 = 0.1 \mu\text{F}, 5\%$	
$R_9 = 4700 \Omega, 0.5 \text{ W}$	$C_7 = 4700 \text{ pF}$	
$R_{10} = 10 \text{ k}\Omega, 1 \text{ W}$	$C_8 = 4700 \text{ pF}$	
$R_{11} = 10 \text{ k}\Omega, 12 \text{ W}$	$T_1 = \text{EAA 91}$	
$R_{12} = 10 \Omega, 12 \text{ W}$	$T_2 = \text{E80CC}$	
$R_{13} = 0.1 \text{ M}\Omega, 0.5 \text{ W}$	$T_3 = \text{EAA 91}$	
$R_{14} = 33 \text{ k}\Omega, 0.5 \text{ W}, 5\%$	$T_4 = \text{PL 5557}$	
$R_{15} = 33 \text{ k}\Omega, 0.5 \text{ W}, 5\%$	$T_5 = \text{PL 5557}$	
$R_{16} = 0.1 \text{ M}\Omega, 0.5 \text{ W}$	$T_6 = \text{GZ 34}$	
$R_{17} = 10 \Omega, 12 \text{ W}$	$V.D.R_1 = V.D.R. 5 \text{ mA}$	
$R_{18} = 20 \text{ k}\Omega, 3 \text{ W}$	at 50 V	
	$V.D.R_2 = V.D.R. 1 \text{ mA}$	
	at 230 V	

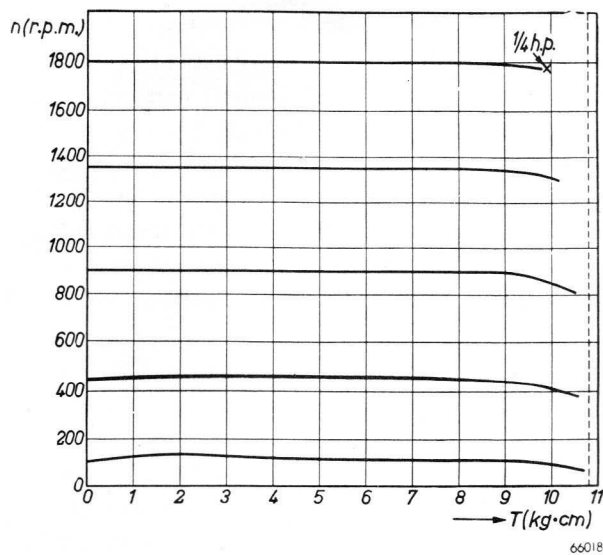


Fig. 8.10. Number of revolutions n of a 200 volt d.c. 1/4 h.p. motor (maximum speed 1800 r.p.m.) fed by the control circuit of Fig. 8.9 as a function of the torque T for different settings of the control knob R_{10} . The stalled torque is indicated by the broken line at the right.

An electronic time delay circuit has been extensively used for this purpose, and has proved very satisfactory.

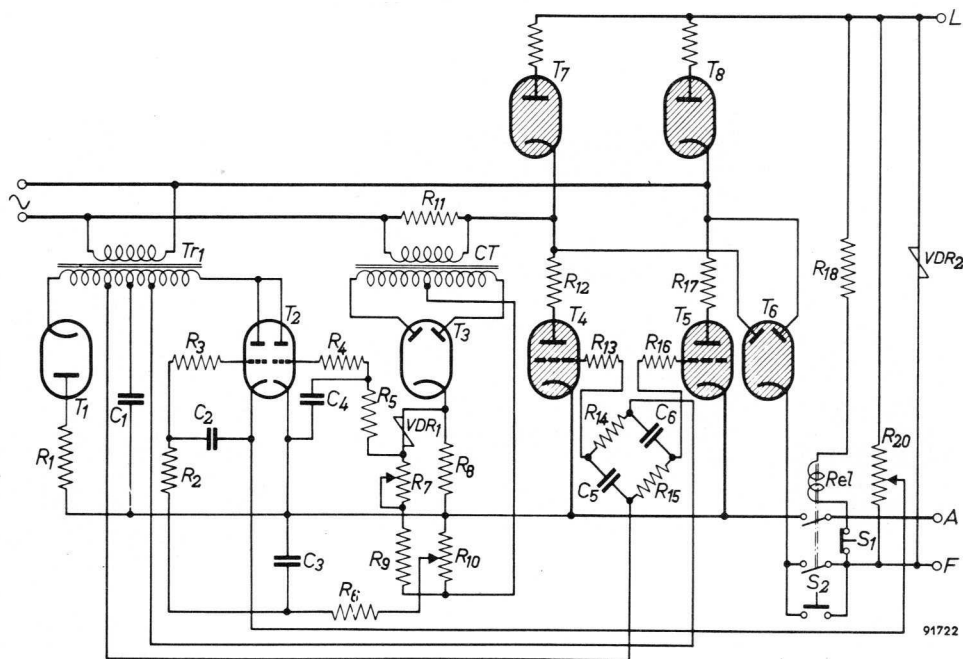
Performance

Simplification may in general be expected to result in the sacrifice of some features of performance. In the present case, however, all features associated with other systems are retained.

Actual speed-torque characteristics taken on a 1/4 h.p. motor are shown in Fig. 8.10. It will be observed that even at about 1/15 of full speed the characteristic is reasonably level. Between half and full speed there is no measurable fall in the speed-torque characteristic, until the point is reached at which the current limiting control begins to operate.

No special precautions were taken to stabilize the mains voltage when the readings were taken

Fig. 8.11. Complete motor-control circuit as shown in Fig. 8.9 but with mains transformer eliminated and two additional gas-filled rectifying tubes T_7 and T_8 .



for these curves. Provided that the field flux required is not sufficient to saturate the iron circuit in the motor, the system is insensitive to mains voltage variations. Artificial variations of $\pm 10\%$ of the rated supply voltage resulted in about $\pm 2\%$ change in speed on the average.

Reversing, when required, can be accomplished by a reversing contactor in the armature circuit or by electronic field reversal. In the latter case a separate rectifier must be used for providing the reference voltage.

Field weakening by means of a variable resistance regulator can, if desired, be used in the normal way to increase the speed range. Fully automatic field weakening, however, introduces complications which hardly justify the use of the term "simplified" and therefore has not been considered under this heading.

Elimination of the mains transformer

A substantial saving in cost can be made by eliminating the mains transformer and using a bridge-connected rectifier circuit. The additional rectifying tubes required to form the bridge circuit can be diodes, and their cost is generally much less than the transformer which they replace.

The simplified control circuit of Fig. 8.1 can be used equally well with a bridge-connected mains rectifier circuit. The complete circuit is shown in Fig. 8.11, and represents an even more inexpensive form of motor control circuit.

The main disadvantage of eliminating the trans-

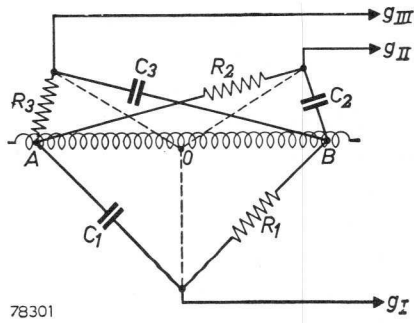


Fig. 8.12. Rearrangement of the control circuit shown in Fig. 8.1 for controlling a three-phase rectifier.

former is that the motor voltage must be chosen to suit the rectified supply voltage which does not work out very conveniently. Thus for a 220 volt a.c. supply the rectified voltage will be about 175 volts, and for a 380 volt a.c. supply about 315 volts. For such voltages specially wound motors must be used. For higher powers, a three-phase bridge-connected rectifier circuit may be considered. In this case with a 380 volt three-phase a.c. supply, the d.c. output voltage is about 500 volts. This again is a rather inconvenient voltage. As, however, specially built motors are more likely to be used for higher powers, the three-phase bridge rectifier circuit may have quite good possibilities.

Control of multi-phase rectifiers

For motors of 2 h.p. and upwards, multi-phase rectification is generally used. Either three-, four- or six-phase rectification may be considered according to the power output required and the size of thyratrons available.

By using a capacitor C_3 (Fig. 8.1) with sufficient

storage capacitance, the same d.c. bias will serve to provide each thyratron grid with a.c. lagging 90° on the anode voltage. A convenient method of providing the a.c. grid potentials for three-phase rectification is shown diagrammatically in Fig. 8.12. The transformer winding AOB represents the secondary of the transformer in Fig. 8.1. The circuit is drawn vectorially to indicate the phase relationships between the voltages in each component and is self-explanatory.

The mathematical relations between the C and R values are:

$$\begin{aligned} \omega C_1 R_1 &= 1, \\ \omega C_2 R_2 &= \tan 75^\circ, \\ \omega C_3 R_3 &= \tan 15^\circ. \end{aligned}$$

In the case of four-phase rectification no additional RC circuits are required, and the circuit arrangement is as shown in Fig. 8.13. In this case the extra grids are simply connected to points A and B . No diagram has been drawn for the case of six-phase rectification, as the method of construction is sufficiently indicated by the above examples.

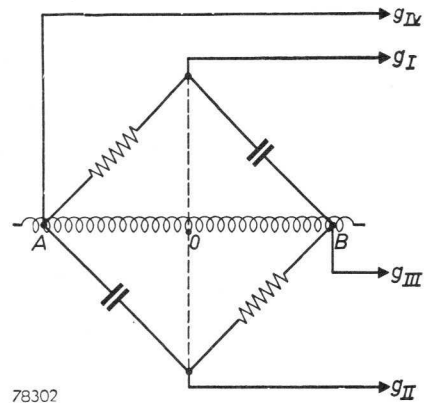


Fig. 8.13. Rearrangement of the control circuit shown in Fig. 8.1 for controlling a four-phase rectifier.

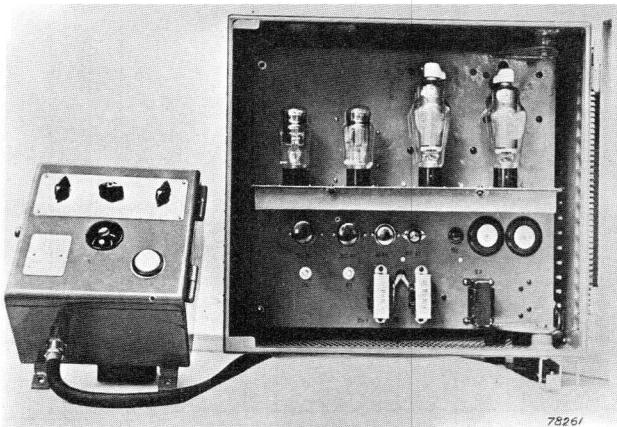


Fig. 8.14. D.c. motor control equipment with separate control box. (By courtesy of Schindler A.G. St. Gallen, Switzerland.)

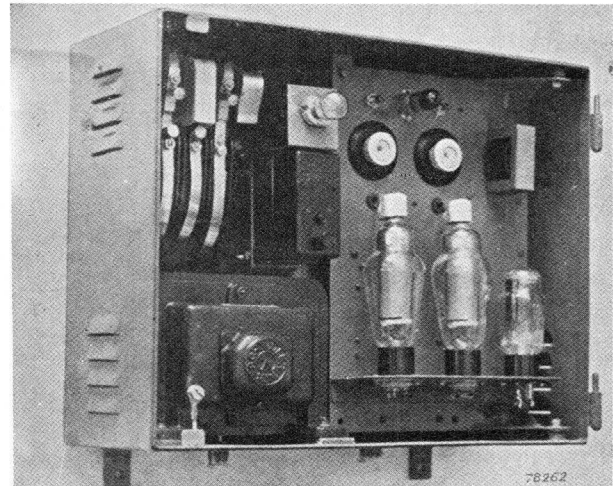


Fig. 8.15. D.c. motor control equipment. (By courtesy of Schindler A.G. St. Gallen, Switzerland.)

Motor control with speed stabilization

CIRCUIT I

Fig. 9.1 shows a circuit for controlling the armature voltage of a 2-kW motor. The field voltage may be derived from a simple rectifier circuit which is omitted in the diagram for the sake of clearness. The thyratrons PL 5559 which deliver the armature voltage are vertically controlled. The variable d.c. bias of these tubes is produced by a bridge circuit con-

as easily can be seen from the circuit diagram. Since the cathode of the left-hand triode system is connected to the grids of the thyratrons Th_1 and Th_2 via the phase-shifting network, the thyratrons are extinguished or fired with a large angle of delay when the triode system mentioned above is cut off. The firing angle becomes smaller when anode current starts to flow in the triode. This will be the case when the anode current in the right hand triode system re-

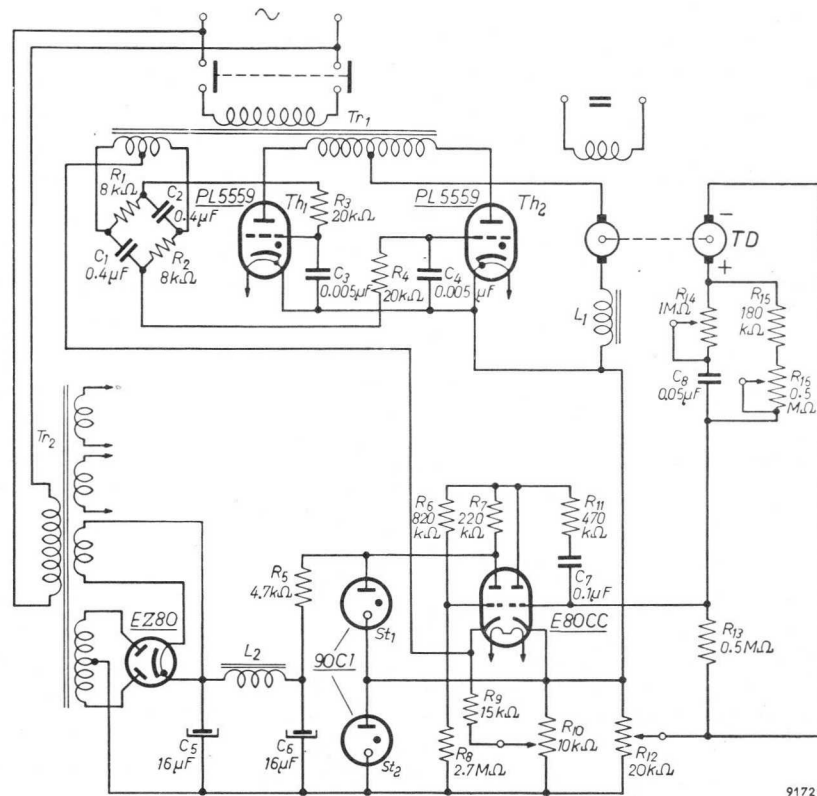


Fig. 9.1. Motor control circuit with speed regulation by means of a tachodynamo.

sisting of the stabilizing tubes St_1 and St_2 , and the resistors R_9 and R_{10} , and the left hand triode system of the double triode E80CC. When this system is non-conducting, its cathode potential is equal to the potential of the slider of R_{10} . This potential is negative with respect to the cathodes of the thyratrons

duces, i.e. when its anode voltage increases. This anode voltage is applied to the grid of the left-hand system via the voltage divider R_6 — R_8 . Reduction of the anode current of the right-hand system may be caused by such a reduction of the voltage across R_{12} — which is proportional to the voltage at the

tacho-dynamo — that the grid of the triode becomes less or more negative with respect to its cathode. On the other hand, the firing angle of the thyratrons is increased and the speed of the motor consequently decreased when the voltage delivered by the tacho-dynamo increases.

An RC-filter is connected between the anode and

the grid of the right-hand triode to prevent hunting. The RC-constant must be so adjusted that the gain of the triode is minimum at the critical frequency. The control circuit described above provides such a constancy of the speed of a motor that the deviations are smaller than 1%, whilst the number of revolutions can be varied over a range of 1 : 20.

CIRCUIT II

Another circuit for controlling the speed of a d.c. shunt motor is given in Fig. 9.2. The obtained constancy of the speed is slightly smaller than with the circuit described above, but in Fig. 9.2 a tacho-dynamo can be dispensed with.

The armature voltage is delivered by two thyratrons PL 5559 which are horizontally controlled. The phase shift network consists of R_1 and the transductor Td . The d.c. premagnetization of Td is determined by the anode current of the left-hand triode system of the double triode E 90 CC. The grid voltage of this system is proportional to the anode voltage of the right-hand system, which in turn is controlled by the voltage difference between the potential of the slider of R_{18} and that of R_6 . The voltage at R_6 is equal to the armature voltage and it can easily be

seen from the figure that an increase of the armature voltage results in an increase of the grid voltage of the right-hand triode. Consequently its anode voltage and the grid voltage of the left-hand triode decreases so that the d.c. current through Td decreases. The firing angle of the thyratrons becomes then larger so that the armature voltage decreases.

When, however, the armature voltage is used as a reference for the number of revolutions the IR -drop which occurs at the armature must be compensated for. Therefore, a current transformer Tr_3 is provided in the anode circuits of the thyratrons. The secondary voltage of this transformer is rectified by an EB 91 and at R_5 a d.c. voltage exists which is proportional to the current through the armature. The voltage at R_5 is partly applied to the right-hand triode system of T so that also the current through the armature controls the firing angles of the thy-

ratrons. When the armature current increases, also the IR -drop increases, so that the voltage at the armature must rise to compensate this IR -drop. An increase of the armature current causes an increase of the voltage at R_5 and consequently a decrease of the grid voltage of the right-hand triode system. As described above this results in a smaller firing angle of the thyratrons and a larger armature voltage.

When R_5 is carefully adjusted a stabilization of the motor speed of about 1-2% may be achieved when the motor rotates at full speed; the stabilization is about 5-8% when the speed of the motor is one tenth of its maximum.

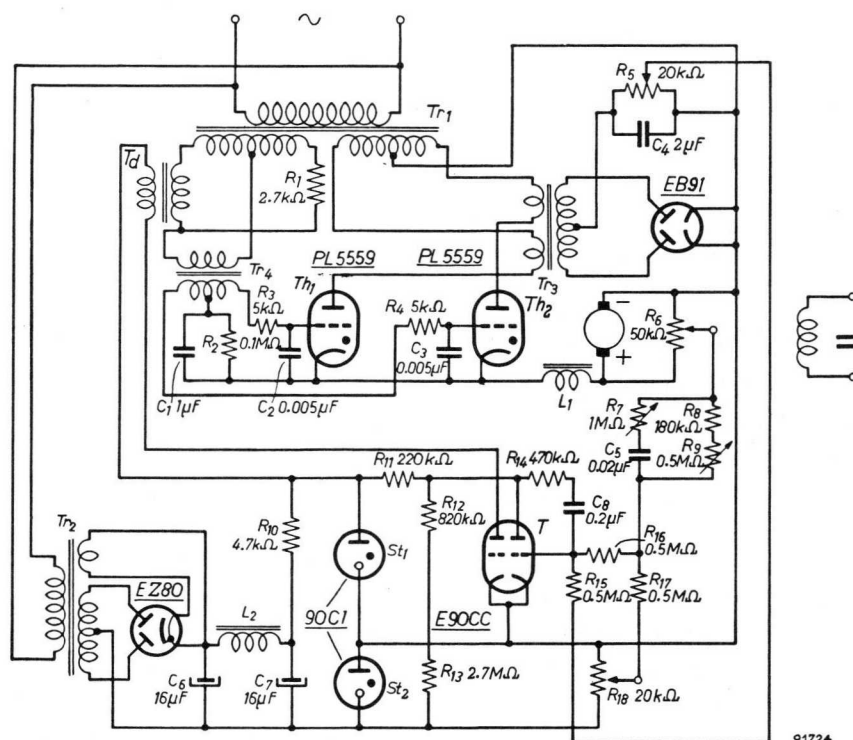


Fig. 9.2. Motor control circuit with speed regulation and IR -drop compensation.

Reversal and braking of motors

Reversal of the direction of rotation of a motor is easily achieved by reversing the armature supply by means of a contactor. Braking is accomplished in the simplest case by disconnecting the armature from the rectifier and connecting it in parallel with a resistor in which the kinetic energy of the armature is converted to heat (dynamic braking). A much more effective method of reversal and braking is as follows.

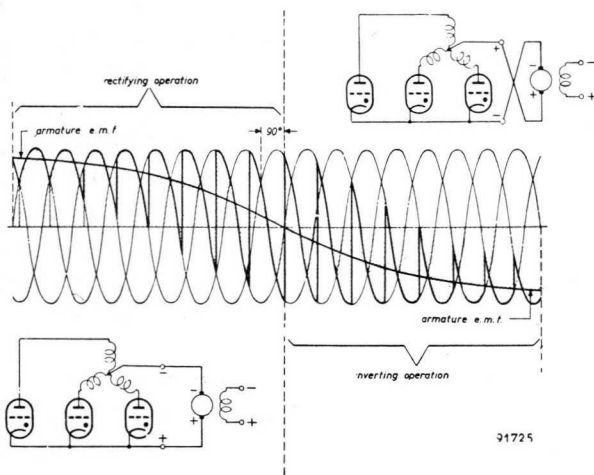


Fig. 10.1. Inverter action of an electronic motor control system when reversing the motor.

The thyristors of the armature rectifier are first blocked so that no current flows in the armature; then the armature connections are reversed by a contactor. Since the e.m.f. of the armature is now applied to the armature rectifier circuit with reverse polarity, inverter action occurs, in which the kinetic energy of the motor is converted into electrical energy and fed back into the power line (electrical braking).

This is illustrated in Fig. 10.1 for a three-phase armature rectifier. The firing angle of the thyristors is at first very small in order to avoid heavy short-circuit current, but is gradually increased with decreasing armature e.m.f. as indicated. At $\varphi = 90^\circ$ the voltage is zero and the motor is at rest. Further

increase of the firing angle causes the motor to start and to speed up in the reverse direction.

An improvement to this arrangement is to replace the contactor by a second set of thyristors connected in inverse-parallel to the original tubes. A circuit of this type which is intended for connection to a single-phase mains, is described below. Its simplicity renders this circuit particularly suitable for controlling small motors, such as are used e.g. to control the feed in automatic milling machines.

In this circuit the thyristors connected in anti-parallel are vertically controlled, but the variable direct grid voltage is derived by means of additional rectifiers from an alternating voltage, the amplitude of which is influenced by the pick-up. By interconnecting isolating transformers, the grid circuits of the thyristors can thus be separated, as required for tubes connected in antiparallel.

Below a description will be given of a phototube-controlled circuit for feeding a motor and reversing its rotational direction. On such a photo-electrically controlled installation the condition is imposed that the two thyristors connected in anti-parallel in the armature circuit of the d.c. shunt motor are extinguished at the mean illumination of the phototube, and that one of the thyristors passes current during an increasing part of the half cycle as the illumination of the phototube increases or decreases, so that the rotational speed and direction of the motor are determined. When the illumination of the phototube differs from the average value, the direct grid voltage of one tube should therefore be such that it passes a larger current, whereas the direct grid voltage of the other tube should be rendered more negative or at least at the same value. In deriving these direct grid voltages from alternating voltages of corresponding amplitude, they should therefore vary with the illumination of the phototube.

This condition can be satisfied in a simple way by means of a circuit in which amplifying tubes with a variable μ are used. The control grid of such tubes consists of a helix with a variable pitch. In this

way the tube is given a curved I_a/V_g characteristic the slope of which varies over a wide range. Fig. 10.2 represents the slope or mutual conductance of such a tube (EF 85) as a function of the negative control grid voltage. This characteristic reveals that the mutual conductance can be varied between 1 and 6000 $\mu\text{A}/\text{V}$, which means that the amplification

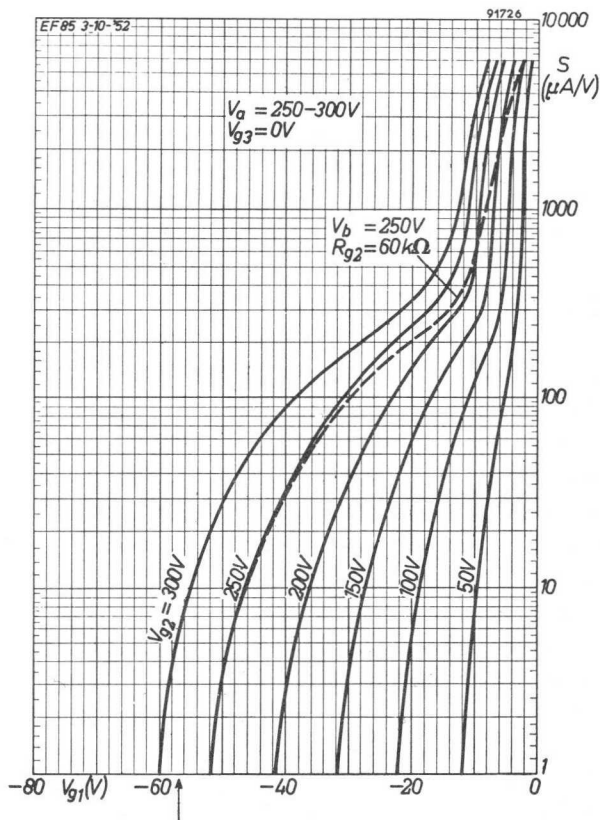


Fig. 10.2. Mutual conductance of a variable-mu tube as a function of its grid voltage with the screen-grid voltage as parameter.

factor can be varied accordingly by shifting the working point. By applying a constant alternating voltage in series with a variable direct voltage to the control grid of such a variable-mu tube, the amplitude of the amplified alternating voltage will become a function of the direct grid voltage.

In the circuit of Fig. 10.3 an alternating voltage $V_{g\sim}$ and a direct voltage are applied to the grid of the tube T_1 ; this direct voltage consists of a constant negative voltage V_1 and a variable control voltage V_c . The voltage V_1 is so chosen that the average mutual conductance of the tube is obtained at the mean value of the control voltage V_c . At an increasing control voltage the working point is shifted to an area with a higher mutual conductance, which results in the alternating voltage across the primary

of transformer Tr_1 being increased. Conversely, the tube will operate in an area with a smaller mutual conductance when the control voltage V_c is decreased, in which case the amplitude of the alternating voltage at transformer Tr_1 is reduced. At the secondary of Tr_1 an alternating voltage V_1 will thus be induced, the amplitude of which depends on the magnitude of V_c .

To obtain a second alternating voltage, the amplitude of which varies in the opposite direction, a second variable-mu tube, T_2 , is used. The grid voltage for this tube, derived from a voltage divider formed by the resistors R_2 , R_3 and R_4 and from the negative grid bias source V_2 , will have such a value at the mean control voltage V_c that the mutual conductance in the working point is equal to that of the tube T_1 . When the amplitudes of the alternating grid voltages $V_{g\sim}$ of both tubes are identical, the amplitudes of the alternating output voltages V_{o1} and V_{o2} will therefore also be identical. By increasing the control voltage V_c , the mean value of the direct anode current of tube T_1 , and hence the voltage drop across R_2 , is increased. As a consequence the direct grid voltage of T_2 is reduced, so that the amplification factor and the alternating output voltage V_{o2} are also reduced. Conversely, the alternating output voltage V_{o1} will decrease and V_{o2} will increase when the control voltage V_c is reduced. It is thus seen that the amplitudes of V_{o1} and V_{o2} vary in opposite directions.

Fig. 10.4 shows the circuit of the phototube-controlled rectifier for feeding a motor which is used for automatically advancing the clutch of an automatic milling machine. In this rectifier the thyratrons are controlled by means of the circuit described above. The alternating voltages, having an r.m.s. value of 1 V, applied to the control grids of two variable-mu

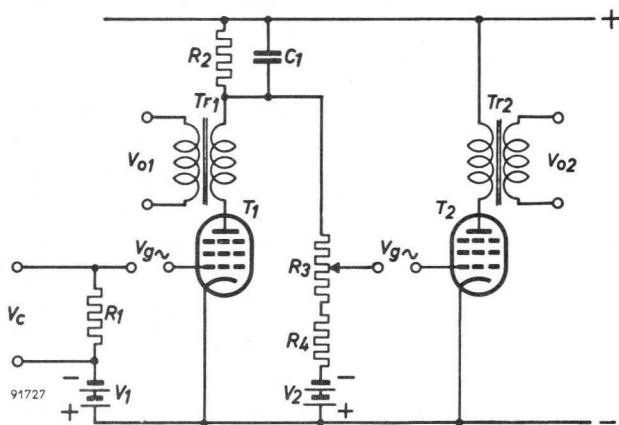


Fig. 10.3. Circuit with variable-mu tubes for controlling thyratrons.

pentodes EF 85, are supplied by the corresponding transformer windings. The required negative grid biases are taken from a common voltage divider, fed by a rectifier which is stabilized by means of the tube 150B2; the biases can be adjusted by means of the 10 kΩ potentiometers. The variable alternating voltages are supplied by the secondaries of the transformers Tr_1 and Tr_2 ; after having been rectified by two germanium diodes OA 81, these voltages are fed to the grids of the two thyratrons PL 1607 connected in anti-parallel. To prevent the transformer cores from being premagnetized by direct current, which would affect the voltage gain, the primary windings of Tr_1 and Tr_2 are separated

from the anodes of the corresponding tubes by capacitors.

The voltages at the secondaries of Tr_1 and Tr_2 have been plotted in Fig. 10.5 as functions of the control voltage applied to the first variable-mu pentode. At equilibrium the output voltages of the two transformers are approximately 14 V; a variation of ± 1.75 V in the control grid voltages of the first tube results in the output voltages of Tr_1 and Tr_2 being changed from 14 V to a maximum of 50 V and to a minimum of 2 V and 5 V respectively.

Since the direct voltages applied to the grids of the thyratrons must vary between positive and negative values for vertical control, the direct grid voltages

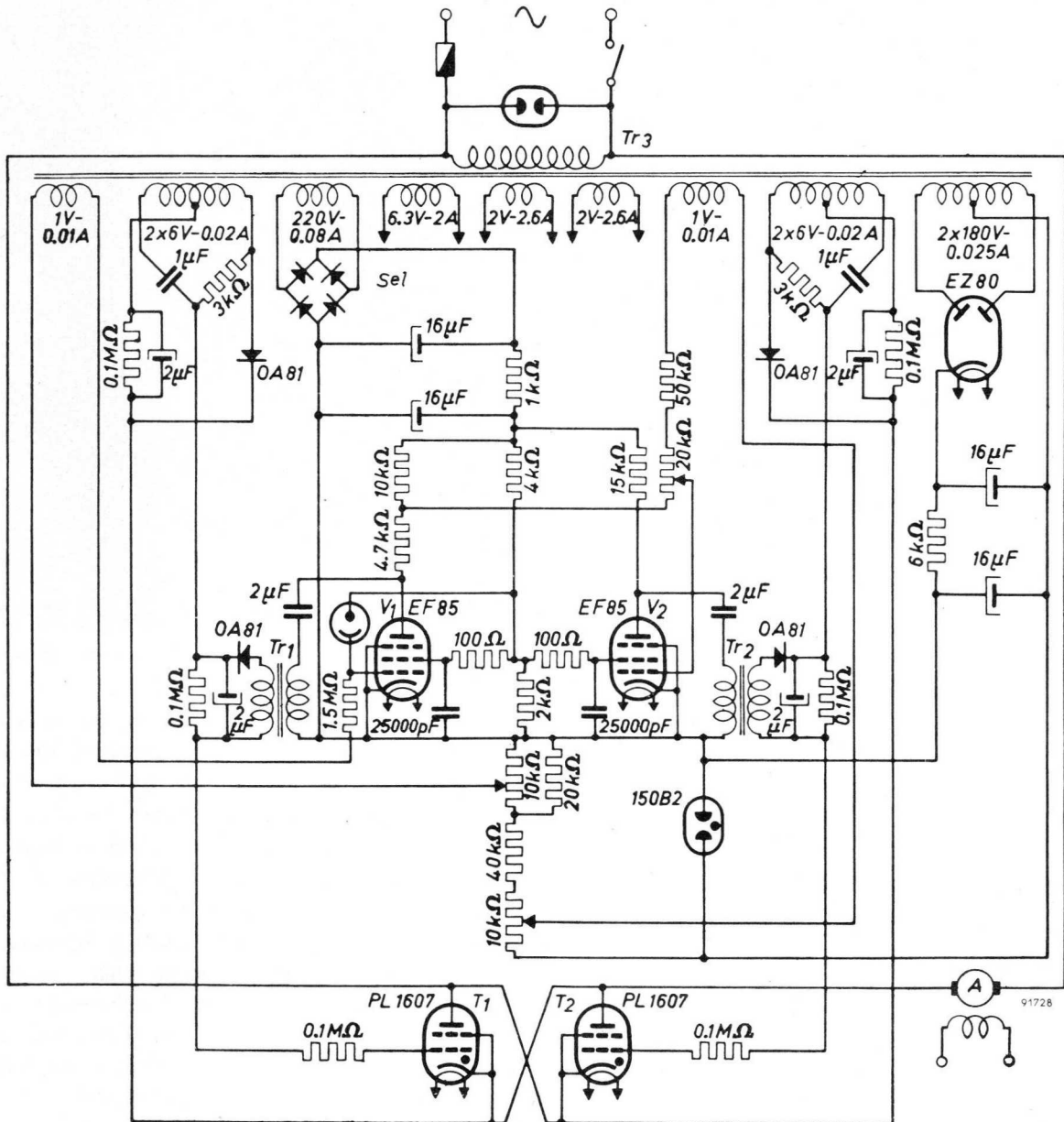


Fig. 10.4. Photoelectrically controlled rectifier for feeding and reversing motors.

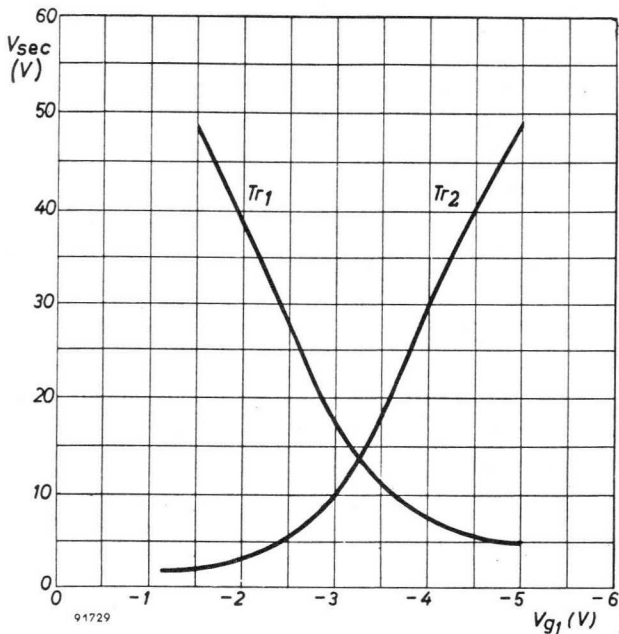


Fig. 10.5. Graph representing the control voltages obtained in the circuit of Fig. 10.4 as a function of the grid voltage V_{g1} applied to the first variable-mu pentode.

derived from the variable alternating voltages are connected in series with opposed constant direct voltages the values of which are equal to half the obtainable maximum value. These compensating

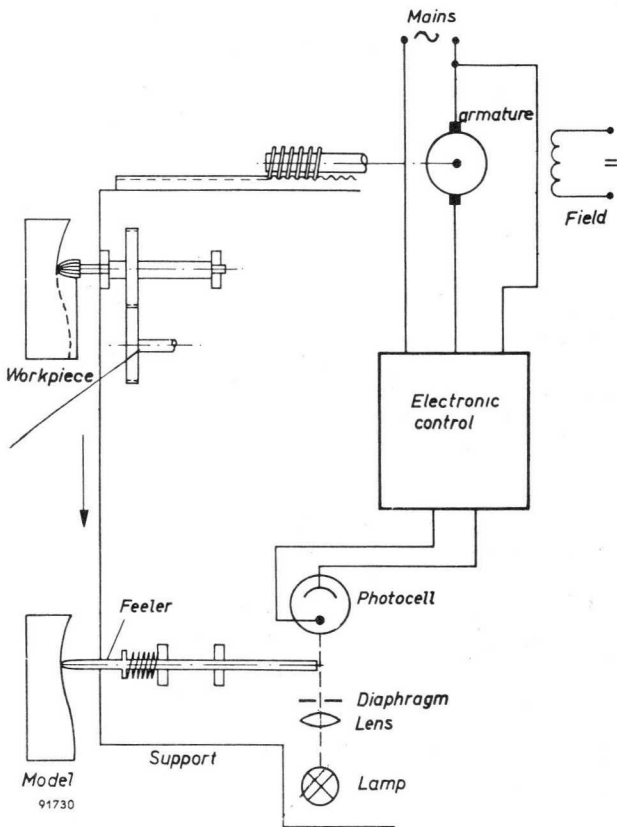


Fig. 10.6. Schematic representation of a device for controlling an automatic milling machine by means of a feeler.

voltages are obtained by rectifying half the alternating voltages required for the phase-shifting networks by means of two germanium diodes OA 81. The alternating voltages in quadrature that are required for controlling the thyratrons PL 1607, are taken from the phase-shifting networks, which are connected in the customary way.

The constant field current of the motor is supplied by a simple metal rectifier, which has been omitted for the sake of simplicity. The operation of an automatic milling machine that is electronically controlled by means of a feeler is shown schematically in Fig. 10.6. The spindle of the cutter is mounted to-

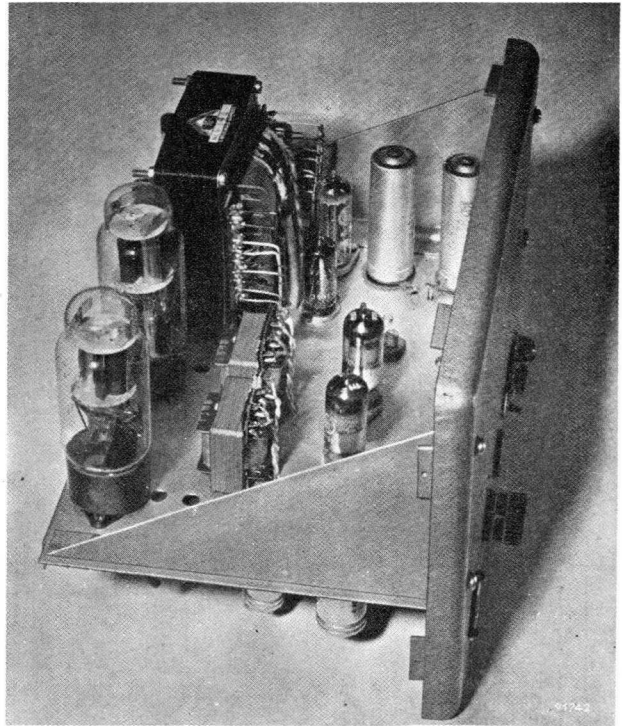


Fig. 10.7. Electronic equipment of the device represented in Fig. 10.6.

gether with the feeler on the support, which is advanced in the direction of the arrow. When the resiliently mounted feeler is displaced from its idling position by the contours of the model, the illumination of the phototube increases or decreases, depending on the direction in which the feeler is moved; the motor then starts immediately in the corresponding direction, thus correcting the deviation. In contrast to the customary control devices with a contact feeler, this installation operates continuously, and even sudden alterations in the form of the model are followed rapidly and without difficulty, so that a perfect copy of the workpiece is obtained.

Fig. 10.7 shows the electronic equipment of the installation, mounted on a separate chassis.

Paper register control

A typical example of register control is paper positioning in wrapping machines and other paper-processing equipment. The paper for the final product such as paper bags, boxes etc. is usually supplied in reels, printed with a trade name or other matter at regular intervals by some cheap printing process. This roll of paper must be cut into suitable lengths and it is obvious that the printed matter should always occupy the same position on the cut pieces.

the margin of the paper together with the trade name.

Fig. 11.1 shows the block diagram of such a device. The travelling paper is provided with register marks M at regular intervals, indicating the position at which the paper should be cut. The width of the marks should be roughly twice the maximum permissible error — for example $2 \times \frac{1}{16}'' = \frac{1}{8}''$. The phototube P is excited by the beam of light emitted by the lamp L and reflected by the bright

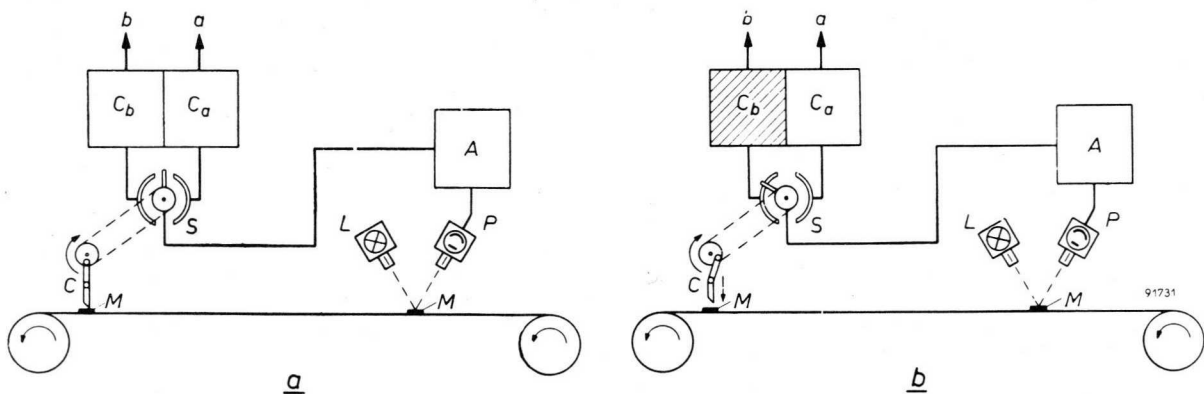


Fig. 11.1. Block diagram of a regulating device for cutting paper.

It is therefore necessary that the cutting frequency is accurately related to the speed at which the paper passes through the machine. It is true that a slight error of, say, $\frac{1}{16}''$ may be of little consequence for a single piece, but since the errors are cumulative this would result in a total error of as much as 6" after 100 cuts.

Mere synchronisation of the cutting frequency and the speed of travel does not, however, ensure satisfactory operation because it does not take into account the uncontrollable expansion or contraction of the paper due to temperature and humidity variations. A regulating device is therefore required which detects and subsequently corrects the positive or negative errors of every cut. The obvious solution is to use for this purpose a phototube-controlled device which responds to register marks printed on

surface of the paper. When a (dark) register mark passes the beam the light is temporarily absorbed instead of being reflected towards the phototube, so that an electric signal is produced by the tube. This signal is amplified in amplifier A , and fed to the slider of the rotary switch S which rotates at the same speed as the wheel operating the cutter C .

When the cut is at the correct position the signal will be produced at the instant that the slider is at its neutral centre position, so that it is not transmitted to either of the controlling units C_a or C_b (see Fig. 11.1a). When, however, the cutting frequency is slightly too low compared with the paper speed the slider transmits the signal to the controlling unit C_b which temporarily slows down the paper by means of a braking device connected to b (see Fig. 11.1b). This may be achieved, for example, by means

of a magnetic clutch or a variable transmission gear. When, on the other hand, the cutting frequency is too high, the signal is fed to the controlling unit C_a which temporarily accelerates the paper speed by means of a relay and a servo-motor connected to a . Errors are thus corrected before the cumulative error has reached an inadmissibly high value.

Fig. 11.2 shows the circuit of the electronic part of the regulating device. The direct current required is supplied by an AX 50 gas-filled rectifying tube T_1 . The gas-filled phototube F , type 3546, is d.c. fed, so as to respond to variations in light at every instant. (If the phototube were a.c. fed no signal would be produced by the register marks during the half cycles when the phototube anode is negative.)

When the phototube is excited by the reflection of the beam of light from the bright paper surface a photo-electric current will flow which gives rise to a voltage drop across the resistor R_6 , so that the capacitor C_4 is charged with the polarity indicated in Fig. 11.2. During the short interruptions of the beam of light by the register marks this capacitor will produce a negative voltage at the control grid of the

EF 86 pentode T_2 . This temporarily reduces the anode current of the EF 86 as a result of which a positive voltage pulse occurs at its anode and is transmitted via the capacitor C_2 to the control grid of one or the other of the PL 5557 thyratrons depending on the position of the rotary switch S . If the paper speed is too high, thyatron Th_2 will ignite; and if too low, thyatron Th_1 will ignite. At the correct speed the switch S is in its neutral position during the passage of the register mark so that neither of the thyratrons will ignite.

Once a thyatron has ignited, it will remain conductive because it is d.c. fed. The relay Rel_2 (or Rel_1) will be energised, so that the braking (or accelerating) circuit connected to b (or a) is closed. In the meantime, however, a second contact of this relay is opened, to disconnect the capacitor C_3 from the positive supply voltage. This capacitor has previously been charged as indicated in Fig. 11.2, so that the PL2D21 thyatron Th_3 was ignited as a result of the positive voltage applied to its first grid. As soon as C_3 is disconnected from the supply voltage it discharges via the resistors R_{14} and R_{15} and the catho-

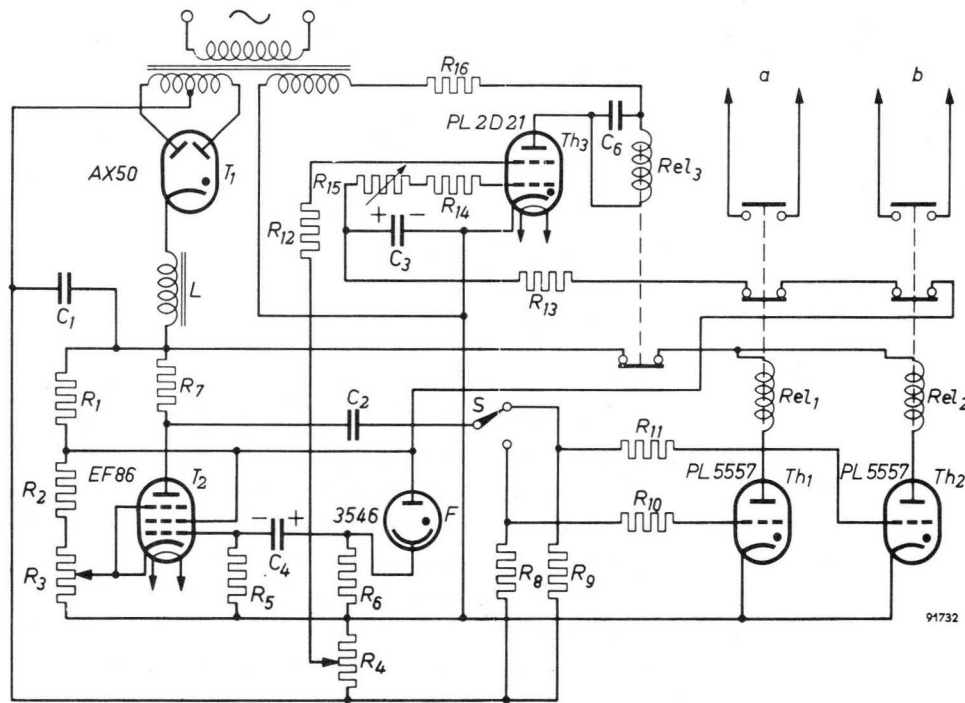


Fig. 11.2. Circuit of the electronic part of the regulating device.

$R_1 = 15 \text{ k}\Omega$	$R_9 = 40 \text{ k}\Omega$	$C_1 = 16 \mu\text{F}, 250 \text{ V}$	Transformer primary: mains voltage; secondary: $2 \times 300 \text{ V}, 0.3 \text{ A},$ $250 \text{ V}, 0.1 \text{ A},$ $4 \text{ V}, 4 \text{ A},$ $6.3 \text{ V}, 0.3 \text{ A},$ $2.5 \text{ V}, 10 \text{ A}.$
$R_2 = 6 \text{ k}\Omega$	$R_{10} = 10 \text{ k}\Omega$	$C_2 = 0.01 \mu\text{F}$	
$R_3 = 2 \text{ k}\Omega$	$R_{11} = 10 \text{ k}\Omega$	$C_3 = 2 \mu\text{F}$	
$R_4 = 2 \text{ k}\Omega$	$R_{12} = 10 \text{ k}\Omega$	$C_4 = 0.01 \mu\text{F}$	
$R_5 = 1 \text{ M}\Omega$	$R_{13} = 1 \text{ k}\Omega$	$C_6 = 2 \mu\text{F}$	
$R_6 = 2 \text{ M}\Omega$	$R_{14} = 10 \text{ k}\Omega$	$L = 10 \text{ H}, 300 \text{ mA}$	
$R_7 = 0.1 \text{ M}\Omega$	$R_{15} = 0.5 \text{ M}\Omega$		
$R_8 = 40 \text{ k}\Omega$	$R_{16} = 2.5 \text{ k}\Omega$		

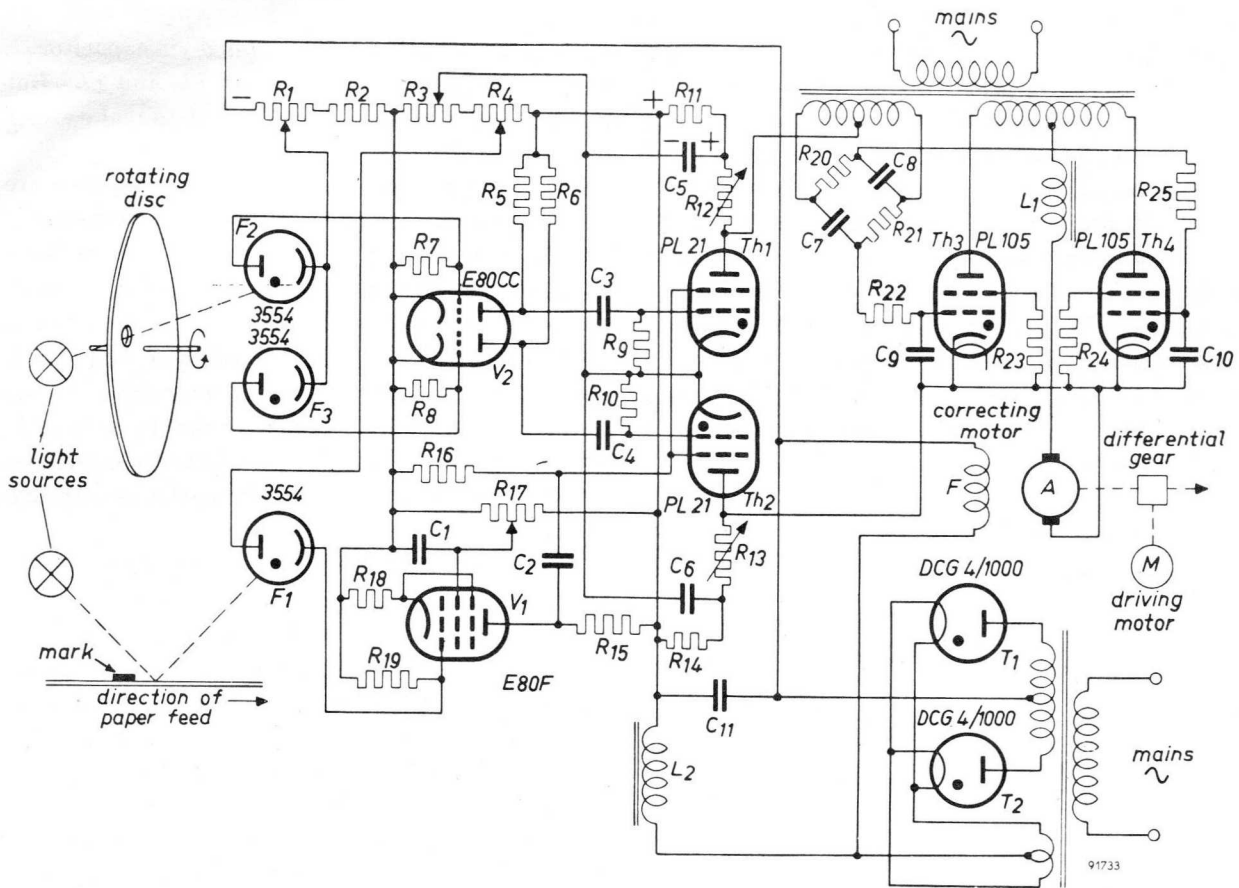


Fig. 11.3. Electronic regulating device using no mechanical relays.

de-to-grid path of the thyatron Th_3 , and since a fixed negative grid bias of about -2 V derived from R_4 is applied via the resistor R_{12} to the second grid of this tube, it will extinguish after a short interval. As a result Rel_3 will no longer be energised, so that it will drop out and the thyatron PL 5557 also extinguishes. The relay Rel_2 (or Rel_1) then drops out and the braking (or accelerating) circuit is interrupted. The capacitor C_3 is then again charged via R_{13} , so that the thyatron Th_3 ignites again. In this way the duration of the braking or accelerating action is determined and can be adjusted by means of the variable resistor R_{15} .

An alternative register control

The device as described, using mechanical relays, does not, however, work satisfactorily for very high cutting speeds. It is possible, of course, to increase the maximum speed of this register control device by printing the register mark opposite only every second, third or fourth etc. trade mark, but finally a limit will be reached. In this case a device which does not employ mechanical relays must be used.

A suitable circuit is given in Fig. 11.3. Instead of a rotating switch, two phototubes F_2 and F_3 are provided which are illuminated by a light source if a hole in a disc rotating synchronously with the cutting frequency lets the beam pass through. The phototubes are mounted so that the one (F_2) is illuminated just before a cut is made, and the second (F_3) just after the cut. At the instant when the cut is being made neither cell is illuminated. At that instant, however, the light falling on phototube F_1 is reduced by the dark register mark, provided the travelling paper is at the correct position for cutting. If this is not the case, the reduction of the light falling on F_1 will coincide with the illumination of F_2 or F_3 according to whether the paper speed is too high or too low.

This is illustrated in Fig. 11.4. The paper is driven by a motor working at constant speed. An auxiliary "correcting" motor, which is coupled to the main motor by a differential gear, runs at a normal speed if the speed of the paper is correct. It is a d.c. shunt wound motor whose field is fed by a rectifier equipped with the tubes T_1, T_2 . The armature is supplied

at normal voltage by a second rectifier equipped with thyratrons Th_3, Th_4 . To these tubes are applied alternating control grid voltages which lag by 90 degrees behind the anode voltages; they are produced by the phase-shifting network consisting of C_8, R_{20} , and C_7, R_{21} . As long as the controlling thyratrons Th_1 and Th_2 (PL2D21) are non-conducting, no voltage difference exists between their anodes and consequently no further voltage appears in the control grid circuits of thyratrons Th_3 and Th_4 (PL 105). These tubes will obviously then ignite with approximately 90 degrees phase delay so that the output voltage of the rectifier is reduced causing the motor to run at normal speed.

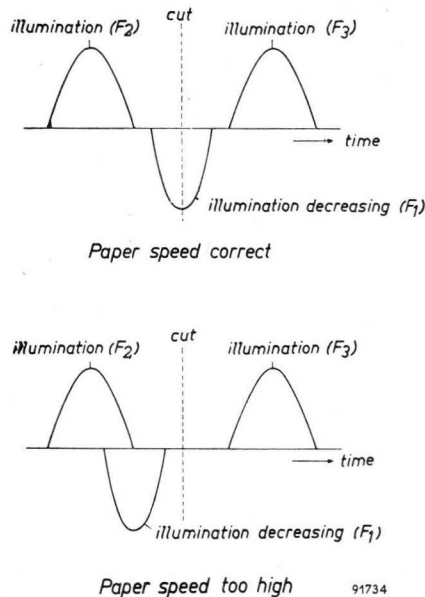


Fig. 11.4. Position of voltage impulses for correct paper speed, and for the case when the paper speed is too high.

Each time the phototube F_2 or F_3 is illuminated a negative voltage appears at the corresponding control grid of the double triode V_2 , causing a decrease of the anode current of that particular section. Since this is only a momentary decrease, a positive voltage pulse arises at the anode which is applied via capacitor C_3 or C_4 to the first grid of thyatron Th_1 or Th_2 . However, this does not result in ignition of either thyatron, since their second grids receive also a negative bias which can be preadjusted by means of potentiometer R_2 .

Phototube F_1 is normally illuminated so that a positive voltage drop appears across resistor R_{19} and tube V_1 passes current. If, however, the light falling on F_1 is reduced for a moment by the dark register mark, the voltage drop across R_{19} is correspondingly reduced and the sudden decrease of the anode cur-

rent flowing through V_1 produces a positive voltage pulse at the anode which is applied via capacitor C_2 to the second grids of thyratrons Th_1 and Th_2 . But this pulse alone is also not sufficient to make either of these tubes ignite.

If now the paper speed is correct, positive pulses are applied successively to the grids of thyratrons Th_1 and Th_2 when the register mark passes by, so none of these tubes ignites. Matters are different, however, if the paper speed is, for instance, slightly too high. In this case the pulses caused by F_2 and F_1 will partially or completely coincide, as is shown in the lower part of Fig. 11.4. As a result the thyatron Th_1 will ignite, and capacitor C_5 , which has been charged with the polarity indicated, can discharge through Th_1 and R_{12} .

Since resistor R_{11} is comparatively large, recharging of C_5 takes a greater time than discharging, so the thyatron will finally extinguish again when the voltage across C_5 has become smaller than the arc voltage. As long as Th_1 is ignited its anode potential corresponds to the arc voltage, and between the anodes of both thyratrons Th_1 and Th_2 appears a voltage difference which is applied as a negative potential to the control grids of thyratrons Th_3 and Th_4 causing the output voltage of the rectifier to drop almost to zero for a short time. The speed of the correcting motor therefore decreases, thus reducing the paper speed and re-establishing its synchronism with the cutting frequency.

The duration of the speed decreases and thus the amount of correction can be varied by means of R_{12} over a certain range. If the paper speed is too low, the pulse caused by F_1 will coincide with that transmitted by F_3 , causing thyatron Th_2 to fire. Now the voltage difference appearing between the anodes of Th_1 and Th_2 is applied to the control grids of thyratrons Th_3, Th_4 as a positive potential, thus causing the rectifier output voltage to rise to its full value. The speed of the correcting motor is correspondingly increased, again restoring the synchronism with the cutting frequency.

Lateral register control

Another type of register control frequently used is for checking the position of a strip of paper or fabric fed through a processing machine. Lateral displacements of the strip passing through the machine are counteracted by a servo-motor which rotates in a clockwise or anticlockwise direction, driving gearing which leads the paper back to the correct position.

It is possible to use as detecting elements miniature

quantity of light increases the motor starts to run in a clockwise direction, its speed increasing approximately linearly with the intensity of light. Similarly, the speed of the motor when running in anticlockwise direction increases with the reduction of the quantity of light. When the phototube is receiving the maximum quantity of light or is in complete darkness the motor thus runs at full speed in a clockwise or anti-clockwise direction, whilst its speed decreases as the average intensity of light is approached.

Fig. 11.5 shows the circuit of this device. The field coil FW of the d.c. shuntwound motor is fed from the rectifier formed by the transformer Tr_3 and the gas-filled rectifier tube T_1 (AX 50). The direct voltage supplied by this rectifier is also used, after having been smoothed by the filter L_2C_3 , for feeding the gas-filled phototube type 3554 and the EF 86 pentode V_2 which serves as a preamplifier.

The armature A of the motor is fed from the a.c. mains via the choke L_1 and the two PL 5559 thyratrons Th_1 and Th_2 connected in anti-parallel. When both thyratrons are blocked or only pass small, equal currents, the armature remains at rest, but as soon as the phase of the control voltage applied to one of these thyratrons is shifted, so that its current increases, the motor will rotate at the corresponding speed in one direction or the other. Since as a rule the current drain of servo-motors is fairly small, two PL 5559 thyratrons, which will pass a mean anode current of 2.5 amperes, suffice.

Special attention should be paid to the control circuit of these tubes. The cathodes are at different potentials so that the tubes must be controlled by shifting the phase of a voltage peak applied to the control grid with respect to that of the alternating anode voltage. The transformer Tr_4 supplies two alternating voltages in anti-phase, thus providing the required negative grid bias during the half-cycles when the anodes of the corresponding tubes are positive. The capacitors C_1 and C_2 shunted across the grid-protecting resistors R_2 and R_3 , are charged as indicated in Fig. 11.5 during the positive half cycles of the grid bias and this negative voltage is added to the negative alternating grid voltage during the following half cycle, which safeguards the thyratrons from random ignition. The ignition peaks superimposed on this grid bias are supplied by the transformers Tr_1 and Tr_2 , the primaries of which are fed by the two thyratrons Th_3 and Th_4 (PL2D21).

The cathodes of the latter tubes are interconnected,

so that they can be controlled by means of a sinusoidal voltage superimposed on a varying (negative or positive) direct voltage (vertical control). The sinusoidal grid voltages must be delayed by 90° with respect to the anode voltages. This is achieved by means of the phase-shifting networks C_4R_7 and C_8R_8 . The varying direct voltage is applied by a special rectifier comprising the four selenium cells Sel and the E 80 CC double triode V_1 .

Assuming the grid voltage of both triode sections of the E 80 CC to be identical, the anodes of both triodes will then also be at the same potential. By suitable choice of the working points of these tubes this potential may be made negative with respect to the centre tap of the right-hand secondary of the transformer Tr_6 . Both thyratrons Th_3 and Th_4 are then almost completely blocked, i.e. current is passed only during very short intervals of each half cycle. Since the small currents then flowing through Th_1 and Th_2 are identical the motor shaft will not run in either direction but vibrate slightly, which is conducive to rapid starting of the motor.

If the grid of the left E 80 CC section is made more negative its current will decrease so that the voltage at its anode will rise, but the resulting reduction of the voltage drop across the cathode resistor R_{13} will decrease the negative grid voltage of the other triode section, so that the anode current of the latter increases and the voltage at its anode decreases. The increased voltage at the anode of the left E 80 CC section will cause the ignition point of thyatron Th_4 to be advanced, while Th_3 is completely blocked. Since these thyratrons are a.c. fed by means of transformer Tr_5 , current will then flow through Th_4 during part of each cycle, giving rise to voltage peaks across the secondary of the transformer Tr_2 which ignite thyatron Th_2 .

The latter is also a.c. fed, so that the mean value of the current flowing through this tube and the armature of the servo-motor is determined by the instant at which Th_2 is ignited in each cycle.

When the negative grid voltage of the left E 80 CC section is further increased the ignition point of the thyratrons Th_4 and Th_2 is obviously advanced, so that the mean value of the current flowing through the armature is also increased.

If the grid of the left E 80 CC section is made less negative than that of the other section the reverse will obviously occur, the ignition point of thyratrons Th_3 and Th_1 being advanced.

The grid of the right E 80 CC section is given a fixed potential by means of the voltage divider R_{14} , R_{15} .

switches operated by the travelling material, and switching the servo-motor on or off by means of contactors. This method has, however, serious drawbacks. First, to avoid continuous operation of the contactors, which would soon lead to a breakdown, it would be necessary to introduce a fairly large "dead zone" which obviously reduces the accuracy of the regulating system. Secondly, the material is often so delicate (thin tissue paper, for example) that it is not mechanically strong enough to operate switches. Finally — and this will usually be the decisive factor — contactors can only switch the

motor on or off so that it either operates at full speed or stops, the speed thus being independent of the magnitude of the error to be counteracted. This makes a further increase of the dead zone necessary to avoid the risk of hunting.

In the device described below the detecting element again consists of a phototube, and the quantity of light falling on its cathode determines both the direction and the speed of rotation of the motor for correcting lateral displacement of the material. When the normal quantity of light falls on the phototube the motor remains at rest. As soon as the

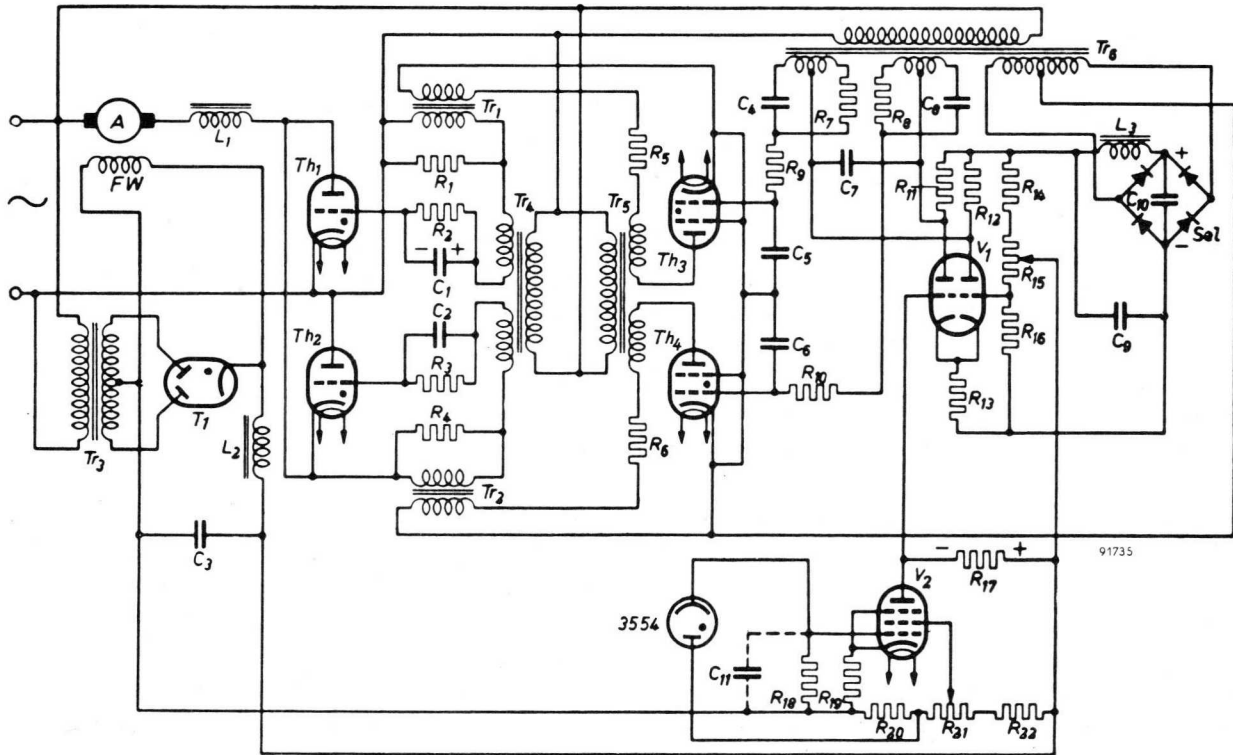


Fig. 11.5. Lateral register control circuit.

$Th_1 =$ PL 5559	$R_7 =$ 15 k Ω	$R_{21} =$ 10 k Ω	$Tr_1 = Tr_2 =$ primary: 3500 turns 0.12 mm ϕ ;
$Th_2 =$ PL 5559	$R_8 =$ 15 k Ω	$R_{22} =$ 4 k Ω	secondary: 3500 turns 0.12 mm ϕ .
$Th_3 =$ PL2D21	$R_9 =$ 50 k Ω	$C_1 =$ 1 μ F	$Tr_3 =$ primary: mains voltage;
$Th_4 =$ PL2D21	$R_{10} =$ 50 k Ω	$C_2 =$ 1 μ F	secondary: 2 \times 285 V, 0.3 A,
$T_1 =$ AX50	$R_{11} =$ 25 k Ω	$C_3 =$ 16 μ F	6.3 V, 0.2 A,
$V_1 =$ E80CC	$R_{12} =$ 25 k Ω	$C_4 =$ 0.2 μ F	5 V, 4.5 A,
$V_2 =$ EF 86	$R_{13} =$ 4.4 k Ω	$C_5 =$ 0.05 μ F	5 V, 4.5 A,
$R_1 =$ 100 k Ω	$R_{14} =$ 70 k Ω	$C_6 =$ 0.05 μ F	4 V, 4 A.
$R_2 =$ 50 k Ω	$R_{15} =$ 50 k Ω	$C_7 =$ 0.01 μ F	$Tr_4 =$ primary: mains voltage;
$R_3 =$ 50 k Ω	$R_{16} =$ 40 k Ω	$C_8 =$ 0.2 μ F	secondary: 12 V, 0.01 A,
$R_4 =$ 100 k Ω	$R_{17} =$ 10 k Ω	$C_9 =$ 8 μ F	12 V, 0.01 A.
$R_5 =$ 40 k Ω	$R_{18} =$ 2 M Ω	$C_{10} =$ 8 μ F	$Tr_5 =$ primary: mains voltage;
$R_6 =$ 40 k Ω	$R_{19} =$ 500 Ω	$C_{11} =$ 1000 pF	secondary: 110 V, 0.1 A,
	$R_{20} =$ 8 k Ω		110 V, 0.1 A,
$L_1 =$ 5 H, 2 A			6.3 V, 1.2 A.
$L_2 =$ 10 H, 60 mA			$Tr_6 =$ primary: mains voltage;
$L_3 =$ 10 H, 60 mA			secondary: 2 \times 15 V, 0.02 A,
$Sel =$ selenium rectifier for 220 V, 20 mA.			2 \times 15 V, 0.02 A,
			2 \times 90 V, 0.03 A,
			6.3 V, 0.6 A.

R_{16} , whilst the potential of the other grid is determined by the difference between the voltage taken from R_{15} and the voltage drop across the load resistor R_{17} of the EF 86 pre-amplifying tube V_2 . The potentiometer R_{15} is so adjusted that the two grids

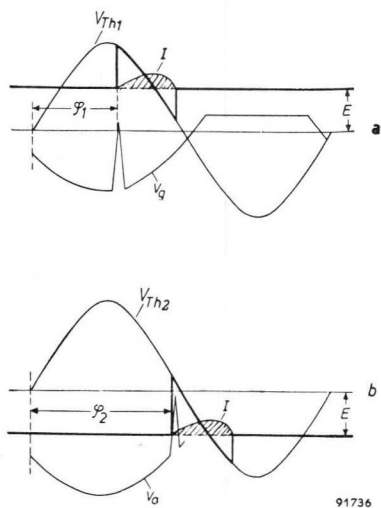


Fig. 11.6. Rectifier and inverter action of tubes Th_1 and Th_2 .

of the E 80 CC tube have the same potential when the quantity of light impinging on the phototube and hence the current flowing through R_{17} are of their average value.

The capacitor C_{11} is required to introduce a time

delay in the circuit and its value should be determined experimentally.

The circuit has the advantage that the motor is braked very efficaciously if the illumination of the phototube is changed correspondingly. This is because of the kinetic energy fed back to the mains in form of electric energy during the braking process by means of one thyatron which is operated as inverter during this period.

This may be illustrated by Fig. 11.6. In the upper part (a) the shape of the output voltage is shown, thyatron Th_1 being ignited with a firing angle φ_1 and thyatron Th_2 being non-conducting. The motor then runs in one direction producing a counter electromotive force E which is in opposition to the positive half cycles of the mains voltage (with respect to Th_1). A current I therefore flows and supplies the motor with electrical energy.

Assuming now that a medium illumination of the phototube takes place so that both thyatrons receive igniting peaks with approximately 180 degrees phase delay during each cycle. Obviously Th_1 will be now completely blocked but Th_2 is able to ignite with a firing angle φ_2 , since the counter electromotive force still present augments the anode voltage of this tube (Fig. 11.6b). A current therefore flows, but now in the opposite direction, and since the polarity of E remains unchanged, electrical energy is fed back into the mains. The kinetic energy of the motor is, of course, reduced by the same amount, thus producing a very effective braking action.

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