● You can get Aerovox paper tubulars by the handy carton—ten in a box. Buy a box of the voltage and capacity you use most. Also get other values. Keep them on hand for jobs that must be done in a hurry.

Individually-tested
PAPER TUBULARS

● Sold by the hundreds of thousands, true, yet each and every Aerovox paper tubular continues to be *individually* tested. Please remember that.

Also, constant refinement has resulted in a high-quality product regardless of the low cost. Non-inductive section of selected foil and paper; heavily-waxed paper tube; extra-generous wax-filled ends neatly milled for a smooth finish; tinned copper leads that will not pull loose—these are typical refinements.

And now, to complete a fine job, these paper tubulars come dressed up in sparkling yellow, black and red varnished-paper jackets. They have eye appeal. They look as good as they really are.

AEROVOX PAPER TUBULARS

Type 484:
400 v. D.C.W. — .01 to 1.0 mfd.

Type 684:
600 v. D.C.W. — .001 to .5 mfd.

Type 1084:
1000 v. D.C.W. — .001 to .1 mfd.

Type 1684:
1600 v. D.C.W. — .004 to .05 mfd.

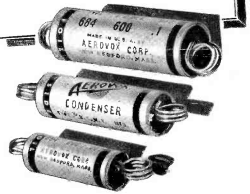
Ask Our Jobber...

He'll gladly show you these new Aerovox paper tubulars in sparkling yellow-black-and-red jackets. By all means get a stock of these paper tubulars and have them always on hand for those rush jobs. Ask for latest catalog—or write us direct.

NEW BEDFORD, MASS.,
U. S. A.
Sales Offices in All
Principal Cities

AEROVOX
CORPORATION

In Canada
AEROVOX CANADA LTD.
Hamilton, Ont.
EXPORT: 100 Varick St., N. Y.
Cable 'ARLAB'



Radio Editors of magazines and newspapers are hereby given permission to reprint in whole or in part, with proper credit to the Aerovox Corporation, the contents of this issue of the Aerovox Research Worker.

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

VOL. 13, NOS. 10 and 11 OCTOBER-NOVEMBER, 1941

50c per year in U.S.A.
60c per year in Canada

INDUSTRIAL APPLICATIONS OF ELECTRONIC DEVICES

PART II

By the Engineering Department

AEROVOX
Corporation

A paper by the Engineering staff of Aerovox Corporation. In order to preserve the unity of the text, this material which is too lengthy to be included in the usual four page edition of the Research Worker, is being published in three eight-page editions. Part I appeared in the combined August-September issue. Part III will appear in the combined December-January issue.

AEROVOX PRODUCTS ARE BUILT BETTER

Printed in U. S. A.

Copyright 1941 by Aerovox Corporation

Industrial Applications of Electronic Devices

PART II

SEVERAL tubes distinctly different from conventional vacuum tubes have been designed specifically to meet the rigorous demands of industry. In general, these special types may be considered to take up where the better-known high-vacuum tubes leave off. Their design and characteristics, as well as the manner in which they operate, differ so markedly from comparable features of the high-vacuum tube that an understanding of industrial tube operation is prerequisite to a study of the machinery and devices in which they are employed.

Essentially, most industrial tubes are controlled, high-current rectifiers. This is as might be expected since a large number of industrial demands are for electronic equipment that will switch high levels of electric power. These tubes have been provided with great sensitivity to meet another industrial demand—a minimum of apparatus.

Although some large vacuum tubes are used in industry, their capabilities per unit of cost do not begin to equal those of other special tubes. Industrial tubes differ constitutionally from the familiar high-vacuum tube mainly in the introduction into the former of certain inert gases or mercury vapor. This is in order that the useful phenomena of ionization may be made available. Electrically, they provide higher efficiency than do vacuum tubes, increased power - handling ability, reduced power loss, and lower voltage drop. In many cases, tremendous power amplification is indicated by the ratio of controlling power to controlled power.

In industrial tubes, ionization of gas or mercury vapor is enlisted to obtain the high anode (plate) currents commonly associated with these tubes. Their peculiar features of operation are due directly to employment of the ionization principle.

An interesting point is that industrial tubes may have hot or cold cathodes, depending upon the type of tube and the purposes for which it is intended. Several cold-cathode tubes have been developed. Dispensing with the heated filament is a useful expedient in cases where economy of installation, operation, and maintenance is an essential factor.

Noteworthy among these special type tubes are gaseous triodes and tetrodes, grid-glow tubes, thyratrons, ignitrons, and externally-controlled rectifiers such as the magnetron and permatron. Several of the important types will be discussed in this article. Our limited space does not permit a description of each of the numerous tubes having useful industrial characteristics, so we have selected widely-used representatives of each class.

GASEOUS TUBES

The gas-filled triode or tetrode, unlike its high-vacuum counterpart, is not primarily an amplifier. In its applications, the switching of current is of much more importance than amplification; although the power con-

verter, motor generator, and vibrator transformer. Inverter development continues, however, and more serviceable models are apt to be forthcoming soon.

In inverter circuits, gaseous tubes perform the function usually carried out by mechanical circuit interrupters—that of commutating direct-current flow through the primary winding of a transformer to induce an alternating current in the secondary. The fact that the firing rate may be controlled in the gaseous tube makes possible this action in the primary-circuit. During discharge periods, tube current flows through the transformer primary; and during periods of deionization, it is stopped. By proper choice of certain circuit components (particularly by arranging resistance-capacitance circuits to obtain proper time constants), the number of conduction intervals per second, and therefore the frequency of the secondary voltage, may be determined.

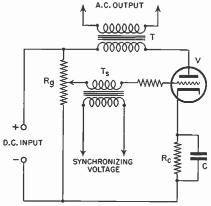


FIG. 4

A representative, basic one-tube inverter circuit is shown in Figure 4. V, is a gaseous triode, such as a thyratron, supplied with a positive anode voltage through the primary winding of the output transformer, T, from the d.c. power source. By means of the potentiometer, Rg, connected across the d.c. supply, a positive potential is applied to the thyratron grid. Rc is a cathode resistor and C its shunting capacitor.

Briefly, operation of the circuit is as follows: Direct-current flow takes place from the positive terminal of the d.c. power supply; through the output transformer primary, the tube, the capacitor; and to the negative terminal of the d.c. supply, quickly charging the capacitor to a voltage equal to the d.c. supply voltage if the resistance of the transformer primary is low enough and Rc is high enough. Still further, the primary inductance causes current to continue flowing beyond the instant when the capacitor is charged, eventually bringing the capacitor voltage up to a value higher than that of the d.c. supply before the flow finally ceases.

The tube then ceases to conduct because, due to the high capacitor voltage, its anode has become more negative than its cathode by the amount of the final capacitor voltage. Conduction cannot be resumed until the capacitor has discharged through the resistance, Rc, sufficiently for the grid-cathode voltage to attain the *critical value* for the tube.

The net result is that current flows in the output transformer primary in short pulses and that an induced alternating voltage appears across the secondary winding. The magnitude of this voltage, with respect to that of the d.c. supply, will be determined by the turns ratio of the output transformer.

The rate at which the tube and capacitor discharge and the d.c. pulses are sent through the transformer may be controlled by the potentiometer, Rg, and by the time constant of the Rc-C combination. This will establish the frequency of the output voltage. However, a small synchronizing voltage of the frequency at which output-voltage alternations are desired (or a multiple or submultiple thereof) may be applied to the thyratron grid through the transformer, Ts. This synchronizing voltage might be generated by an oscillator, miniature alternator, buzzer, or similar a.c. source.

There are several single-tube inverter circuits in somewhat limited use, but push-pull inverters are more generally employed. Figure 5 shows one such two-tube arrangement.

This circuit embraces the two thyratrons, V_1 and V_2; a direct-current reactor, CH; a storage capacitor, C; the synchronizing-voltage transformer, Ts; and the output transformer, To. As in the single-tube arrangement, the tubes in this circuit perform a switching or commutating operation, and the capacitor, C, serves to supply power during the switching period.

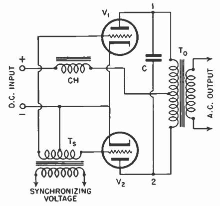


FIG. 5

In examining the action of the circuit, let us assume that both thyratron plates are positive and that the grid of V_1 has been carried sufficiently positive by the excitation voltage introduced through Ts to initiate the discharge in that tube. V_1 will then be in a conducting condition and current will flow from the positive side of the input d.c. source through the upper half of the output transformer primary and back to the negative side of the d.c. source through V_1. The grid of V_2 is negative at this time and that tube is non-conducting.

The voltage drop developed across the transformer primary by the current flowing through its upper half charges the capacitor rendering point 1 negative and point 2 positive.

When the grid polarity reverses, no change is thereby occasioned in the conduction of current by the V_1 plate circuit, the V_1 grid having lost control; but the second thyratron, V_2, becomes conducting, effectively connecting point 2 to the negative side of the d.c. line. The result is that a momentary negative voltage is applied to the plate of V_1 and control is thereby restored to the plate of V_1 and control is thereby restored to the V_1 grid.

The action is repetitive and produces an alternating voltage in the windings of the output transformer.

of the grid voltage but its phase as well, and control will be restored to the grid each time the anode voltage passes through zero.

In Figure 2, a gaseous triode is shown supplied with alternating potentials from a common source. A cathode tap on the secondary winding of the transformer, T, is placed so that the anode voltage, Ep, is developed by one section of the secondary and the grid voltage, Eg, by the other section. It is evident that the anode and grid voltages are 180 degrees out of phase with each other.

The grid voltage will be negative when the anode voltage is positive, a satisfactory condition for a negatively-controlled tube. However, the tube discharge will not be initiated until the negative half-cycle of grid voltage is at the ignition point for instantaneous anode voltage.

Reference to the two diagrams, A & B, of Figure 3 will clarify the mechanics of this process. Diagram A depicts the anode voltage alternations by the wave Ep and opposite-phase grid-voltage alternations by the wave Eg. Shaded portions of the positive half-cycles of Ep indicate intervals during which anode current flows through the load, R. (Figure 2).

Assume that the grid voltage level, P is the ignition potential for the particular plate voltage, X. The grid voltage half-cycle will again reach this value at P′, and on succeeding half-cycles at P″, P‴, P* and P**. In such case, anode current will begin to flow at this grid voltage, P, as indicated by the shaded portion of the first Ep half-cycle. However, when Eg next passes through the ignition potential, at point P′, the discharge is not extinguished for the reason that the grid lost further control after point P. The discharge continues, therefore, until the anode voltage reaches the zero line (point 0) when Ep is interrupted long enough for ionization to be curtailed and grid-control restored.

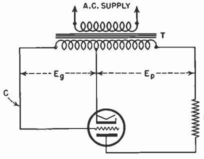


FIG. 2

When Eg again reaches the ignition potential, at P″ and P‴, it is of no consequence, since the anode potential has swung into the negative half-cycle and conduction does not occur. Not until the Eg ignition potential is reassumed at P*, when Ep is again positive, does conduction occur.

It will be observed from the shaded areas that conduction exists during the part of each positive half-cycle of anode voltage between the instant of firing and the end of the half-cycle. These shaded areas may be widened or narrowed (with the same values of alternating anode and grid voltages) by moving the Eg curve horizontally along the horizontal axis, changing its position with respect to the Ep curve. This is equivalent to stating that the interval of current flow may be lengthened or shortened by shifting the phase of the grid-voltage.

Diagram B in Figure 3 shows the result of shifting the Eg curve somewhat to the right, the Ep curve remaining stationary. Here, the points P and X correspond to identical values in Diagram A, but notice the shorter interval (shaded area) during which the tube conducts current.

Grid voltage phase shifting obviously cannot be accomplished in the unaltered arrangement shown in Figure 2. However, simple circuit additions are possible whereby the Eg phase may be shifted over a useful range. For example, the grid voltage may be obtained through a fixed capacitor inserted into the circuit at point C and a plate-to-grid variable resistor employed for phase-shifting adjustments. The conducting interval in each positive half-cycle of anode voltage will be inversely proportional to the setting of this resistor; extending over the entire half-cycle when the resistance is cut out entirely, the anode and grid voltages being in phase at this setting.

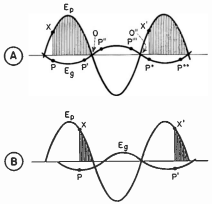


FIG. 3

Numerous methods for starting and stopping gaseous tubes by means of phase shifting have been devised. Some of these systems, abundantly described in the literature on these tubes, employ manual means of adjustment and others are fully automatic in operation. In the latter category may be included the practice of placing a photocell between anode and grid in the arrangement described in the preceding paragraph. Here, the varying resistance of the photocell replaces the manually-varied resistor. Still other phase-controlling circuits utilize bridge arrangements of resistance and inductance.[1] In general, any of the familiar phase-shifting networks may be employed for gaseous-tube control.

Individual experimenters will find the entire subject of phase-controlled gaseous rectifiers fertile territory, since almost limitless arrangements may be worked out for particular applications. Such arrangements might make use of grid voltages of various magnitudes, frequencies, and waveforms as individual requirements dictate.

INVERTERS

The inverter is an electronic device for converting direct current into alternating current. Its chief novelties are its full electronic action and general compactness, although this device has not yet supplanted the rotary con-

---

[1] *Ref. "Electron Tubes In Industry," Henney. pp.* 166-179.

trolled in the switching operation is usually hundreds of times larger than the power that controls the tube, and this might be regarded as a form of amplification.

The distinguishing electrical behavior of the industrial tube is due to the uncommon action of its grid electrode. The grid in a gaseous tube serves only to start and stop the flow of plate current, exerting no modulating effect upon this current once it has begun to flow. As a result, the plate current is either at its maximum value or at zero. Thus, the gaseous tube answers every description of a one-way current valve.

In a high-vacuum tube, plate current is reduced very nearly to zero by some value of negative grid voltage. If the grid voltage is then made less negative than this value, more plate current will flow in accordance with the Eg-Ip characteristic of the tube. Further variation of the magnitude or polarity of the grid voltage produces corresponding plate current variations.

In a gaseous tube, on the contrary, the plate current rises very sharply to its maximum value (for the applied plate voltage) at the instant that the grid voltage is made less negative than the cut-off value for that plate voltage. This rise may be delayed or graduated only by circuit conditions, not by grid voltage changes.

This peculiar action of the gaseous tube grid is attributed to a thin sheath of positive ions which forms around the grid structure as soon as ionization of the gas takes place and shields the grid electrostatically from the other tube elements.

The plate current of a gaseous triode may be in the hundreds of amperes, compared with the vacuum triode plate current which rarely exceeds several hundred milliamperes. The current-handling capability of the gas triode is therefore many times greater than the maximum values normally afforded by high-vacuum tubes.

Each value of plate voltage has a corresponding value of grid voltage which will prevent the discharge within the gaseous tube from taking place. A more negative value of grid voltage has no effect whatever, but a *less* negative value will allow the discharge to obtain. Once the discharge has been initiated, however, the grid loses control, as explained earlier, and no variation of the grid voltage amplitude will then alter the value of plate current or stop its flow. Only by removing the plate voltage long enough for deionization to occur may the plate current be interrupted and control be restored to the grid.

A definite time interval elapses between the instant of removal of the plate voltage and complete deionization. This *deionization time*, due to the fact that the ions and electrons do not disappear immediately from the active space, may be as great as several microseconds. The grid regains control only at the end of this deionization interval. Similarly, the gaseous tube does not "fire" immediately when the anode voltage is applied, but a few microseconds later. This interval is termed the *ionization time*. Industrial tubes used in certain circuits, such as inverters, must possess a short deionization time. In other applications, longer deionization times can be tolerated.

There are both positive-controlled and negative-controlled gaseous tubes. However, the latter type is most widely used at this writing.

High currents flow in gaseous tubes with low voltage drop. Hence, larger plate currents are obtained with lower plate voltages, a feat not possible with costly high-vacuum tubes. The greater current and power flow is due to the increased electron density provided by ionization. Plate power loss is very low.

In controlled-rectifier circuits employing gaseous tubes, it is possible to effect grid control of the unidirectional anode current flow either by means of a direct or an alternating grid voltage. In the latter case, the phase of the grid voltage may be so regulated with respect to the anode voltage phase that any desired portion of the positive half-cycle of the latter may be rectified.

THE THYRATRON

The thyratron is a hot-cathode, grid-regulated, heavy-current triode or tetrode. Like other industrial tubes, its internal power loss is very low compared to the high-vacuum tube, a feature which makes it ideal for the handling of large currents, and its cathode is designed for the emission of electrons in profuse numbers.

Depending upon type, the thyratron may be either gas-filled or it may contain a small amount of mercury to be vaporized during operation. Ionization of the gas neutralizes the space-charge electrons, thereby providing through the tube a constant voltage drop of low magnitude.

Once the thyratron plate current has been started, its actual value cannot ordinarily be altered by changes in the grid voltage. The control element in the thyratron, as in other gaseous tubes, does not permit a continuous control of plate current but serves solely as a trigger for initiating current flow.

For any value of thyratron plate voltage, there is a distinct value of direct grid voltage (the ignition point) at which ionization just occurs and plate current flow is started. From this point on, the effect of the grid voltage is negligible, the grid regaining control only when the tube discharge is extinguished long enough for deionization to take place. There is no initial flow of electrons when the grid is more highly negative than the ignition point.

Thus, the important thyratron characteristic curve does not depict the relationship between grid voltage and plate current, as is customary with high-vacuum tubes, but rather the Eg-Ep combinations at which plate current flow is just initiated.

Thyratron grid control is restored also when the plate voltage falls to a very low value approaching zero when Ep is less than the voltage required to maintain the arc; it being assumed that the time interval is sufficient for deionization to take place. Thus, if the thyratron anode is supplied with alternating voltage, control is restored twice during each cycle. The grid may then postpone the tube discharge to a point on the positive half-cycle corresponding to the extent to which the grid voltage is more negative. Operation of the tube may therefore be conveniently obtained over any predetermined portion of the alternating plate-voltage cycle. This feature is utilized in several industrial applications, as will be shown later.

Among its many important industrial applications, the thyratron finds employment as a heavy-current rectifier in which off-on action is obtained either by adjustment of the amplitude or phase of the grid voltage, in DC-to-AC inverters, and in trigger-type high-current control devices.

GRID-GLOW TUBES

The grid-glow tube is an interesting gaseous controlled-rectifier tube of the cold-cathode type. By dispensing with the filament-heating equipment necessary to most tubes, greater economies in auxiliary equipment and power consumption are effected.

In the grid-glow tube, the gas discharge is initiated directly by the tube potentials. The positively-charged anode attracts electrons from the cold cathode region with sufficient velocity to ionize the gas and produce the additional electrons required to carry the normal tube current.

When the grid voltage is positive in a grid-glow tube, the voltage between the grid and cathode is the sum of the anode and grid voltages. At a certain value of this sum (when the positive grid voltage has exceeded its critical value), a grid-cathode discharge through the gas is initiated, and shortly thereafter this discharge transfers to the anode, forming the main discharge of the tube. Thus, conduction in a grid-glow tube is established automatically by two steps in quick succession.

The length of the time interval between the initiation of the grid-cathode discharge and the formation of the main discharge depends largely upon the value of plate voltage. The voltage between the plate and grid electrodes must always be sufficiently high to transfer the discharge.

A particular advantage of the grid-glow tube is that it may be controlled by a low-voltage high-impedance source such as a photocell, by low values of current, and by the discharge of small condensers.

4-ELEMENT CONTROL TUBES

Several advantages are claimed for tetrode versions of the high-current grid-controlled rectifier tube. In general, these follow the advantages of tetrode and pentode vacuum tubes over the simpler triode type. For example, the gaseous tetrode draws less grid current than the triode, thereby presenting a higher impedance to the source of control voltage.

A particular feature of the shield-grid control tube is that the point at which the discharge is initiated in the gas may be varied by means of the screen voltage and may be made either positive or negative thereby. A fluctuating screen voltage will impart to the tube a control characteristic of reversing polarity, being successively positive and negative over various portions of the a.c. anode-voltage cycle. This feature enables interesting phase-controlled circuit arrangements.

POOL-TYPE CATHODES

Use has been made extensively of the mercury pool as a cold-cathode emitter of electrons. A typical example is the mercury-arc rectifier which is to be found in numerous stationary high-power installations. The mercury pool emits electrons in huge quantities in a rectifier tube and makes a surprisingly rugged cathode.

Special advantages of the pool-type cathode are that it requires no heating, is capable of heavy emission, will withstand severe instantaneous overloads, and possesses long life.

In the mercury-arc rectifier, the *initial electrons* which move to the anode during positive half-cycles of anode voltage are supplied by a "keep-alive" circuit consisting of a small arc maintained between a special keep-alive electrode and the cathode pool surface. When the arc "strikes" between the anode and the pool, a *cathode spot* is formed on the surface of the mercury and this becomes a far better source of electrons than common filaments and hot cathodes.

Such a rectifier has a very low voltage drop and may be employed to handle thousands of amperes, the main disadvantage of the light-duty types being the wasteful keep-alive circuit they require.

THE IGNITRON

The ignitron is an improvement upon the mercury-arc rectifier just described. This tube, while retaining the desirable characteristics of the arc rectifier (e.g., the cold, pool-type cathode, high current capacity, and long life), dispenses with the undesirable keep-alive circuit.

In the ignitron, the cathode spot is formed initially by a spark passed between a suitable substance, such as a carborundum crystal, and the cathode pool into which it is immersed. The discharge then shifts quickly to the nearby positively - charged anode within a few microseconds.

The ignitron electrode consumes little current compared to the keep-alive electrode of the conventional mercury-arc rectifier which must be kept supplied to maintain the arc.

The ignitron provides a controlled rectifier of the pool type which may be put into service instantly. No prolonged warm-up periods are required by this device.

EXTERNAL CONTROL. THE KATHETRON, MAGNETRON, AND PERMATRON

Up to this point, only tubes with internal control electrodes have been described. However, the control of current flow through high-level rectifiers is not entirely a property of the conventional grid alone. It is a matter of record that common mercury-vapor rectifier tubes of the heated filament type have been controlled by means of grids wound around the outside of their bulbs. Such simple successes have led to refinements of the external control electrode, and these introduce a still different class of high-current control tubes.

Although certain disadvantages of externally-controlled tubes may be at once apparent, distinct advantages of the external electrode are its isolation (in some circuits) from the discharge path and the possibility of insulating it from the other elements. Also, it may be readily applied experimentally to certain of the diode type rectifiers.

Both electrostatic and electromagnetic control have been accomplished externally. Electrostatic control is enabled by an external control grid which sets up an electrostatic field within the tube. Electromagnetic control is based upon the ability of a magnetic field passed through the anode-cathode interval to operate upon the discharge in the same manner as a negative grid voltage.

The kathetron is a special tube utilizing electrostatic control. The control-grid electrode, taking the form of a wire coil or mesh, is wound around the outside of the envelope and sets up a useful field inside the tube by a two-step chain of events: the external charge induces charges on the inside wall of the tube envelope, and these in turn set up the internal field.

The magnetron is a high-vacuum rectifier tube in which plate current flow is controlled by an external magnet winding. Operation of the magnetron, and other magnetically-controlled rectifiers, depends upon the ability of a magnetic field to deflect electrons in motion out of their normal cathode-anode path. Electrons moving toward the positively-charged anode are accelerated or retarded according to the strength of the magnetic field set up inside the tube by the external coil. Actually, their paths are bent by the field, and if the resulting curvature is great enough, they will not reach the anode at all and no current will flow.

Like the magnetron, the permatron makes use of an external magnet coil. The permatron is functionally identical with the thyratron, except in the respect of external control.

The permatron has a hot-filament cathode in its base end; an anode, usually of the circular plate type, in its opposite end. Between the anode and cathode extends a cylindrical "collector" electrode which completely surrounds the discharge path and may be connected either directly to the cathode or through a high resistance to the anode. When the magnetic field is applied across the tube (i.e., perpendicular to the discharge path), electrons leaving the cathode are deflected toward the collector and their velocity reduced to such an extent that ionization is prevented. Thus, the application of a magnetic field of sufficient intensity will stop conduction of current through the rectifier. Polarity of the magnetic field is of no consequence.

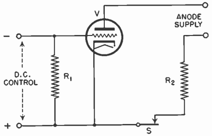


FIG. 1

When the magnetic field is removed by interrupting the magnet supply current, conduction is resumed and continues until the anode voltage is removed or reversed in polarity.

In permatron tests, as great as 200 kilowatts of power through the tube have been triggered by 1 watt flowing in the control-magnet winding. Various low-level sources of magnetizing current have been utilized in this high power-sensitivity control.

Outside of the realm of controlled rectifiers as such, the permatron has found special application in land-telegraph relay circuits, automatic battery chargers, and automatic faders for neon signs.

GASEOUS-TUBE CONTROL CIRCUITS

There are almost limitless ways of applying gaseous tubes to control operations. In general, a method may be found for employing the advantages of these tubes in any system in which their power-handling capabilities are not exceeded. Where the controlling current or voltage is of a low order of magnitude, appropriate vacuum-tube amplifiers may be called into service to raise these impulses to the level required by the control grid. By an adequate combination of photocell, vacuum-tube amplifier, and gaseous-tube circuit, even the tiny amount of energy in the light from a distant star might be utilized to start up a heavy electric motor or to turn on all the lights of a large exposition.

Figure 1 shows one of the simplest gaseous-tube control circuits. V is the thyratron or other gas-filled rectifier, arranged to control the load circuits. R_2 represents the load which may consist of a relay, motor, heater, or similar device to be actuated by the d.c. output of the tube. The anode supply is either a.c. or d.c. R_1 is an input shunt resistor across which the control current develops grid voltage. This component might be the load resistor in a vacuum-tube rectifier interposed between an amplifier and the gaseous tube when working with tiny control currents. S is a circuit-opening switch employed to interrupt the anode current momentarily to deionize the tube when used with a d.c. plate supply.

When direct current is supplied to both anode and grid in this circuit, the anode will normally be connected to the positive pole of its supply. The polarity of the grid voltage will depend upon whether the tube is positively- or negatively-controlled.

The value of steadily-applied control voltage developed across R_1 must be maintained at, or slightly higher than, the critical value for ionization. A reasonable reduction below this level will then trigger off the discharge and maximum current will flow through the load, R_2 until deionization is accomplished by means of the switch, S, or a reversal of the anode voltage polarity. Control of this circuit is achieved either by reducing the steadily-applied grid voltage or removing it entirely from the grid.

The anode supply might likewise be an alternating voltage, whereupon control action will remain substantially the same and rectification will be obtained through the tube.

If both anode and grid voltages are alternating, the tube discharge will be controlled not only by the magnitude