Nov. 13, 1934. C. STANSBURY ET AL 1,980,707

CIRCUIT CONTROLLER

Filed Nov. 7, 1931 3 Sheets-Sheet 1

Fig. 1

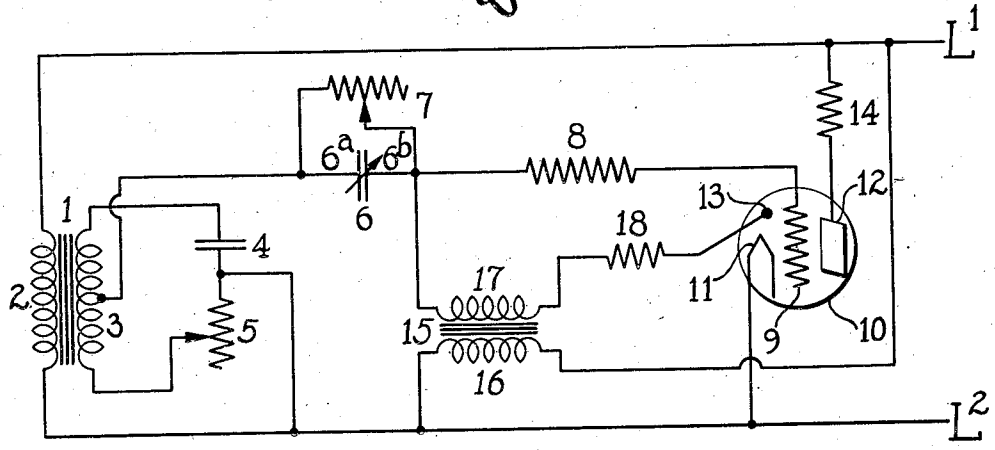
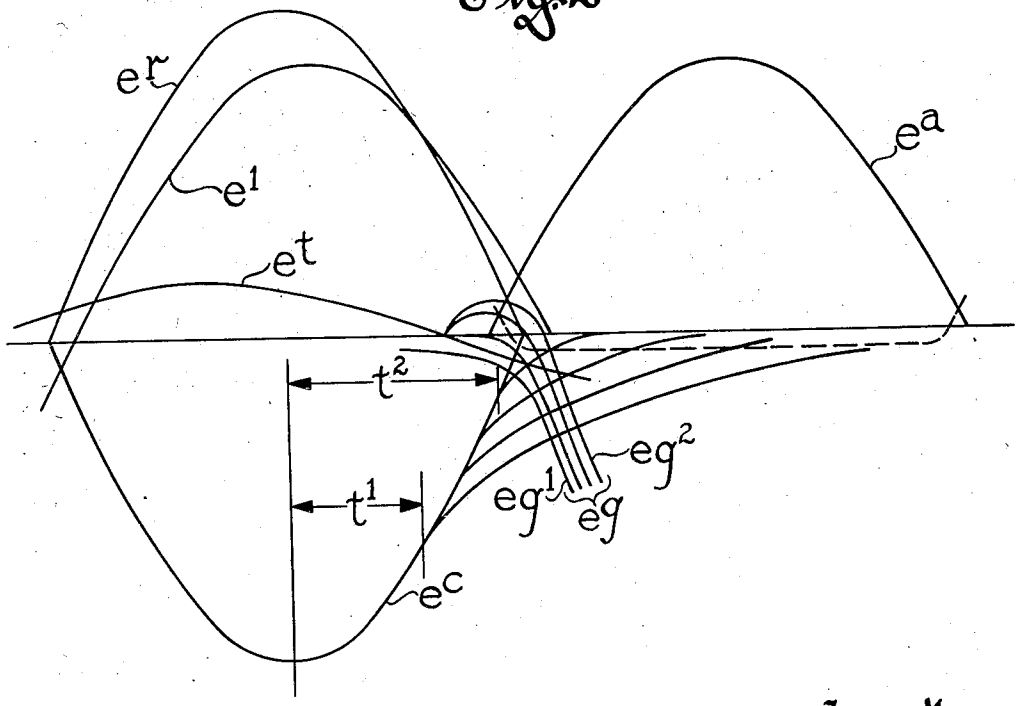


Fig. 2



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CIRCUIT CONTROLLER

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Fig. 3

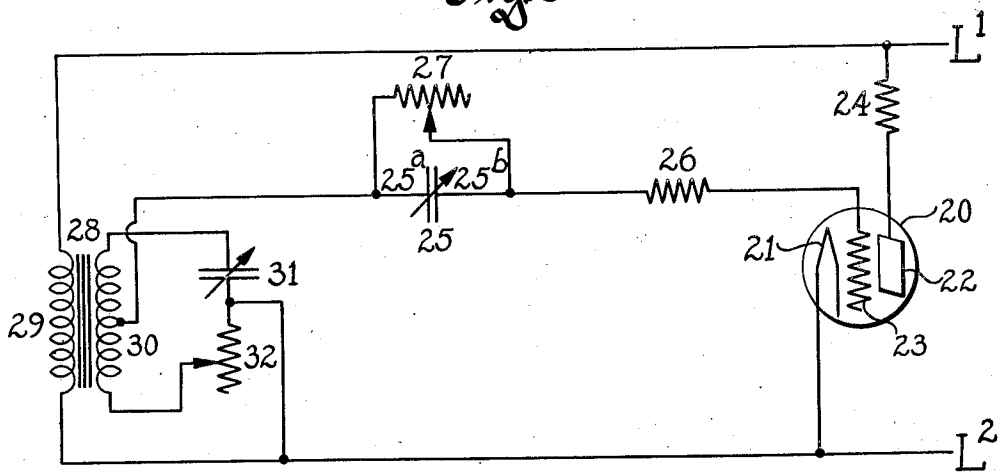


Fig. 4

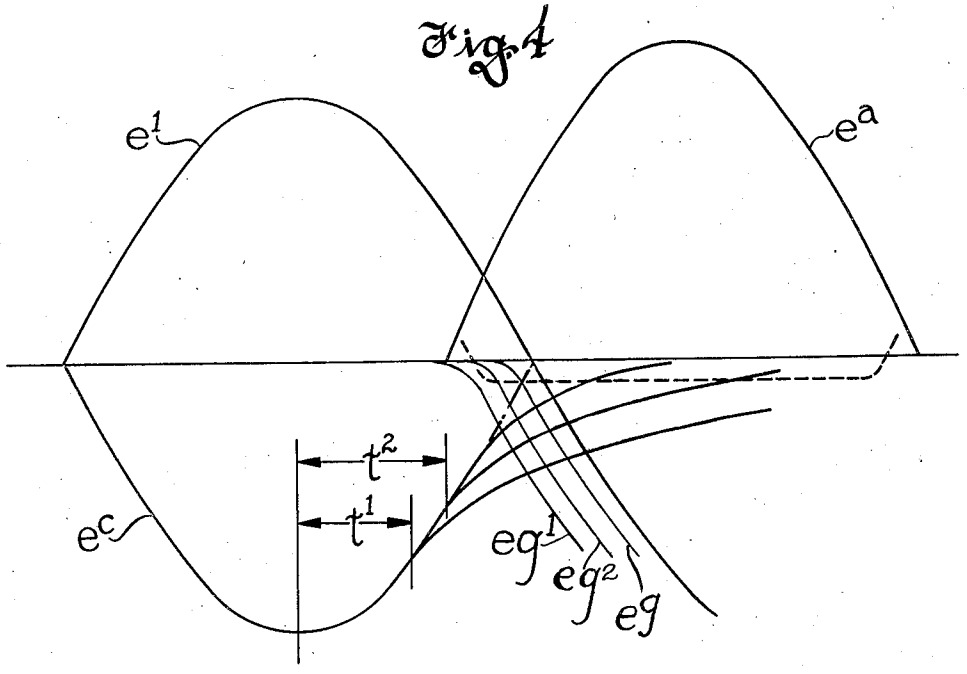
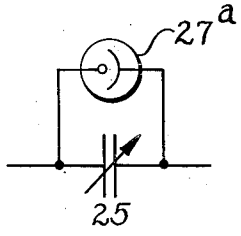


Fig. 3a



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CIRCUIT CONTROLLER

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Fig. 5

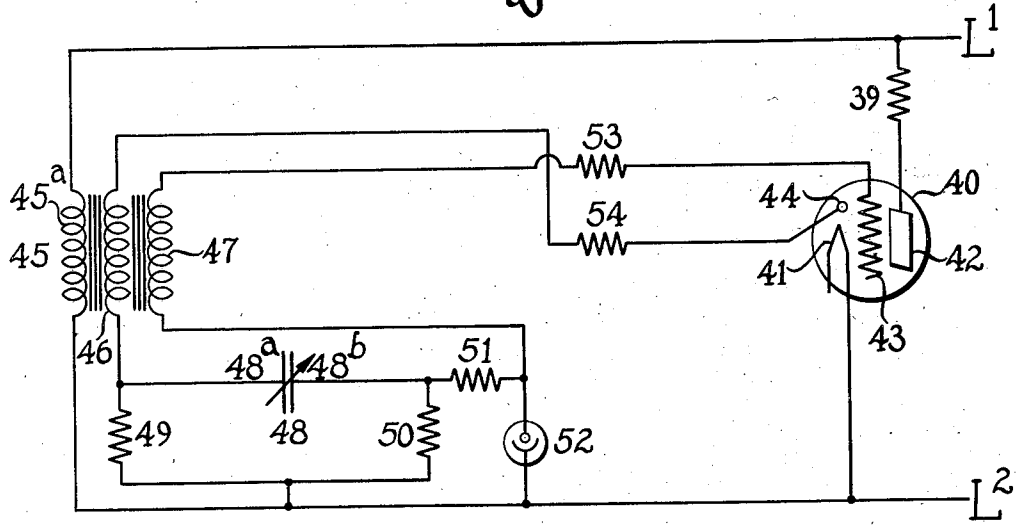
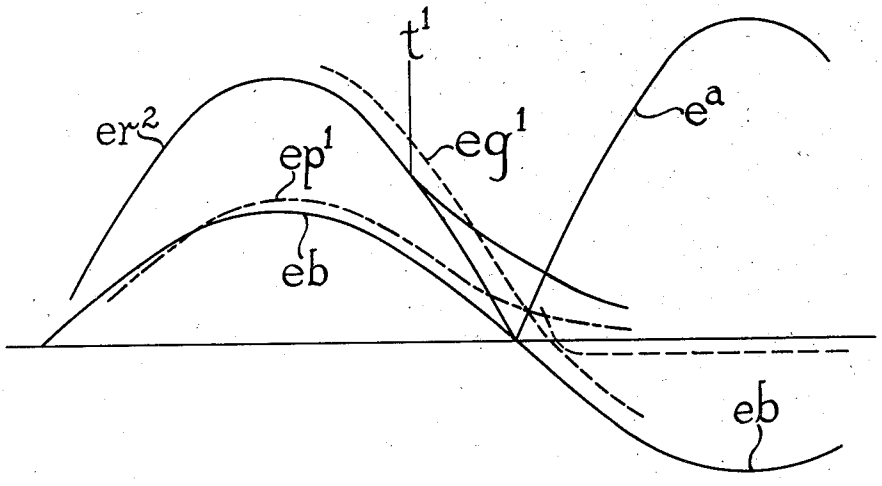


Fig. 6



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UNITED STATES PATENT OFFICE

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CIRCUIT CONTROLLER

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Application November 7, 1931, Serial No. 573,588

12 Claims. (Cl. 175—363)

This invention relates to the control of gaseous electron discharge tubes having a control electrode or grid and being supplied with an alternating voltage on the main electrodes.

An object of the invention is to provide for accurate control of the current passed by a gaseous electron tube which is supplied with alternating current, by varying the grid potential of said tube.

Another object is to provide a control system of the aforementioned character in which a relatively small variation of the controlling quantity produces a relatively great variation of the current supplied through the electron tube.

Another object is to provide a control system in which the initiating control element requires a minimum of current and a minimum of voltage variation to produce a maximum effect upon the controlled current.

Another object is to provide a control system in which a minimum of variation of the controlling current varies the current passed by the tube from substantially maximum to substantially zero value and vice versa.

Another object is to provide a control system of the aforementioned character whose response to the controlling influence is substantially unaffected by supply voltage variations.

Other objects and advantages will hereinafter appear.

In the co-pending application, Serial No. 455,444 by Stansbury, a system is described wherein the control electrode is supplied with the transient discharge voltage of an energy storage circuit so as to initiate discharge through the tube at different moments of the positive half cycle of the supply voltage and to thereby vary the effective current passing through the tube during each half cycle. By varying the discharge period of the storage circuit, the moment of ignition of the tube during each positive half cycle may be varied. The system described in said aforementioned application is particularly suitable in cases where it is desired to gradually vary the effective current passing through the tube from cycle to cycle. Such a control is generally called a continuous control.

The system disclosed in the present application differs from that of the aforementioned application in that the control of the current passing through the tube during succeeding positive half cycles is preferably, through not necessarily, discontinuous, that is, if during a given half cycle the tube passes current and the operating conditions vary so as to require a correction, the system preferably prevents the tube from conducting during the succeeding half cycle or during several succeeding half cycles until such time as the departure from normal operating conditions is corrected.

The critical grid voltage at which a gaseous tube becomes conducting for different anode voltages is influenced by the temperature at which the tube is operating and is also affected during the life of the tube by various other factors. It has been found however that the ignition potential for zero grid voltage remains very stable and is practically unaffected by the aforementioned factors. The method of control described in the present application is designed to initiate current passage through the tube when the critical grid voltage is substantially zero and therefore produces results which are much more reliable and consistent than the results obtained by other control methods.

The method of accomplishing this result resides in superposing upon the negative discharge voltage of the energy storage circuit which is impressed upon the grid, an alternating biasing voltage which by itself tends to make the grid of the tube less negative than the critical voltage at the beginning of the positive half cycle of the alternating current supply. If, under these conditions, the discharge voltage of the energy storage circuit upon which this alternating biasing voltage is superposed, combines with the latter so that the resultant voltage on the grid at the beginning of the positive half cycle is less negative than the critical grid voltage the tube starts and continues to conduct during substantially the entire positive half cycle. On the other hand, an increase of the negative value of the discharge voltage of the storage circuit at the beginning of the positive half cycle or a reduction of the alternating biasing voltage maintains the grid voltage more negative than the critical voltage at the beginning of the positive half cycle and thus the tube does not permit any current flow during the corresponding half cycle.

It will be noted, however, from the following description that to some extent it is possible to vary the moment of ignition near the beginning of the positive half cycle by either a variation of the storage discharge circuit voltage or of the alternating biasing voltage.

The system is particularly useful where it is desired to control a gaseous elctron discharge tube by means of photo-electric devices. Such devices are generally capable of handling only an infini-

tesimally small current and heretofore it has therefore generally been necessary to amplify the current of such photo-electric devices and in turn employ the amplified current for the control of the gaseous tube. With the present invention a part of the energy which supplies the ignition potential of the grid is furnished directly by the alternating biasing voltage referred to and only the energy represented by the discharge voltage of the energy storage circuit need to be controlled by the photo-electric cell or similar device. This latter energy is of sufficiently low magnitude to permit direct control by the photo-electric device without intervening amplifiers.

The accompanying drawings show various systems embodying our invention.

Figure 1 illustrates the control of a gaseous electron discharge tube through a photo-electric cell or other control element having a relatively high impedance and low current capacity. The biasing voltage in this system is supplied by a separate circuit which superposes its voltage upon the discharge voltage of the energy storage circuit.

Fig. 2 is a diagram of the voltages obtaining in the system illustrated in Fig. 1.

Fig. 3 is the diagram of a modification of Fig. 1, wherein the separate circuit for supplying the biasing voltage is eliminated, said biasing voltage being supplied from the same source which furnishes the energy for charging the energy storage circuit.

Fig. 3^a shows the connection of a photo-electric cell to the system illustrated in Fig. 3.

Fig. 4 is a diagram of the voltages of Fig. 3.

Fig. 5 is a further modification of the system illustrated in Figs. 1 and 3 in which the relation between the variations of the current or voltage of the controlling and the controlled element are the reverse from those illustrated in Figs. 1 and 3, and

Fig. 6 is a voltage diagram of the system illustrated in Fig. 1.

Referring now particularly to Fig. 1, the system is supplied from the alternating current lines L^1 and L^2. A transformer 1 has its primary winding 2 connected across the lines L^1 and L^2. A secondary winding 3 of said transformer has connected in series between its terminals the condenser 4 and the adjustable resistance 5. The common terminal of the condenser and the resistance is connected to the line L^2. The winding 3 is provided with a mid-tap to which is connected one plate 6^a of a condenser 6. An impedance or other variable control element 7 is connected in shunt with said condenser. The other plate 6^b of said condenser is connected through a relatively high resistance 8, to a grid 9, of an electron tube 10 having, besides the grid, a cathode 11, an anode 12, and an auxiliary anode 13. The cathode 11 which may be of the heated type or which may be activated in any other well known manner is connected to the line L^2 while the anode 12 is connected to the translating device 14 which has its other terminal connected to the line L^1. A transformer 15 has a primary winding 16 which is connected between the lines L^1 and L^2. One terminal of a secondary winding 17 of said transformer is connected to the condenser plate 6^b while its other terminal is connected through a resistance 18 to the auxiliary anode 13.

The operation of Fig. 1 may best be understood by reference to Fig. 2 and is as follows:

The transformer winding 3 has induced in it a voltage which by means of the condenser 4 and resistance 5 is divided into a capacity and a resistance component so that a voltage e^1 which is the vector difference of the voltage between the mid-point of winding 3 and its upper terminal, and that of the condenser 4, is impressed upon a circuit from the cathode 11 over line L^2, through condenser 4, upper half of winding 3, condenser 6, and parallel impedance 7, resistance 8 to grid 9. The transformer is connected so that substantially during the entire half cycle when the line L^1 is negative with respect to the line L^2 the potential of the grid tends to become positive with respect to the cathode.

There is also induced in the secondary winding 17 of transformer 15 a voltage e^t which voltage causes a current flow from said winding to the auxiliary anode 13, cathode 11, line L^2, condenser 4, and resistance 5, winding 3, condenser 6, and parallel impedance 7 and back to the winding 17. The voltage impressed upon the condenser 6 is thus the resultant of the positive values of the voltages e^1 and e^t and is indicated in the diagram by e^r. As a result of this impressed voltage the condenser plate 6^b acquires a potential e^c which is negative with respect to the cathode 11 and whose amplitude is approximately equal and opposite to that of the voltage e^r if the value of the resistance 8 is relatively high. The potential of the condenser plate 6^b thus becomes increasingly negative during the half cycle of the line voltage when the anode is negative until it has reached its maximum value when the condenser begins to discharge again. As the discharge current cannot flow in the direction opposite from the direction of the charging current, it can only pass through the resistance 7 from the plate 6^b to the plate 6^a. This discharge current and the resulting voltage follow, as is well known, an exponential law as indicated in the diagram. The voltage which is impressed upon the grid 9 is now the difference between the discharge potential of the condenser and the voltage e^1 as indicated by e^g in the diagram. It will be noted that just prior to the time t^1, which time is determined by the value of the resistance 7, the grid potential is low but as e^1 continues to vary as a sine function the grid potential e^g after the moment t^1 becomes increasingly negative. For a given value of 7 the grid is always more negative than the critical grid voltage of the tube during the positive half cycle, as indicated by eg^1, and, therefore, the tube never conducts any current. If, however, the impedance 7 is decreased so that the potential of the condenser 6 follows the sine curve up to the moment t^2 the resultant grid potential eg^2 is more positive than the critical grid potential during the first part of the positive half cycle and thus the tube 10 becomes conducting and continues to conduct current for the remainder of the positive half cycle.

It is obvious that the moment of ignition of the tube can thus be varied by varying the value of the impedance 7 or by varying the voltage e^t of transformer 15 to thereby vary the voltages e^r and e^c, or the value of the condensers 4 and resistance 5 may be varied which causes a variation of the voltage e^1. The latter voltage may also be varied by varying the voltage impressed upon the transformer winding 3 or by varying the transformer ratio.

An inspection of the diagram shows the relatively small variations of the value of the impedance 7 which determines whether the tube

is conducting or non-conducting during the corresponding half cycle.

The system shown in Fig. 3 is similar to the system shown in Fig. 1 except that the transformer 15 and the auxiliary anode 13 illustrated in Fig. 1 have been omitted. The system consists of a gaseous electron tube 20 having a cathode 21 which may be heated in any convenient manner, an anode 22 and grid 23. The cathode is connected to the line L^2, and the anode is connected through a translating device 24 to the line L^1 of an alternating current supply system. A condenser 25 having plates of opposite polarities 25^a and 25^b, respectively, has the plate 25^b connected to the grid 23 through an impedance 26 which is preferably non-inductive. A variable control impedance 27 is connected in shunt with the condenser 25. A transformer 28 has its primary winding 29 connected across the supply lines L^1 and L^2, while connected across the terminals of its secondary winding 30 is a condenser 31 in series with an adjustable resistance 32. The common terminal of the condenser 31 and the resistance 32 is connected to the line L^2 while the mid tap of the winding 30 is connected to the condenser plate 25^a. The variable resistance 27 may be replaced by a photo-electric cell 27^a as indicated in Fig. 3^a.

The operation of the system illustrated in Figs. 3 and 3^a will now be explained, having reference to Fig. 4 which shows the relation of the voltages of the system. As the lines L^1 and L^2 are energized, the voltage impressed upon the tube 20 is capable of causing the current to pass therethrough during those half cycles when the line L^1 is positive with respect to the line L^2, but only if the grid 23 has a potential which is less negative than the critical grid control voltage of the tube. In Fig. 4, e^a is the line voltage while the dotted line indicates the critical grid potential. If, on the other hand, the grid voltage during any part of the positive half cycle becomes less negative than the critical voltage the tube begins to conduct current at that moment and this current continues for the rest of the corresponding half cycle irrespective of subsequent changes of the grid potential. The transformer 28 is connected in such a way that the potential of the center tap of winding 30 during the critical part or all of the negative half cycle is positive with respect to line L^2. Under these conditions, electrons can freely flow from the cathode 21 to the grid 23. A charging current therefore flows from the winding 30 to the condenser 25 and parallel resistance 27 through resistance 26, grid 23, cathode 21, line L^2, to the midpoint between condenser 31 and resistance 32 back to the winding 30. The condenser 25 is thereby charged to the potential e^c and inasmuch as the impedance between the cathode 21 and the grid 23 is relatively small the grid potential e^g with respect to the cathode is practically zero as indicated in the diagram. Since also the total impedance of the circuit which has been traced is small outside of the condenser 25, the voltage impressed upon said condenser during the charging period is substantially equal in magnitude but opposite to the voltage e^1.

After this charging voltage e^c has reached its maximum value, it decreases again while the condenser 25 discharges. On account of the unilateral conduction of the tube 20, however, no electrons can flow from the grid to the cathode so that the discharge current of the condenser can pass only through the impedance 27 and the discharge rate is thus determined by the value of this impedance. The potential of the condenser therefore changes according to an exponential curve as indicated in the diagram whereby the shape of the curve depends upon the impedance 27. It has been found that the sinusoidal shape of e^c changes into the exponential shape at a time t^1 from the moment at which said potential is a maximum which time is substantially independent of the amplitude of e^c. As the potential of e^1 at this moment continues to be positive, the potential impressed upon the grid by the discharge of the condenser and the component e^1 of the transformer potential is the resultant and thus varies in accordance therewith as illustrated by the curve e^g.

Shortly before or after the grid potential e^g departs from substantially zero value to become substantially negative the potential of the line L^1 with respect to the line L^2 becomes positive so that now the tube tends to conduct current provided it is not prevented from so doing by a grid potential which is more negative than the so-called critical potential which is indicated by dotted lines in the diagram. It is apparent that for a given resistance 27 the grid potential eg^1 is always more negative than the critical potential and therefore the tube does not become conducting during the positive half cycle. If, however, the resistance 27 is decreased, the grid potential eg^2 is shortly after the beginning of the positive half cycle for a brief interval less negative than the critical voltage and the tube therefore becomes conducting at the moment t^2 and continues to conduct current during the remainder of the positive half cycle. The voltage e^1 is the vector difference of the voltage between the midpoint of winding 30 and its upper terminal and that of the condenser 31. Hence the phase displacement between the voltages e^c and e^1 and the anode voltage e^a may be varied by varying the relation of the resistance 32 and the condenser 31, thus affording a second method of controlling the moment of starting the discharge tube.

If the resistance 27 is replaced by a photo-electric cell 27^a as illustrated in Fig. 3^a, the resistance of the latter will vary in accordance with the illumination thereof. Therefore, if the illumination of the cell is above a certain value, the tube becomes conducting and if it is below a certain value, the tube remains non-conducting during the corresponding positive half cycle.

It is also apparent that the variation of the voltage e^a between the lines L^1 and L^2 which proportionally increases the voltage e^1 increases e^c during the charging period in the same proportion. Hence the variation in the grid voltage e^g is practically unaffected by variations in the line voltage and the moment at which the discharge in the tube is initiated is thus substantially unaffected by such line voltage variations.

Referring to Fig. 5 the gaseous electron tube 40 has a heated cathode 41 connected to line L^2, and an anode 42 connected through a translating device 39 to the line L^1 of an alternating current supply system. The tube is further equipped with a control electrode or grid 43 and an auxiliary anode 44. A transformer 45 has its primary winding 45^a connected across the lines L^1 and L^2. The transformer has two secondary windings 46 and 47 respectively. One terminal of the secondary winding 46 is connected to one plate 48^a of a condenser 48, the

other plate 48^b of said condenser being connected through a resistance 50 to the line L^2. A resistance 49 connects the plate 48^a to the line L^2. There is also a resistance 51 which is connected in series with a photo-electric cell 52 between the plate 48^b and the line L^2. The common terminal of the resistance 51 and photo-electric cell 52 is connected to one terminal of the winding 47, the other terminal of said winding being connected through a resistance 53 to the grid 43. The free terminal of winding 46 is connected through a resistance 54 to the auxiliary anode 44.

The operation of the system of Fig. 5 is as follows:

During the half cycle of the alternating voltage when the line L^1 is negative with respect to the line L^2 a voltage is induced in the transformer winding 46 of such polarity that a current is caused to flow from the auxiliary anode 44 to the cathode 41 over line L^2 through resistance 50, condenser 48, winding 46, resistance 54 back to the anode 44. A branch current also flows in a circuit parallel with the resistance 50 through the resistance 51 and the photo-electric cell 52, the potential at the common terminal of 51 and 52 depending upon the relative resistance values of two series connected elements and the voltage drop of resistance 50. A third current flows through the resistance 49. The currents flowing through the resistances 50 and 51 also pass through the condenser 48 and charge the latter in such a manner that the potential of plate 48^b is positive with respect to the cathode 41. The potential of plate 48^b varies in accordance with the curve er^2 in diagram Fig. 6. The voltage impressed upon the condenser 48 is the vector difference of the voltage of the winding 46 and the voltage drop through the resistance 50. The relation of its phase and that of the main voltage e^a therefore depends upon the relative value of the capacity of the condenser 48, the impedance of winding 46 and the resistance 50. As the instantaneous value of the voltage of the winding 46 reaches its maximum and then decreases again towards zero the condenser begins to discharge again, the discharge current tending to pass through winding 46, resistance 54 and auxiliary anode 44 to the cathode 41. However, no current can flow from the cathode 41 to the anode 44 and the condenser 48 can therefore discharge only through the resistances 49 and 50, the rate of such discharge depending upon the value of these resistances. The condenser voltage at first follows the sinusoidal law of the voltage of the winding 46, but at the moment t^1 it departs therefrom and follows an exponential law, the steepness of the exponential curve depending upon the value of the discharge resistances 49 and 50. It will be seen that at the moment when the voltage of the transformer winding 46 passes through zero the voltage er^2 has still a substantial positive value.

The photo-electric cell 52 has essentially the characteristics of a non-inductive resistance. Hence the resistance 51 and the cell 52 which are connected in parallel with resistance 50, act as a voltage divider and the potential of their common terminal, which depends upon the value of the resistance of the cell 52, is represented by the curve ep^1, whose amplitudes are proportional to those of er^2.

The winding 47 has induced in it a voltage which is in phase with and proportional to the voltage of winding 46 and is represented in the diagram by e^b. This voltage plus the voltage ep^1 is impressed upon the grid 43 during the discharge period of the condenser. The grid voltage eg^1 is thus the sum of the voltages e^b and ep^1 as illustrated in the diagram. If during the positive half cycle this voltage is at all times less than the critical voltage of the tube 40, no current will pass through the latter. If, however, at any time during the positive half cycle the voltage eg^1 of the curve intersects the critical grid voltage curve, the tube becomes conducting and thereafter passes current during the remainder of the positive half cycle.

As indicated, ep^1 may be varied by varying the resistance of the photo-electric cell 52. By decreasing the illumination of the cell, thus increasing its resistance, the instantaneous values of ep^1, and therefore also the instantaneous values of the grid voltage eg^1, become more positive and if sufficiently high the grid voltage eg^1 exceeds the critical voltage of the tube near the beginning of the positive half cycle so that the tube 40 becomes conducting. Hence if the illumination of the photo-electric cell is above a certain value the tube is conducting current during the positive half cycle and if it is below a certain value the tube remains non-conducting.

It is obvious that the controlling effect may also be varied by varying the voltages er^2 or e^b. It is also possible as in the other systems described, to vary the capacity of the condenser 48 or to vary the value of the discharge resistances 49 and 50.

It is also apparent that the alternating biasing voltage which is superposed upon the discharge voltage of the energy storage circuit may have superposed upon itself a unidirectional component, or may be a undirectional voltage of constant amplitude.

What we claim as new and desire to secure by Letters Patent is:

1. The method of controlling the flow of current through a gaseous electronic tube subjected to an alternating potential and having a controlling electrode which consists in periodically storing energy in a circuit, effecting discharge of said energy to produce periodically a transient voltage, superposing an alternating potential upon said transient voltage and subjecting said controlling electrode to the resultant potential.

2. The method of controlling the flow of current through a gaseous electronic tube subjected to an alternating potential and having a controlling electrode which consists in storing energy in a circuit during alternate half cycles of said alternating potential, effecting discharge of the stored energy during the other half cycle to produce a transient voltage, superposing an alternating potential upon said transient voltage and subjecting said controlling electrode to the influence of the resultant cyclic potential.

3. In combination, an alternating current supply, a circuit to be supplied thereby, a gaseous electron tube for controlling the current of said circuit and having a control electrode, an adjustable energy storage circuit, adjustable means to impress voltages upon said storage circuit and said electrode and to subject the latter to a potential which is the resultant of the voltage impressed thereupon and the transient voltage resulting from the discharge of said storage circuit.

4. In combination, an alternating current supply, a circuit to be supplied thereby, a gaseous electron tube for controlling the current of said circuit and having a control electrode, an adjustable asymmetrically conducting circuit, in-

cluding an adjustable energy storage circuit, adjustable means to impress voltages derived from said supply upon said circuits and adjustable means to subject said control electrode during alternate half cycles to a potential which is the resultant of the voltage of said asymmetrically conducting circuit and the transient voltage resulting from the discharge of said storage circuit.

5. In combination, an alternating current supply, a circuit to be supplied thereby, a gaseous electron tube controlling the current of said circuit and having a control electrode, an adjustable energy storage circuit connected to said control electrode, means to supply an adjustable charging current to said storage circuit and to impress a voltage upon said control electrode and adjustable means to superpose upon said first-mentioned voltage a transient voltage resulting from the discharge of said storage circuit.

6. In combination, an alternating current supply, a circuit to be supplied thereby, a gaseous electron tube for controlling the current of said circuit and having a control electrode, an adjustable energy storage circuit, adjustable means to supply a charging current to said storage circuit and to impress a transient voltage of said storage circuit upon said control electrode and adjustable means to impress upon said electrode a supplemental alternating voltage.

7. In combination, an alternating current supply, a circuit to be supplied thereby, a gaseous electron tube for controlling the current of said circuit and having a control electrode, an adjustable condenser and a parallel adjustable substantially non-inductive impedance connected to said control electrode, adjustable means to impress upon said condenser a potential which is a function of the supply voltage and to impress upon said control electrode a transient discharge voltage of said condenser and a supplemental potential which is a function of the supply voltage.

8. In combination, an alternating current supply, a circuit to be supplied thereby, a gaseous electron tube for controlling the current of said circuit and having a control electrode, a transformer connected to said supply, an adjustable condenser and a parallel adjustable substantially non-inductive impedance connected between said control electrode and a winding of said transformer, means connected to said transformer to vary the phase relation between said supply voltage and the voltage impressed upon said control electrode and to impress upon said control electrode a transient discharge voltage of said condenser and a supplemental potential which is a function of the supply voltage.

9. In combination, an alternating current supply, a circuit to be supplied thereby, a gaseous electron tube for controlling the current of said circuit and having a control electrode, a transformer having a primary winding connected across said supply and a secondary winding having an intermediate tap, an adjustable condenser and a parallel adjustable substantially non-inductive impedance connected between said tap and said control electrode, an impedance connected between one end of said secondary winding and one terminal of said supply, and an adjustable condenser connected between the other end of said winding and said terminal of said supply.

10. In combination, an alternating current supply, a circuit to be supplied thereby, a gaseous electron tube for controlling the current of said circuit and having an auxiliary anode and a control electrode, an impedance connected across said supply, an adjustable condenser and a parallel adjustable substantially non-inductive impedance connected in circuit with said control electrode and said first impedance and means in circuit with said first impedance and said auxiliary anode to impress upon said condenser a potential which is a function of the supply voltage and to impress upon said control electrode a transient discharge voltage of said condenser and a supplemental potential which is a function of the supply voltage.

11. In combination, an alternating current supply, a circuit to be supplied thereby, a gaseous electron tube for controlling the current of said circuit and having a cathode, an auxiliary anode and a control electrode, an adjustable condenser, a transformer having a primary winding connected across said supply, a secondary winding in circuit with said auxiliary anode and said condenser, one substantially non-inductive impedance each for connecting opposite plates of the condenser to said cathode, an adjustable voltage divider in parallel with one of said impedances and another secondary winding of said transformer connected between the voltage divider and the control electrode.

12. In combination, an alternating current supply, a circuit to be supplied thereby, a gaseous electron tube for controlling the current of said circuit and having a cathode, an auxiliary anode and a control electrode, an adjustable condenser and a parallel adjustable substantially non-inductive impedance, a transformer having a primary winding connected across said supply and a secondary winding provided with an intermediate tap, said condenser being connected between said control electrode and said intermediate tap, a second condenser and a second impedance for connecting the respective end terminals of said secondary winding to said cathode, a second transformer having a primary winding connected across said supply and having a secondary winding connected in circuit with said auxiliary anode and said control electrode.

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