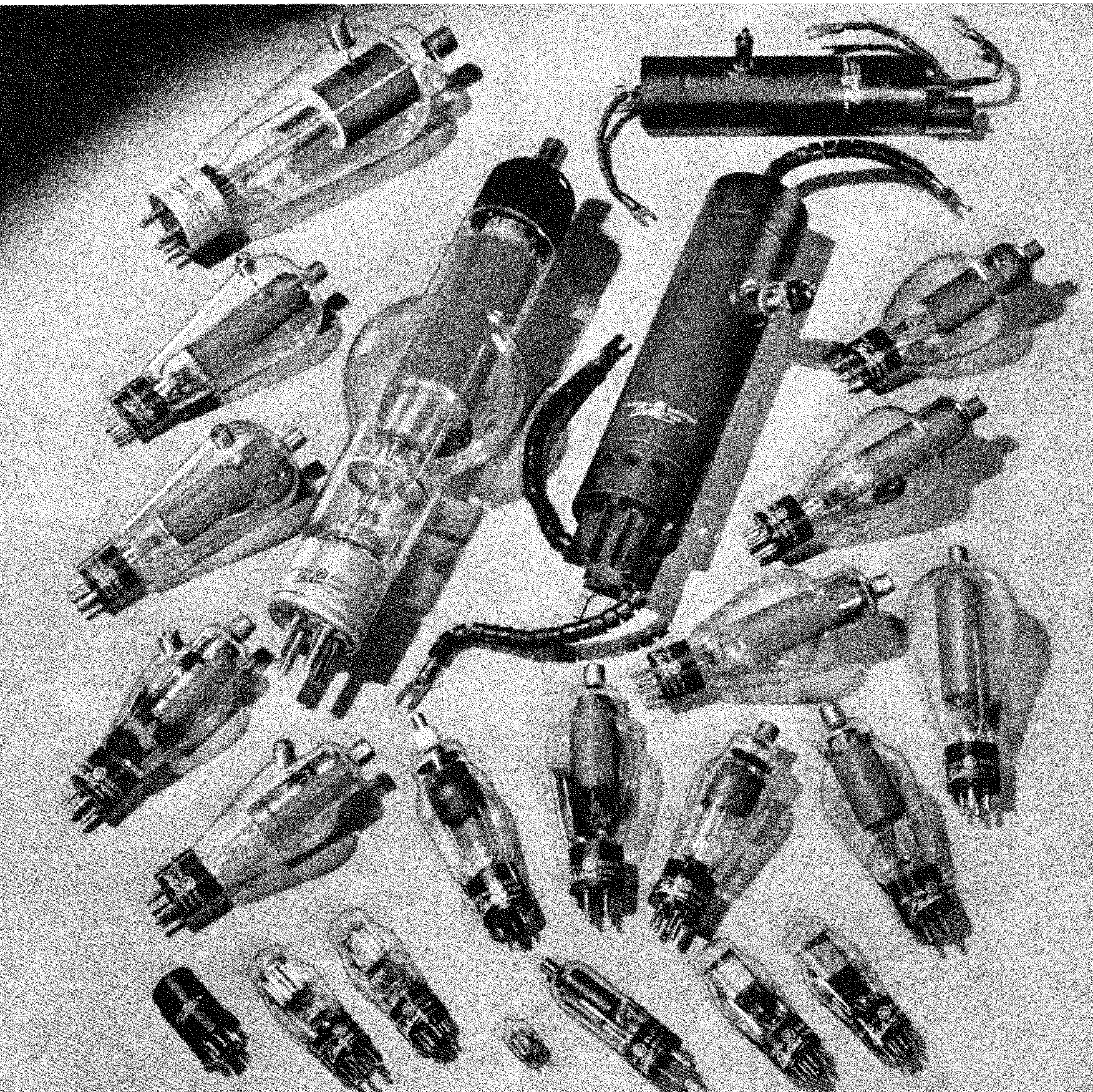
GENERAL ELECTRIC

THYRATRONS



DESCRIPTION

A thyratron is a thermionic gas tube in which one or more electrodes initiate the current flow.

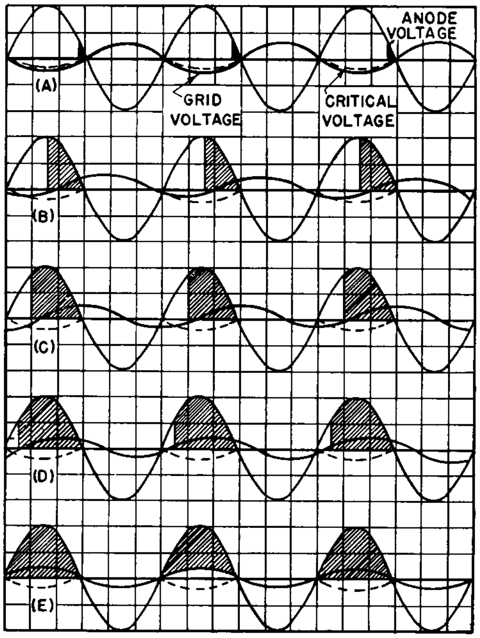
The gas used may be one of the inert gases such as argon, xenon, or helium, or the vapor pressure of a few drops of mercury. The presence of this gas neutralizes by ionization, the electron space-charge around the cathode created by the electrons emitted from it. This space-charge, which is negative in effect and tends to drive the electrons back into the cathode, is one of the limitations on the amount of current a high-vacuum electronic tube can carry. Another limitation of high-vacuum tubes is the ability of the cathode to emit the electrons which comprise the unidirectional current flow. This factor however, can be controlled by design of an electron-emitting source satisfactory for the size of the tube required.

The absence of space charge and its accompanying losses in the thyratron allows larger electrode spacing and smaller-size electrodes for a given current-carrying capacity than is possible with high-vacuum tubes. The elimination of space-charge also permits the use of an electron-emitting cathode of higher efficiency and much larger current-carrying capabilities than otherwise could be used. A gas-filled tube, therefore, can carry much higher current than a high-vacuum tube of corresponding dimensions. The vapor pressure, however, is sufficiently low so that the anode can withstand, when negative, the voltage for which the tube is designed.

The construction of the thyratron is similar to that of the phanotron. In the thyratron, however, the addition of an electrode called a grid increases greatly the usefulness of the tube. Inasmuch as the action of the grid is quite different from that of the grid in the high-vacuum three-electrode tube, it is necessary to describe its action in detail.

The grid, as employed in the thyratron, controls only the starting of the discharge. After starting, under usual operating conditions, it neither modulates, limits, nor extinguishes the arc. Herein lies the fundamental difference between the thyratron as ordinarily used, and the high-vacuum tube. In a gas tube, the positive ions neutralize the space-charge with the result that a prohibitively high current would have to be supplied to the grid before it could gain control with anode current flowing. In order to enable the grid to act with practical amounts of current, the anode voltage must be reduced substantially to zero or made negative for a period long enough for the gas or vapor to become deionized. Once this deionization takes place the grid can resume control. In a high-vacuum tube, since this ionization is not present, the grid can control the flow of current. Any change in the grid voltage of a high-vacuum tube will cause a corresponding change in the current. If an alternating voltage is applied to the anode of the thyratron, the grid has an opportunity to regain control once each cycle and can delay the starting of the arc for as long a period during the subsequent positive half-cycle as the grid voltage is sufficiently negative. This means that the grid can control the average current flowing through the tube and that this averaging can be made as fine-grained as desired by increasing the frequency of interruption.

If the grid as well as the anode is supplied with alternating current, the phase relation between the grid and anode determines the amount of average current passing through the tube. Fig. 1 shows the wave forms occuring with a shift in phase between the grid and anode. Example A shows the wave forms with the tube in an almost nonconductive condition, while E illustrates rectification throughout the entire half wave. The other diagrams show several intermediate stages of grid control.



K-9033592 1-10-45

Fig. 1—Control of Thyratron Anode Current by Variations in the Grid Voltage

The voltage conditions for starting the current depend largely upon the structural design of the tube. A tube may be designed so that within the normal anode voltage limits the current always starts at a negative grid voltage, always at a positive grid voltage, or at a negative voltage for high anode voltages and a postive voltage for low anode voltages.

Negative-control tubes require relatively little grid power and are therefore suitable for use with high-impedance circuits.

Positive-control tubes are useful in applications where it is desired that no current flow in the absence of grid excitation.

The intermediate type of tube is often used in inverter circuits and is usually designed to ensure as rapid deionization as possible, as the time allowed for deionization in certain circuits is sometimes very short.

DEFINITIONS OF RATINGS

The ratings of gas-discharge tubes are given in terms of fundamental conditions on the tube itself rather than in terms of any circuit constants. Values for a particular tube are given on the individual tube descriptive sheets, (i.e., in terms of actual anode voltage and current, grid voltage and current, etc.).

The **Maximum Peak Inverse Voltage** is a rating which is common to both thyratrons and phanotrons. It is the highest instantaneous voltage that the tube will safely withstand in the direction opposite to that in which it is designed to pass current and depends upon operation within the specified temperature range and within the surge current rating. It should be emphasized that the maximum rating of the tube refers to the actual inverse voltage and not to the calculated values. A cathode-ray oscilloscope or a spark gap connected across the tube is useful in determining the actual peak inverse voltage.

The **Maximum Peak Forward Voltage** is a rating which applies only to thyratrons. It is the maximum instantaneous voltage that can be held back by the action of a suitable grid voltage and for mercury-vapor tubes depends particularly upon operation within the maximum temperature specified.

The **Maximum Instantaneous Anode Current** is the highest instantaneous current that a tube can safely conduct under normal operating conditions in the direction of normal current flow.

The **Maximum Surge Current** rating is a measure of the ability of a tube to withstand extremely high transient currents; it is also a measure of the stiffness of the anode circuit in which the tube will operate satisfactorily at rated temperature and with maximum peak inverse voltage applied.

The **Maximum Average Anode Current** is a rating based on tube heating. It is the highest average current which can be carried continuously through the tube.

The grid current ratings are given in terms of the **Maximum Instantaneous Grid Current** and the **Maximum Average Grid Current;** the integration period is the same as that for the anode current.

In addition to the above ratings, there are a number of other tube characteristics. The **Voltage Drop** from anode to cathode is a characteristic which becomes important when the anode supply voltage is low, as it then becomes a large part of the working voltage. The typical voltage drop which may be encountered is included in the tube ratings, and the maximum is given in the Specifications. This includes the effect of temperature change during tube life and variation between individual tubes.

The **Control Characteristic** shows the relation between grid and anode voltage for the starting of a discharge, and gives the range of variations between tubes held at a condensed-mercury temperature of 40 C. In the case of gas tubes, temperature is not an important factor, The control characteristic is affected somewhat by the temperature, and this information is also available in the form of characteristic curves.

The **Ionization Time** may be defined as the time required for conduction to occur when the tube is operated with ample anode voltage and with the grid or grids at a potential substantially more positive than required for discharge.

The **Deionizatoin Time** is the time required under normal conditions to bring about the deionization necessary to regain control. The time given is based on a condition of full maximum average anode current and condensed-mercury temperature of 40 C.

Condensed-Mercury Temperature is the temperature which controls the mercury-vapor pressure and hence many of the tube characteristics. This is measured on the bulb just above the base, the point where the mercury vapor is condensing within the tube. Satisfactory tube operation depends upon operating within the specified temperature limits. When the tube is being heated it must be remembered that the heating time specified on the Description and Rating sheets refers only to the cathode. Additional heating must be allowed to bring the condensed-mercury temperature within limits.

CLASSES OF TUBES

Thyratrons are built in both glass and metal envelopes. The higher voltage tubes utilize glass construction for ease of insulation. Tubes built for control of large amounts of power at lower voltages (as for motor control and welding applications) are of metal construction to withstand handling and shock, and are adapted for panel-mounting, whereas smaller tubes are generally socket-mounted and may even have all electrodes connected at one end for ease of installation and conservation of space.

Mercury tubes are available where temperature can easily be controlled. Tubes with insert-gas filling are available for those applications where a wide range of ambient temperatures will be encountered. Where inert gas is used the tube characteristics vary only with pressure of the gas and are essentially independent of normal temperature changes.

APPLICATION CIRCUITS#

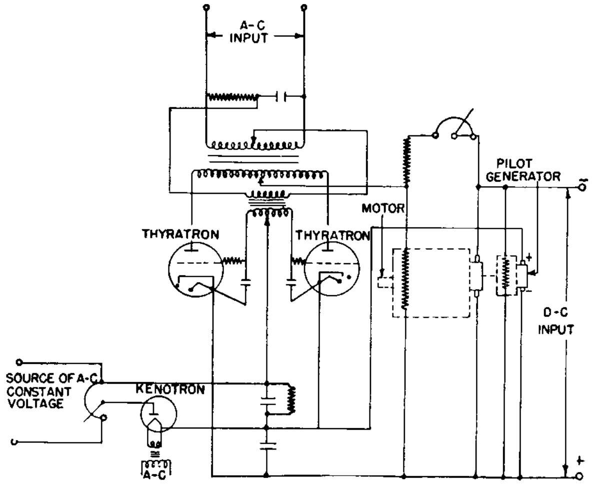
The versatility of these gas-filled tubes gives them a wide field of application. One of their applications is the control of the speed of d-c motors. One of the first motor speed-control applications was completed in 1929. Other trials followed and there is now a large demand for Thy-Mo-Trol (GE's trademark for motor control using electronic tubes) drives, by which d-c motors are operated from

#Circuits shown in ETI-116 are examples of possible tube applications and the description and illustration of them does not convey to the purchaser of tubes any license under patent rights of General Electric Company.

APPLICATION CIRCUITS (CONT'D)

constant potential a-c systems. These can provide speed control over ranges even larger than one hundred to one, operating at constant torque below basic speed by means of armature control and at constant horsepower above basic speed by means of field control. A circuit for such an application is shown in Fig. 2 below.

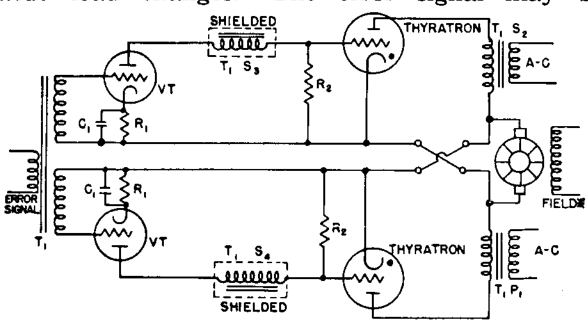
Some of the uses to which such a circuit may be applied include the maintenance of the correct tension during the reeling of the wire output of wire-drawing machines, the correlation of the speeds of various sections of rubber process conveyors to maintain a given loop of rubber sheet between the conveyor sections. It may be used to vary over wide ranges the speed of d-c motors driving frequency changers which supply power to highspeed textile motors, and to maintain the speed of the motors within narrow limits at any given setting, in spite of wide load changes. Used in these and similar applications, the thyratron provides an efficient, dependable aid to modern industry.



K-9033570 12-30-44

Fig. 2—Electron Tube Motor Control Circuit

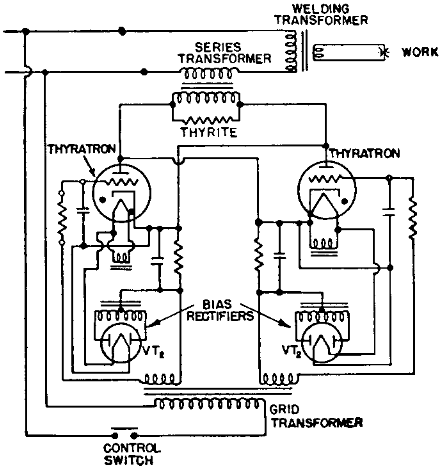
Another application is the thyratron motor-control circuit illustrated in Fig. 3 below. This is another circuit arrangement which can be used to operate a motor at constant speed in spite of wide load changes. The error signal may be obtained from a tachometer and standard source of voltage.



K-9033517 11-2-44

Fig. 3—Motor Control Circuit (*The Field of the D-c Motor is Supplied from a Separate D-c Source)

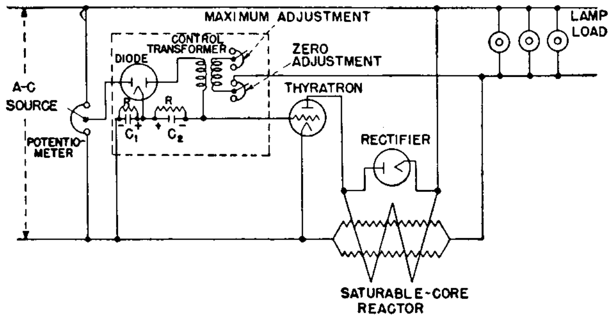
The use of gas-filled tubes for the control of power flow to resistance welders has revolutionized the fabrication of high-production units by accurate timing and uniform heating; the welding of high-strength aluminum alloys has been made practical by the use of thyratron control. Welders so controlled vary in size from 3 to 5 kilovolt-amperes to as high as 2000 kilovolt-amperes. A typical welder-control circuit is shown in Fig. 4 below.



K-9033516 11-2-44

Fig. 4—Thyratron Welder-Control Circuit

One of the first large industrial applications of the thyratron tube was the light-draining control board of the Chicago Civic Opera. This was followed by that of the Radio City Music Hall where 313 lighting circuits were controlled electronically. Many subsequent applications have proved the greater smoothness, efficiency, and flexibility of tube control, particularly with large numbers of circuits, than can be obtained with the conventional resistor board. A circuit for illumination control is illustrated in Fig. 5. The same basic scheme, using a saturable reactor may be applied to electric furnaces where thyratron rectifiers provide precision temperature control.



K-9033503 10-14-44

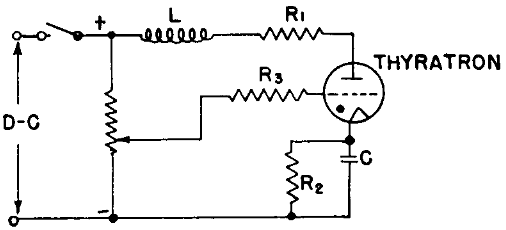
Fig. 5—Feed-back Circuit Used in Illumination Control

Fig. 5—Henney, Electron Tubes in Industry, P-250; McGraw-Hill Book Co., Inc., 1937

Potentiometers are provided to adjust circuits properly when the intensity control is set at maximum and at zero. These adjustments are made easily at the time of installation and are fixed thereafter.

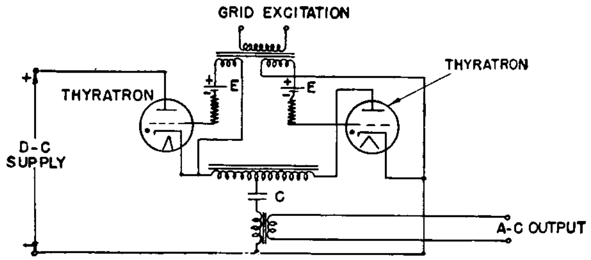
The feed-back circuit compares the voltage on the lamps with the voltage from the intensity control and acts on the grid of the controlled rectifier to hold the lamp voltage constant for any one setting of the intensity control.

Gas-filled tubes may be used in inverter circuits for the conversion of d-c to a-c power, using the deionization time of the tube for commutation. Three typical inverter circuits are shown in Figs. 6, 7, and 8.



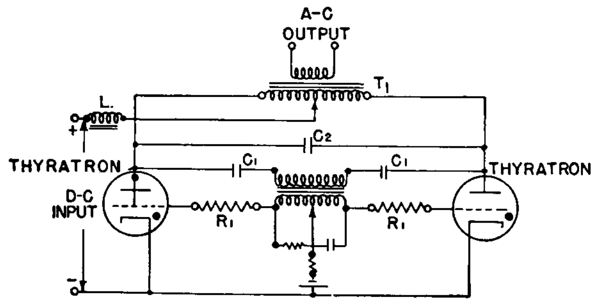
K-9033511 10-14-44

Fig. 6—Fundamental Single-Tube Inverter Circuit



K-9033586 1-9-45

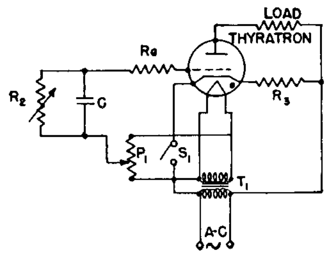
Fig. 7—A Series Connection of Thyratrons for Inverter Operation



K-9033512 10-14-44

Fig. 8—Self-excited Parallel-type Inverter Circuit

The time-delay circuit shown in Fig. 9 may be used for timing purposes in switching sequences for delayed applications of power, for printing presses, and for welding.

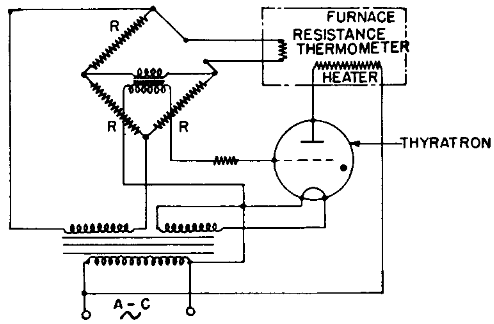


K-9033510 10-14-44

Fig. 9—Time-Delay Circuit

Another use of the thyratron is in temperature-control applications. A circuit for high-temperature control is shown in Fig. 10 below.

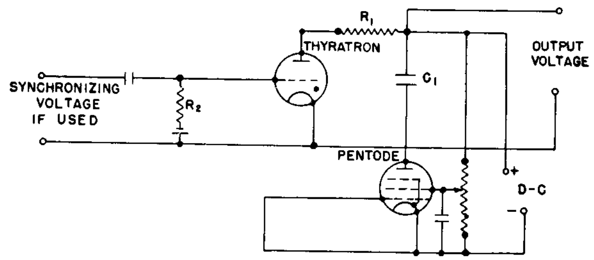
This circuit is generally applicable at temperatures for which a resistance thermometer may be used to form one arm of the a-c Wheatstone bridge. Variation of resistance of any arm of the bridge controls the normal temperature which is obtained. The thyratron is used to control the operation of current contactors when the heater current is extremely high.



K-9033563 1-1-45

Fig. 10—High-temperature Control Circuit

The thyratron may be utilized in relaxation-oscillator circuits to provide a linear time base for cathode-ray oscilloscopes. A relaxation-oscillator circuit is shown in Fig. 11 below in which R_1 and C_1 determine the frequency of operation.



K-9033506 10-14-44

Fig. 11—Relaxation Oscillator Circuit, for Time Base

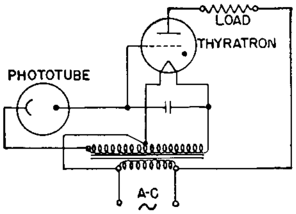
Fig. 6—Henney, Electron Tubes in Industry, P-232; McGraw-Hill Book Co., Inc., 1937

Figs. 7, 8, 10 and 12—Hull, A. W., General Electric Review, Vol. 32, No. 7; July 1929.

Figs. 9 and 11—Maddock, A. J., Journal of Scientific Instruments, March 1943.

APPLICATION CIRCUITS (CONT'D)

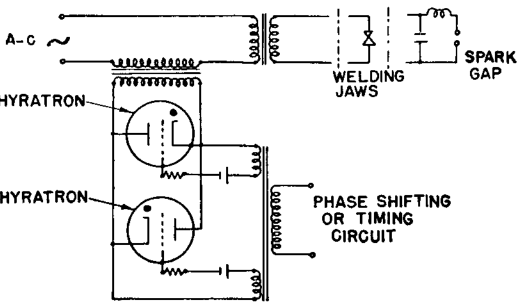
Thyratrons used with phototubes in circuits, such as that shown in Fig. 12 provide a fast, trouble-free, automatic means for counting articles or persons, or for operating doors. It is useful in many switching operations. The turning on of lights, when daylight falls below a certain level of intensity is an example.



K-9033509 10-14-44

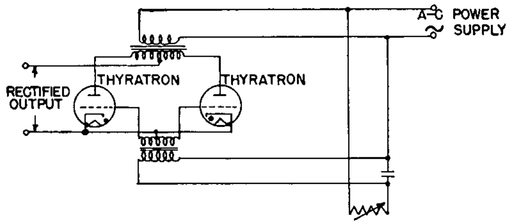
Fig. 12—Photoelectric Relay with a Thyratron (On-off Control Circuit)

Thyratrons are used to control the duration and amount of current passing for welding, X-ray work, or spectographic analysis using spark electrodes. A circuit for such applications is shown in Fig. 13.



K-9033524 1-1-45

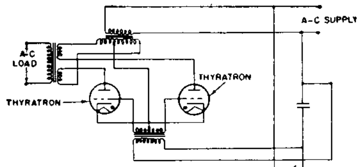
Fig. 13—Impedance Control of Alternating Current



K-9033502 10-14-44

Fig. 14—Variable Resistance Method of Control Producing Variation in Phase Between Resistance and Capacity Voltages

Since thyratrons are essentially rectifiers, one of their main uses is in rectifier circuits providing controlled d-c from an a-c source. Two circuits that may be used for power supply applications are shown in Figs. 14 and 15. Fig. 14 shows an arrangement designed to supply d-c power from an a-c source while Fig. 15 shows a means of supplying a load with variable a-c power from an a-c source.



K-9033565 1-1-45

Fig. 15—Power Supply Circuit Using Thyratrons (Supplying Variable A-c Power from an A-c Source)

In general, applications of these tubes can be used to provide faster operation, reduced maintenance and more precise control than can be accomplished by other methods. The automatic operation, amplification of power, quiet operation, flexibility, and saving of space, are additional features valuable for many industrial applications.

CIRCUIT DESIGN

Tubes are selected for these applications by consideration of the ratings, including peak and average currents to be conducted, and peak inverse and forward voltages to be applied.

If very high-impedance grid-supply voltage is to be used, a tube of shielded-grid construction should be chosen so that the grid current will be small and cause negligible drop in the supply. Ambient temperatures should be considered and mercury tubes used only where the condensed mercury can be held at temperatures above + 40 C.

CIRCUITS

The circuits illustrated are examples of types that may be used in some of the applications discussed in this article. It is impossible to illustrate in any discussion reasonably brief even a fraction of the circuits in which these tubes may be used for specific applications. Those illustrated show a few of the basic circuits for some of the major applications. Many of the others are modifications or combinations of these for the particular requirements of the task the tubes may be called upon to perform.

When a tube has been chosen for the application, the Specifications should be consulted to determine the limits of operation. The remainder of the circuit constants, voltages, and currents may then be checked to assure satisfactory operation of all tubes within the specified limits.

Fig. 13—Griffith, R. C., General Electric Review, Vol. 33, No. 9, Sept. 1930.

Fig. 14—Henney, Electron Tubes in Industry, P-198; McGraw-Hill Book Co., Inc., 1937

INSTALLATION

Mechanical

Thyratrons should be mounted in sockets or supports of good quality with connections of sufficient current-carrying capacity. A shock-absorbing mounting must be used if the tube is to be subjected to excessive vibration or sudden shock.

Electrical

The cathode should be operated preferably from an a-c source. If alternating current is not available, a d-c source may be used.

The cathode must assume operating temperature before electron current is drawn. The delay may be accomplished either by manual or automatic control of the anode or grid circuit. The time required for the cathode to come up to normal operating temperature is included under Technical Information. In the case of mercury-filled tubes, it is also necessary to bring the condensed-mercury temperature to the minimum operating value.

Thermal

When a mercury-vapor thyratron tube is first placed in operation, it is necessary to distribute the mercury properly before anode voltage is applied. This is usually accomplished by applying filament voltage to distill the mercury into the cooling chamber of the tube. The location of the cooling chamber is indicated on the outline drawing by the words "controlling mercury temperature."

The design of equipment should allow the tube to operate within the condensed-mercury temperature limits over the range of ambient temperatures to be encountered.

OPERATION

Four of the fundamental limits on the operation of thyratron tubes are the maximum peak inverse anode voltage, maximum peak forward anode voltage, maximum instantaneous anode current, and the maximum average anode current. These ratings were previously defined under "Definitions of Ratings."

Cathode Circuit

The cathode voltage should not deviate from the rated value by more than five per cent and the cathode should be allowed to attain operating temperature before any other potential is applied. Filament voltage should be set so that voltage fluctuations give an average value equal to the rated filament voltage. Too low filament voltage may result in very short life or perhaps immediate failure due to loss of emission. Too high voltage will shorten the life of the cathode somewhat.

Anode Circuit

Maximum Peak Inverse Voltage—The relations between the peak inverse voltage, the direct voltage, and the rms value of alternating voltage depend largely upon the individual characteristics of the rectifier circuit and the power supply. The presence of line surges, keying surges, or any other transient or wave-form distortion may raise the actual peak voltage to a value which is higher than that calculated from the sine-wave voltages in the transformer.

Maximum Instantaneous Anode Current—The ability of a given tube to conduct this instantaneous current without excessive voltage drop will depend upon cathode heating and the condition of the emitting surface.

Maximum Surge Current—The rating is intended to form a basis for set design in limiting the abnormal currents that occur during short-circuit conditions. It does not mean that the tube can be subjected to repeated short circuits without the probability of a corresponding reduction in life and the possibility of a failure.

Maximum Average Anode Current—In the case of a rapidly repeating duty cycle, this current may be measured on a d-c meter. Otherwise, it is necessary to calculate the average current over a period not to exceed a definite interval of time which is specified for each design of tube. For example, in a two-tube, 60-cycle rectifier feeding into an inductive load (so that the tube conducts approximately half the time with a square wave) a tube with a maximum instantaneous anode current of 15 amperes, a maximum average current of 2.5 amperes, and an integration period of 15 seconds, can carry a series of 15-ampere, 180-degree blocks of current (half the time) for 5 seconds out of each 15 seconds, or a series of 7.5-ampere, 180-degree blocks of current (half the time) for 10 seconds out of each 15 seconds.

Ionization Time—This time varies with the wave form and amplitude of the impressed grid voltage. When the tube is operated under normal conditions, this time will not exceed the value given.

Deionization Time—This time is dependent on temperature, grid voltage, anode voltage, and instantaneous anode current. The value under normal conditions is included under Technical Information.

The ionization and deionization times place a limitation on the maximum frequency at which the tubes can operate for any set of conditions.

The Voltage Drop—Where uninterrupted service is desired, the tube voltage drop should be checked at regular intervals by means of a cathode-ray oscilloscope or other suitable means. This drop is one criterion of tube condition, and its rapid rise from one test to the next will anticipate failure.

Grid Circuit

Approximate Control Characteristic—Since the control characteristic varies with individual tubes, only average curves can be given. In the case of mercury-vapor tubes, variation is also experienced as a function of temperature. For these reasons, and because of variable grid currents, it is always advisable in practice to supply the grid with several times the voltage apparently necessary.

Whenever possible, a phase shift or some other method of control which does not give an objectionable error due to these changes in characteristic should be used. This method permits fixing the time of starting of anode current anywhere in the positive half cycle of anode voltage. The average value of anode current is thereby completely controlled for variations from zero to maximum.

For a strictly on-and-off control, the magnitude method is satisfactory provided ample voltages are used on the grids. With the phase-shift method, more uniform control is obtainable since an excess of these voltages may be used at all times. This method eliminates the effects of grid currents, variation in grid supply voltages and variation in starting characteristic.

Note: The ratings and characteristics of a particular tube are given under Technical Information on the Description and Rating sheet for that tube.

Electronics Department
GENERAL ELECTRIC
Schenectady, N. Y.