

Aug. 31, 1948.

N. R. DAVIS

2,448,422

ELECTRONIC RELAY ARRANGEMENT

Filed April 16, 1946

4 Sheets-Sheet 1

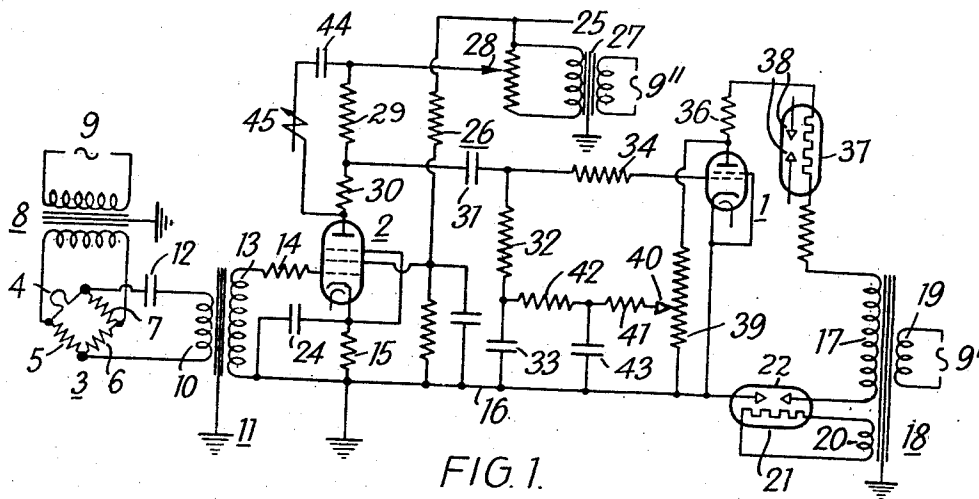


FIG. 1.

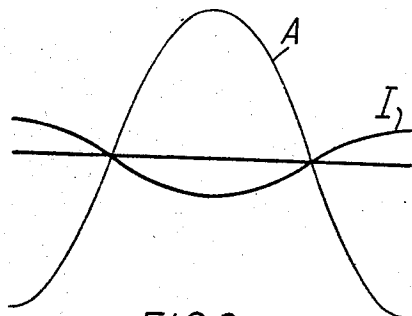


FIG. 2.

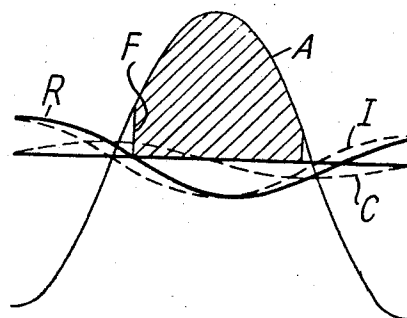


FIG. 3.

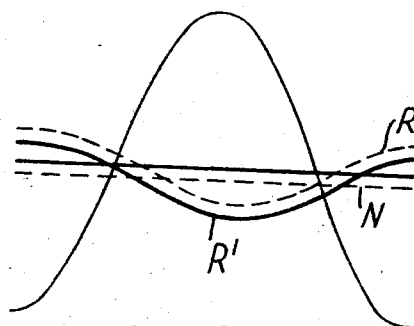


FIG. 4.

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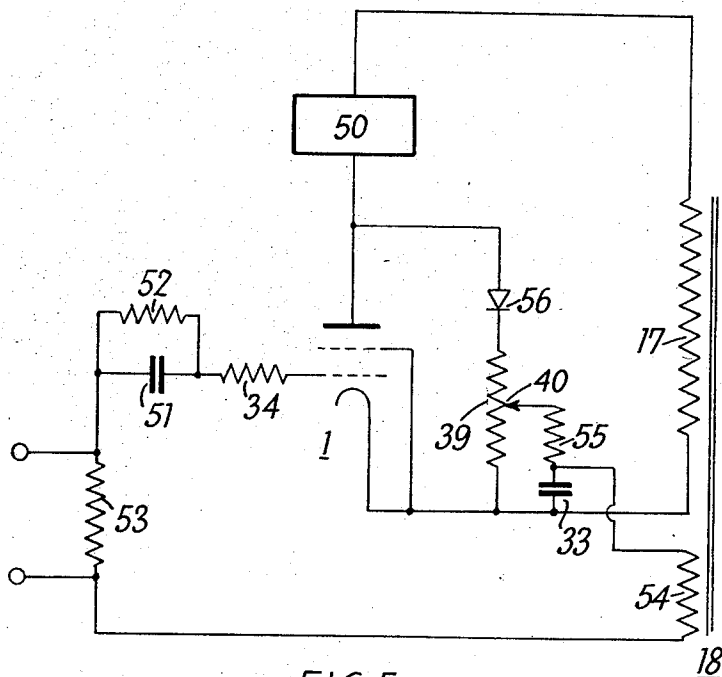


FIG. 5.

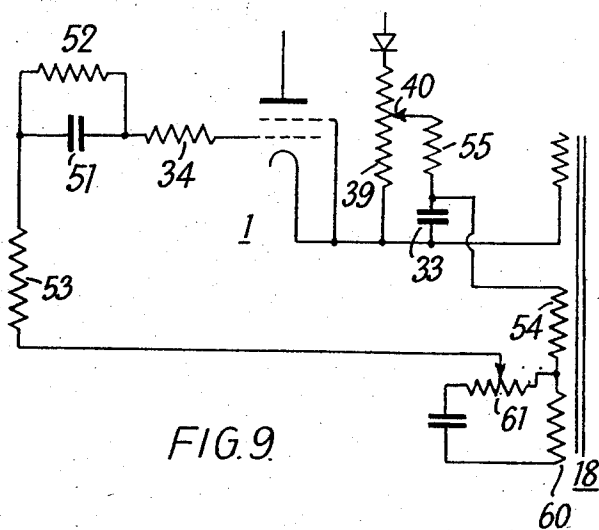


FIG. 9.

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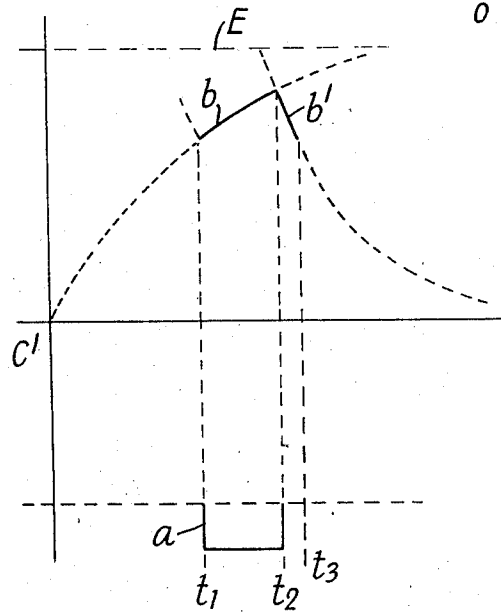
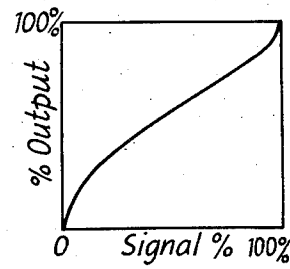
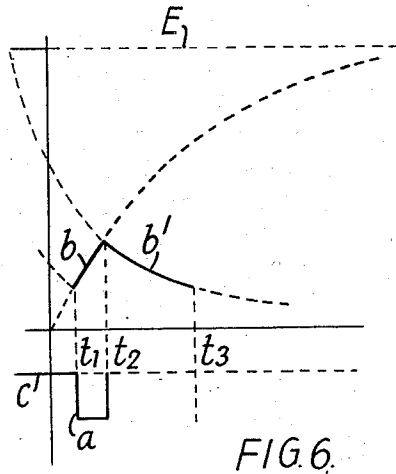
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4 Sheets-Sheet 3



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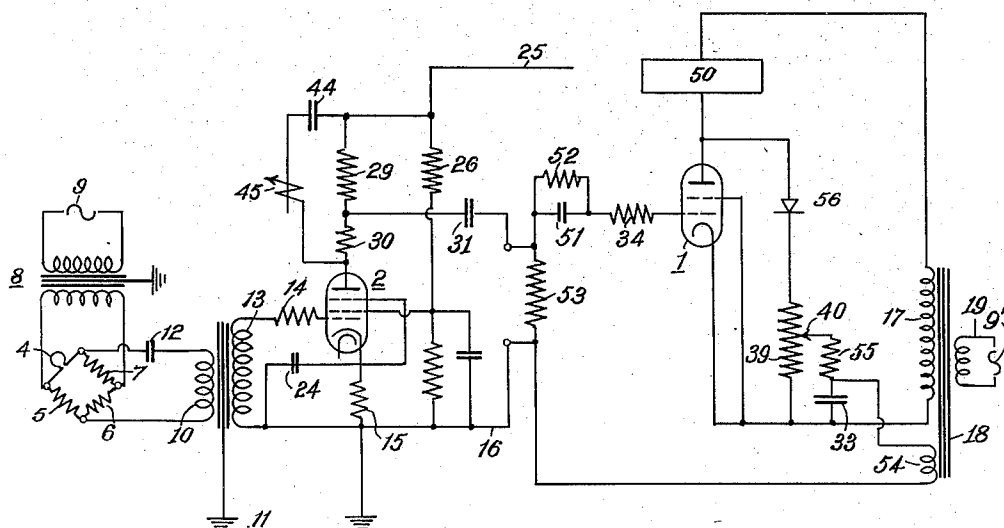


FIG. 10.

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Wenrich Patent

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UNITED STATES PATENT OFFICE

2,448,422

ELECTRONIC RELAY ARRANGEMENT

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Application April 16, 1946, Serial No. 662,527
In Great Britain May 7, 1945

9 Claims. (Cl. 315—194)

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This invention relates to electronic relay arrangements.

The invention has for its object to provide a relay arrangement the mean output of which is a function of the magnitude of a controlling quantity such that the current flowing in the output circuit may be large in relation to the current produced directly in an input or controlling circuit in dependence on said controlling quantity, and which may, when desired, be made sensitive to small variations of said controlling quantity. The arrangement according to the invention is, for example, eminently applicable in the control or regulation of temperatures or other quantities in industrial or other processes, although it is to be understood that the invention is in no way limited in these respects but has general application for the purpose just above broadly set forth.

According to the present invention, an electronic relay arrangement for the purpose above set forth comprises a discharge device of the gaseous conduction kind having its anode circuit energised or adapted to be energised from a source of alternating voltage, and having a control element connected in a control circuit producing a component of voltage dependent on the magnitude of a controlling quantity and including means dependent on anode conduction of said device for changing the resultant effective voltage produced in said control circuit in the sense to cause extinction and firing of the device in response to firing and extinction, respectively, of said device, and time delay means for modifying change of said resultant effective voltage, whereby anode conduction of said device will be periodically initiated and continued for a number of cycles of alternating anode voltage of the device dependent on the magnitude of said controlling quantity, so that the mean anode current of said device in each period of conduction followed by non-conduction will be proportional to or otherwise dependent upon the magnitude of said quantity.

More specifically, the electronic relay arrangement comprises a gaseous conduction discharge device having its anode and cathode connected or adapted to be connected in an alternating current circuit to be controlled by the relay arrangement, with a control electrode or element of said discharge device connected or adapted to be connected with a control apparatus to receive from the latter a variable input or controlling quantity controlling the initiation of anode conduction in said device, in combination with means respond-

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ing with time delay to said anode conduction arranged to produce on said control element a change of voltage such that said anode conduction, after initiation in dependence on the magnitude of said input or controlling quantity, will continue for a number of subsequent cycles of the anode voltage dependent on the magnitude of said controlling quantity. The arrangement according to the invention therefore provides an electronic relay in which a load device in the anode circuit is energised intermittently at a periodicity corresponding with a plurality of cycles of the alternating voltage applied to the anode of the discharge tube with the percentage time during each such period for which said current flows proportional to, or otherwise varying in manner dependent on the magnitude of, the controlling quantity, between limits of the latter.

The electronic relay arrangement according to the invention is useful for example in temperature and other regulating systems where the controlling quantity is dependent upon departure of a regulated temperature or other quantity from a desired constant or arbitrary or otherwise variable value, and the discharge tube has connected in the anode circuit thereof, a load device comprising means for producing a restoring effect on the magnitude of said temperature or quantity. The arrangement according to the invention is, however, applicable to any other kind of control system in which the mean output current is desired to be a function of the magnitude of a controlling or input quantity.

The means responding with time delay to the anode conduction of the gaseous conduction discharge device may for example conveniently comprise a resistance/capacity network or combination.

The response of the relay arrangement to the controlling quantity may be obtained, according to one arrangement, by including in the control circuit for the gaseous conduction discharge device an input impedance connected or adapted to be connected with control apparatus for producing across said impedance a control voltage for the relay arrangement, or, according to another arrangement, by including in said control circuit a control impedance which is itself variable in response to a controlling quantity for the relay arrangement.

According to another feature of the invention, the means responding with time delay to anode conduction of the gaseous conduction discharge device are connected in the control circuit of the latter so as to produce on the control element

thereof a voltage tending to prevent said anode conduction, acting in opposition to a voltage component applied to said control element in accordance with said control quantity for initiating anode conduction of the gaseous conduction discharge device. For example, said time delay means may be connected across the anode and cathode of said device so as to respond to asymmetry of the positive and negative half-cycles of the anode voltage of said device. In an alternative arrangement producing equivalent results, the means responding with time delay to anode conduction of the gaseous conduction discharge device are arranged to produce in the control circuit of said device a voltage component tending to maintain said anode conduction, and said control circuit includes means for producing on the control element of said device a voltage component tending to prevent anode conduction of said device after extinction of the latter, said voltage produced in response to anode conduction of said device falling during said conduction so as to produce on said control element the change of voltage resulting in termination of said anode conduction. For example, the time delay means may in this arrangement comprise a capacitance included in a rectifying circuit connected for energisation in accordance with the anode/cathode voltage of said device. In a preferred arrangement of this kind the control circuit of the gaseous conduction discharge device includes also a capacitance in series with means for applying to the control element of said device an alternating voltage of a phase adapted to prevent anode conduction of said device, this capacitance being chargeable during non-conduction of said device to produce on said control element a uni-directional voltage component tending to maintain non-conduction of said device.

According to another feature of the invention, the electronic relay means includes in combination with the discharge device a controlling apparatus adapted to govern the magnitude of a controlling component of voltage on the control element of said device, which controlling voltage component is an alternating voltage in quadrature, or otherwise phase displaced, preferably by a large amount, with respect to an alternating biasing voltage, which latter voltage will usually be of constant amplitude. This arrangement has the advantage that whilst the biasing voltage will be relatively large in order to be capable of preventing anode conduction during the whole of the alternating cycle applied to the anode of the discharge tube and will be in counterphase or substantially in counterphase with said anode voltage, the quadrature controlling component of voltage may be small, for example, may have a maximum amplitude of only one-tenth that of the biasing voltage since said component will have its maximum value tending to initiate anode conduction when the biasing voltage is zero, or is of only low value. The arrangement can therefore be made sensitive to small variations of the controlling component of voltage and thus of the controlling quantity. The controlling voltage component may, without departing from the scope of this feature of the invention, be a uni-directional voltage, similar considerations as regards sensitivity to those above set forth then also applying, but in general the use of an alternating voltage will be more convenient.

The alternating biasing voltage may conveniently be applied to the control element of the

discharge device directly such as from a suitable transformer, from the supply for the anode, or by being fed into the anode circuit of an amplifying thermionic valve through which the controlling voltage is applied to the control element of the gaseous conduction discharge device, so as to produce a ripple on the controlling voltage derived from said valve.

According to a further feature of the invention, where the control voltage component is an alternating voltage in quadrature or otherwise phase displaced with respect to an alternating biasing voltage, the controlling apparatus includes, or is coupled with the relay arrangement through, a circuit arrangement tuned or adapted to be tuned to the frequency of the alternating input voltage and applying to the relay arrangement a voltage which is phase displaced from, preferably being in quadrature or substantially in quadrature with, the voltage of an alternating current source from which said control voltage component is derived under control of the control apparatus. Conveniently the tuned circuit just above referred to may be a series resonant circuit connected or adapted to be connected with the controlling apparatus to receive current therefrom whilst the control voltage component for the control element of the discharge device is derived from a reactive element of said resonant circuit. In a preferred arrangement the reactive element comprises the primary winding of a transformer of low resistance in series circuit relation with a capacitive element, the secondary winding of said transformer being connected in a circuit controlling, directly or indirectly, the voltage in the control element of the gaseous conduction discharge device.

The invention will now be described by way of example with reference to the accompanying drawings, in which:

Fig. 1 is an electrical circuit diagram of one embodiment of the invention,

Figs. 2, 3 and 4 are diagrams with reference to which the operation of the arrangement of Fig. 1 will be described,

Fig. 5 is an electrical circuit diagram of a further embodiment of the invention,

Figs. 6 and 7 are curves explaining the operation of the arrangement of Fig. 5,

Fig. 8 is a curve showing a regulating characteristic which may be obtained with arrangements according to the invention,

Fig. 9 is an electrical diagram illustrating a modification of the arrangement of Fig. 5,

Fig. 10 is an electrical diagram showing the arrangement of Fig. 5 and a control circuit therefor.

The arrangement shown in Fig. 1, which will be assumed by way of example to be employed for the temperature control of an electrically heated furnace or other enclosure, although applicable for any other desired regulating or control purposes, comprises a gaseous conduction discharge device 1 of the kind known as a thyatron in combination with a thermionic amplifying valve 2 and a controlling apparatus which is indicated generally at 3.

In the embodiment of the invention being described the controlling apparatus 3 comprises a resistance thermometer 4 connected as one arm of a Wheatstone bridge in conjunction with fixed resistors 5, 6 and 7. This Wheatstone bridge is energised either directly or, as in the example shown, through the transformer 8, from a suitable source of alternating current at 9, such as the usual supply mains. The primary winding 10

of an input transformer 11 for the thermionic valve 2 is connected in series with a capacitance 12 across the output points of the Wheatstone bridge. The capacitance 12 is given such value in relation to the inductance of the primary winding 10 as to tune the latter to the frequency of the source 9. Furthermore the transformer 11 is designed so that the ratio of inductance to resistance of the winding 10 is high. The transformer 11 has a secondary winding 13 which is connected through a current-limiting resistor 14 with the control grid of the valve 2, said valve being a pentode as shown, or, alternatively, a tetrode. The cathode of the valve is connected, through a resistor 15 providing automatic grid bias in well known manner, with a negative busbar 16 which is connected with one end of a secondary winding 17 of a transformer 18 for supplying anode current to the gaseous conduction tube 1, as will hereinafter be described in more detail. The primary winding 19 of the transformer 18 is connected with the source 9 as indicated at 9' and said transformer is provided with secondary winding 20 which, in accordance with usual practice, supplies heating current to the operating element 21 of a thermal time delay relay 22, the contacts of which control the circuit of the winding 17 so that the high tension voltage will not be applied to the anode of the thyatron until the cathode thereof has reached the normal operating temperature, it being understood that the cathode heaters of both the thyatron and the pentode or tetrode 2 are in the usual way energised from the winding 20 or a further secondary winding of the transformer 18. The other end of the secondary winding 13 of the input transformer 11 is connected with the negative busbar 16; a decoupling capacitance 24 may be connected between this end of the winding 13 and the cathode of the valve 2 in accordance with usual practice.

The anode circuit of the valve 2 is energised from a suitable source of direct current applied between the negative busbar 16 on the one hand and a positive lead 25 on the other hand. This conductor 25 is, for a purpose which will hereinafter appear, connected with one end of a potentiometer resistance 26, to which there is applied by means of a transformer 27 an alternating voltage from and in phase with that of the source 9 as indicated at 9''. The variable tapping point 28 of the potentiometer is connected through an anode resistor 29 and a decoupling resistor 30 with the anode of the valve 2. The value of this decoupling resistor is large in relation to the anode resistance in the valve 2. The anode circuit of the valve 2 is resistance/capacity coupled with the grid or input circuit of the thyatron by means of the anode resistance 29, a capacitance 31, and a resistor 32 forming the input or control impedance of the thyatron control circuit. The resistor 32, instead of being connected directly with the negative busbar 16, is connected with said busbar through a capacitance 33 which, as will hereinafter be explained, constitutes the terminal element of a time delay network, and in view of its function as hereinafter described may conveniently be referred to as the timing capacitance. The grid of the thyatron is connected with the capacitance 31 through a grid current limiting resistor 34.

The anode circuit of the thyatron includes, in addition to a fixed resistor 35, the operating element of a suitable contactor for controlling the heat input to the furnace; in the example shown

this contactor comprises a thermal vacuum relay of which the heating element is shown at 37 and the contacts at 38. It will be understood that the contacts 38 may be connected in circuit with any desired means for controlling the heat input to the furnace. For example said contacts may be connected directly in circuit with the heating elements where the furnace is of the electrically heated kind. As shown the thyatron is preferably a tetrode.

A potentiometer resistance 39 is connected between the anode of the thyatron and the negative busbar 16. The variable tapping point 40 of this potentiometer is connected with the input of the time delay network hereinbefore referred to, which network comprises two resistors 41 and 42 in conjunction with a capacitance 43 and with the timing capacitance 33.

Preferably the anode resistance 29 and decoupling resistor 30 of the valve 2 are shunted by a capacitance 44 in series with a resistor element 45, the resistance of which falls with increase of applied voltage, this arrangement operating to limit the output voltage of the amplifying valve as hereinafter explained.

In the operation of the arrangement shown in Fig. 1, the pentode or tetrode 2 will apply to the control grid of the thyatron 1 a voltage comprising two components. The first component, which will be referred to as the control component, is derived from the variation of anode current of the valve 2 in dependence upon the alternating control grid voltage of said valve derived from the Wheatstone bridge 3. The second component, which will be referred to as the anti-phase component, is an alternating component injected into the anode circuit of the valve 2 from the potentiometer 26. The primary winding of the transformer 27 is connected with the supply source at 9'' in such direction that the corresponding alternating voltage component applied to the grid of the thyatron is in phase opposition to the voltage applied by secondary winding 17 of transformer 18 to the anode of the thyatron. The potentiometer 26 is adjusted so that the magnitude of the anti-phase component applied to the grid of the thyatron will be sufficient to prevent the thyatron firing when the resistance of the bridge 3 is balanced, and the voltage applied to the primary winding 10 of the input transformer is therefore zero. These conditions are represented in Fig. 2, in which the curve A shows one cycle of the anode voltage on the thyatron and the curve I the anti-phase component of grid voltage derived from the transformer 27 and potentiometer 26; at this time the anti-phase voltage constitutes the resultant voltage applied to the grid of the thyatron. It will be understood that in these circumstances the heating element 37 of the vacuum switch remains de-energised so that there will be no heat input to the furnace.

Assuming now that the temperature of the furnace is such that the bridge 3 is unbalanced, then the alternating voltage appearing across the output points of said bridge will cause an alternating current to flow in the tuned circuit comprising capacitance 12 and winding 10, and since this circuit is tuned and the winding 10 has a large ratio of inductance to resistance, a comparatively large voltage will be produced in the secondary winding 13 of the input transformer and will be substantially in quadrature with the current in the winding 10 and therefore substantially in quadrature with the voltage of the source 9 and the anode voltage of the thyatron. The ar-

rangement is such that the input voltage will lag with respect to the thyatron anode voltage upon unbalance of the bridge due to the furnace temperature being below a predetermined value at which the bridge is balanced; the amplitude of said input voltage will be dependent on the extent to which said bridge is unbalanced and therefore on the extent to which the furnace temperature falls below said value at which the bridge is balanced. The voltage derived from the bridge is amplified by the pentode and applied to the control grid of the thyatron superimposed on the anti-phase component derived from the potentiometer 26 from the transformer 27. As explained above, the secondary voltage of the transformer leads the current in the tuned input circuit by substantially ninety degrees, so that the control component of voltage is substantially in quadrature with both the anode voltage and the anti-phase voltage. These conditions are shown by Fig. 3, in which the curves A and I again represent the thyatron anode voltage and the anti-phase component of the grid voltage, whilst the curve C represents the control component of voltage derived from the valve 2 lagging in quadrature the control component I, giving a resultant grid voltage of the thyatron as shown by the curve R. This resultant voltage is, assuming a sinusoidal supply voltage, also a sinusoidal voltage, but its phase with respect to the anode voltage of the thyatron will depend upon the magnitude of the control component since the latter is in quadrature with the anti-phase component. As will be understood a small variation in the amplitude of the control component will be sufficient to effect a substantial displacement of phase of the resultant grid voltage since the control component is in quadrature with the anti-phase component of grid voltage and, for example, a maximum control component of one volt will provide the required operation in conjunction with an anti-phase component of the order of ten volts.

The arrangement is such that a reduction of the regulated temperature will retard the phase of the resultant thyatron grid voltage, and assuming the voltage derived from the bridge has sufficient magnitude the thyatron will fire at or near the beginning of a cycle as represented by the line F in Fig. 3, with a consequent conduction of anode current for substantially the remainder of the cycle as represented by the hatched area in Fig. 3. The vacuum switch or other contactor is therefore operated to close its contacts and apply heating current to the furnace to tend to raise the temperature thereof. It will be understood that in the absence of further operation the heating current would under these conditions be applied to the furnace during each cycle of the alternating voltage. By the employment of a vacuum switch for controlling the heating current of the furnace, or by equivalent means operating with a time delay, the heating current may be supplied without interruption in spite of the termination of thyatron conduction during alternate half-cycles.

There is applied to the grid of the thyatron a further component of voltage which is derived from the potentiometer 39. Since this potentiometer is connected between the anode and cathode of the thyatron it will be clear that the voltage across said potentiometer will, when the thyatron fires, be less than during the negative half-cycle of the anode voltage when the anode current is zero. As a result a negative voltage will build up on the timing capacitance 33 of the time

delay network 41, 42, 43, 33, and furthermore said voltage will build up at a rate which is dependent on the values of the capacitances and resistors of said network and the setting of the potentiometer 39. The result is that when the thyatron has conducted anode current for a sufficient time to cause this further biasing voltage to neutralise the effect of the input voltage, producing the conditions shown in Fig. 4, in which there is added to the resultant voltage R of Fig. 3 a uni-directional component N derived from the capacitance 33 producing the resultant grid voltage R', the thyatron will not fire at the commencement of the next cycle so that the vacuum switch will reopen its contacts and the heating current to the furnace will be interrupted.

In consequence of the termination of thyatron conduction the mean voltage applied to the potentiometer 39 is zero since the voltage applied to said potentiometer is now the same during each half-cycle of the anode voltage. Consequently the voltage appearing across the capacitance 33 will gradually disappear and a condition will again be reached at which the voltage derived from the input transformer 27 in the anode circuit of the valve 2 will be able to initiate firing of the thyatron and the cycle of operations above described will thus continue.

Due to the exponential charging and discharging voltage curves with respect to time of the timing capacitance in the time delay network the proportion of each cycle of operations during which the charge from said capacitance is being increased and reduced will depend upon the input voltage, that is to say upon the magnitude of the quadrature component derived from the transformer 13 so that the proportion of time for which in each cycle of operation heating current is supplied to the furnace will depend upon the temperature of the furnace. This aspect of the operation will be sufficiently understood by those skilled in the art, but is also described in more detail with reference to Figs. 6 and 7 in connection with Fig. 5. This proportion of time increases with reduction of furnace temperature, so that the average heat input to the furnace is varied in the opposite sense to variations of furnace temperature, thereby to maintain the latter substantially at a desired value.

At the upper limit of regulated temperature the firing of the thyatron is prevented in every cycle of the alternating supply voltage with continuous de-energisation of the furnace whereas at a given lower limit of furnace temperature the quadrature or control component of thyatron grid voltage is sufficiently great that the voltage derived from the potentiometer 39 will never become sufficient to terminate the anode conduction of the thyatron, so that the latter fires in every cycle of the alternating supply voltage and the furnace is continuously energised. Between these limits the average energy input to the furnace is continuously variable in response to variation of furnace temperature. The arrangement enables the energy input to the furnace to be varied over the whole range between said limits, namely from continuous de-energisation to continuous energisation by a small variation in the magnitude of the furnace temperature, with correspondingly sensitive and accurate regulation of the furnace temperature to the desired value. By a suitable choice of the parameters of the time delay network the duration of the complete cycle of operations of the vacuum switch can be selected appropriately to the particular application of the in-

vention. It is contemplated for example that in one particular application of the embodiment shown in Fig. 1 said period may be of the order of sixty seconds.

The well-known anode current/anode voltage characteristic of the pentode or tetrode as employed for the amplifying valve 2 has the advantage that the grid voltage of the thyatron derived from the transformer 27 will not be unduly reduced by the anode-cathode path of said valve in parallel with the coupling capacitance 31 and coupling resistor 32.

The capacitance 44 and resistor 45 operate to limit the magnitude of the quadrature component which may be applied to the grid of the thyatron, so that the phase of the resultant alternating voltage on said grid can never be displaced by more than ninety degrees from the anti-phase relation to the anode voltage of the thyatron irrespectively of the extent to which the bridge is unbalanced. In practice the phase displacement will be limited to a lesser amount than ninety degrees. The resistor 45 may be one of the well known materials having the resistance/voltage characteristic hereinbefore referred to.

It will be understood that the specific arrangement of thyatron and grid circuits thereof as above described may be employed in combination with other controlling means than the amplifying valve above described, and that the combination of thyatron and amplifying valve with their input circuits as specifically described above may be employed in conjunction with other means producing a desired input voltage than those specifically described, for obtaining response to any desired quantity.

In some particular applications of the arrangement shown in Fig. 1 some interference with the desired operation may result from the fact that the timing capacitance 33 of Fig. 1 tends to be charged by the grid current of the thyatron during the positive half-cycles of thyatron anode voltage when the thyatron is not firing and to be so charged in the sense to apply a negative potential to the grid. Fig. 5 shows a modification of the arrangement whereby this objection may be avoided, the arrangement of Fig. 5 including a rectifier in the charging circuit of the timing capacitance and being such that the voltage derived from the anode circuit of the thyatron applies to the timing capacitance, through said rectifier, a charge in the sense to apply a positive potential to the thyatron grid during the positive half-cycles of thyatron anode voltage whilst the negative half-cycles of anode voltage are ineffective to modify the charge on the timing capacitance. This charge will balance the negative charge which the timing capacitance tends to receive from the thyatron grid and when the charge derived across the timing capacitance from the thyatron anode circuit sufficiently exceeds that due to the grid current the thyatron will ultimately fire. The consequent reduction of thyatron anode-cathode voltage drop on the positive half-cycles will then allow the positive charge on the timing capacitance to fall so that the thyatron is extinguished whereupon positive voltage on the timing capacitance again builds up to repeat the above described cycle of operation. In order that the period of operation may be made of sufficient duration and regularity means are also provided whereby a negative voltage component is applied to the grid during the non-conduction of the thyatron so that to extin-

guish the thyatron the voltage on the timing capacitance must fall to a considerably lower value than that necessary to initiate firing. As will be explained in more detail hereinafter the arrangement is controlled by the application of a control component of voltage to the grid circuit of the thyatron, which control voltage determines the values of voltage of the timing capacitance necessary to initiate and terminate firing.

of the thyatron so that due to the exponential charging and discharging voltage-time curves of the timing capacitance with respect to time the percentage time in each cycle of operation for which the thyatron fires will vary with the magnitude of said control voltage in similar manner to that obtained with the arrangement of Fig. 1.

In Fig. 5 the thyatron is again shown at 1, the vacuum relay or other controlled device is shown at 50, connected in the anode circuit of the thyatron for energisation from the anode supply secondary winding 17 of the transformer 13. The thyatron grid is connected through a grid current limiting resistor 34 with a capacitance 51 shunted by a resistor 52, the grid circuit including also in series circuit relation a resistor 53 forming the input or control impedance of the thyatron control circuit, which resistor 53 may be the resistor 32 of Fig. 1, a further secondary winding 54 of the transformer 13 and the timing capacitance 33. The timing capacitance is connected, in series with a resistor 55, between the cathode of the thyatron and the variable tapping point 40 of a potentiometer 39, which potentiometer, as in Fig. 1 is connected between the anode and cathode of the thyatron, but in the arrangement of Fig. 5 has connected in series therewith a dry-plate rectifier 56 which allows current to flow in the potentiometer only during the positive half-cycles of anode voltage.

The input resistor 53 is connected with any desired means producing thereon a control voltage which is representative of some condition on the magnitude of which it is desired that the average anode current of the thyatron, and therefore the average value of some controlled quantity, shall depend. Preferably this input voltage is either derived from a direct current source or is an alternating voltage in quadrature or substantially in quadrature with the voltage produced by the winding 54, although it could be an alternating voltage in phase or anti-phase with the voltage of winding 54. The first mentioned arrangements are in general preferred since the last mentioned arrangement has the disadvantage that a much larger amplitude of the control voltage is required, for the same reasons as described in connection with Fig. 1.

The operation of the arrangement of Fig. 5 will first be described for a case where the input voltage is derived from a direct current source. Fig. 6 is a set of curves of the various components of grid voltage plotted on the ordinates against time, and shows the operation during one cycle of operation, extending over a plurality of cycles of the anode voltage, for example extending over three thousand such cycles of anode voltage. The horizontal line c in Fig. 6 represents a negative control voltage of a given magnitude. At the commencement of the cycle, at time t_1 , the thyatron is extinguished so that the voltage of the secondary winding 54 will cause current to flow between the grid and cathode of the thyatron during alternate half-cycles of the supply voltage, that is to say during the half-

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cycles when the voltage in winding 54 acts downwardly in Fig. 5; on the other hand current will not flow from the winding 54 during the other half-cycles. As a result the capacitance 51 will be charged in the direction to apply a negative potential to the grid, and this negative voltage on capacitance 51 will have a magnitude determined by the values of the several resistances in the grid circuit. The resistance/capacitance combination 52—51 is arranged with a short time constant, for example less than 0.1 second, so that the capacitance 51 comparatively rapidly reaches a steady voltage, said time constant, however, being sufficiently great that the capacitance will hold its charge for a few cycles of anode voltage. This rise in negative voltage on the capacitance 51 is shown at *a* in Fig. 6 increasing the resultant negative voltage on the grid from the line *c* to a value equal to the sum of the control voltage *c* and the voltage *a* on the capacitance 51. Simultaneously the voltage across the capacitance 33 will rise, since at the end of the preceding cycle of operations the thyatron has been conducting so that the anode-cathode voltage thereof had a low value, but upon extinction of the thyatron at time *t*₁ the increase of anode-cathode voltage substantially to the anode supply voltage of the secondary winding 17 will commence to charge the capacitance 33 through the rectifier 56 during the positive half-cycles of anode voltage. The time constant of the resistance/capacitance combination 55—33 is made considerably greater than that of the combination 52—51, for example is about ten seconds. The voltage across the timing capacitance 33 therefore commences from whatever voltage remained at the commencement of the cycle of operation and rises comparatively slowly as shown by the curve *b* toward the final steady state voltage *E* of the capacitance. When the voltage across the capacitance 33 has risen sufficiently to neutralise the sum of the voltages across the capacitance 51 and that across the resistor 53, that is has risen to a value somewhat in excess of the sum of the voltages *c* and *a*, the thyatron will fire, namely at the time *t*₂. The load 50 is therefore energised during following half-cycles of the anode voltage. Due to the fall of the anode-cathode voltage drop to a low value the timing capacitance 33 is no longer charged through the rectifier 56 but discharges through the resistor 55 so that the voltage across said capacitance falls as shown by the curve *b'*. This fall of voltage on capacitance 33 does not, however, immediately extinguish the thyatron, because as a result of the firing of the thyatron at time *t*₂ the fall of grid-cathode resistance causes immediate disappearance of the negative charge on the capacitance 51 so that the voltage *a* is removed and the grid voltage becomes the voltage *c*. Furthermore, the winding 54 is now effective to apply an alternating voltage component to the grid in anti-phase to the anode voltage. The ratio of anode voltage from the winding 17 to the grid voltage from the winding 54 is made less than the gas ratio of the thyatron, that is to say less than the ratio just sufficient to fire the thyatron in the absence of other components of grid voltage. The grid voltage is thus now determined by the voltage of the timing capacitance 33 and the voltage across the input resistor 53 with the superimposition thereon of the alternating voltage from the secondary winding 54. This alternating voltage is in anti-phase

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to the anode voltage so that it is zero at the commencement of the cycle and does not prevent firing of the thyatron so long as there is a sufficient resultant positive component of voltage on said grid at the instant in each positive half-cycle of anode voltage at which the anode voltage reaches the anode-cathode voltage drop of the thyatron.

The grid voltage is therefore sufficient to fire the thyatron at each succeeding positive half cycle of anode voltage until the timing capacitance has been discharged to a voltage substantially equal to the control voltage *c*. When this occurs the thyatron is extinguished, namely at time *t*₃ and the above described cycle of operations is repeated. Thus the capacitance 51 is again rapidly charged negatively in accordance with the line *a* whilst the timing capacitance 33 is charged and discharged comparatively slowly according to curves *b* and *b'*.

From the above description it will be clear that the arrangement operates to fire the thyatron for alternate periods each including a plurality of cycles of the alternating anode voltage, with the intervening periods in which the thyatron is extinguished also each including a plurality of cycles of said anode voltage. As will now be described, the ratio between the duration of the firing periods to the duration of the extinguished periods, that is to say the percentage firing time, is varied by variation of the control voltage.

Assuming that the magnitude of the negative input voltage is increased to the value shown by the horizontal line *c'* in Fig. 7, then at the time *t*₁, that is to say at the end of the preceding cycle, the thyatron is extinguished at a higher value of voltage on the timing capacitance 33 than is the case in Fig. 6. The voltage across the timing capacitance then rises less steeply than in Fig. 6 due to the exponential form of the charging curve. A longer period therefore elapses between the time *t*₁ and time *t*₂ at which latter time the timing capacitance voltage is sufficient to overcome the sum of the voltage *a* and the increased voltage *c* to cause firing of the thyatron. The fall of the voltage across the timing capacitance as the latter discharges is moreover more rapid than in Fig. 6, again due to the exponential form of the discharging curve, so that the resultant grid voltage drops more rapidly from the value substantially equal but opposite to the sum of the control voltage *c* and the voltage *a* produced during extinction of the thyatron on the capacitance 51 to the value of the control voltage. Consequently the number of cycles of anode voltage during which the thyatron fires is reduced and the number of cycles during which the thyatron is extinguished is increased thereby to reduce the resultant percentage time of firing.

In the limit, when the control voltage is made substantially equal to the difference between the steady state voltage *E* of the timing capacitance 33 and the steady state negative voltage *a* produced on the capacitance 51, the thyatron will be continuously extinguished. If the control voltage is reduced to zero the duration of the periods of extinction becomes still shorter than in Fig. 6, the voltage across the timing capacitance being required then to vary only between substantially zero and a value substantially equal and opposite to the voltage *a* in Figs. 6 and 7. If the control voltage is reversed so as to act in the same direction as the voltage across the timing capacitance then the percentage time of firing is increased still further until in the limit when

the control voltage is substantially equal to the voltage a the thyatron fires continuously. It will thus be seen that the percentage time of firing is continuously variable between zero and one hundred percent by variation of the control voltage. The percentage time of firing is plotted in Fig. 8 on the ordinates against the control voltage and it will be seen that over the major part of the range of variation the percentage time of firing is substantially proportional to the magnitude of the control voltage.

When the control voltage is an alternating quantity in quadrature with the voltage from the winding 54 so as to control the firing by phase shifting of the resultant alternating voltage applied to the thyatron grid, the operation will be similar to that above described, adjustment of the phase of said alternating voltage being equivalent to varying the magnitude of a direct control voltage as regards the voltages of the timing capacitance 33 at which firing will be initiated and terminated and therefore having similar effect on the percentage time of firing.

Fig. 10 shows the arrangement of Fig. 5 controlled by an alternating current arrangement in which the resistor 53 corresponds, for example, with the resistor 32 of Fig. 1 forming part of a resistance/capacitance coupling between the anode of the valve 2 of Fig. 1 and the thyatron grid circuit. The valve 2 may for example again be controlled by the means 3 of Fig. 1. The potentiometer 26 and transformer 27 of Fig. 1 are, in connection with the arrangement of Fig. 10, omitted from the anode circuit of the valve, since the anti-phase component of the thyatron grid voltage, produced in the arrangement of Fig. 1 by this means, is in the arrangement of Fig. 5 produced instead by the transformer secondary winding 54.

Instead of the input or control quantity being derived externally and applied to the grid circuit in the form of a voltage developed across the input resistor 53, the latter may itself be subject to variation in accordance with the desired control quantity so as to modify the voltage conditions in the grid circuit in accordance with change of said control quantity. Thus variation of the resistor 53 in Fig. 5 will modify the steady state negative voltage to which the capacitance 51 will be charged. There is then no external control voltage according to line c of Figs. 6 and 7, but instead each period of thyatron extinction must be sufficient for the voltage on the timing capacitance 33 to rise from substantially zero to the steady state value of the voltage on capacitance 51, that is to overcome the voltage a of Figs. 6 and 7, so that the duration of each period of extinction is reduced as the value of resistor 53 is increased, since this reduces the value of the voltage a in Figs. 6 and 7. On the other hand, when the thyatron fires, it will continue firing for a number of cycles of the anode voltage sufficient for the voltage on the timing capacitance to fall again substantially to zero, so that the duration of each firing period increases with increase of the value of resistor 53. Adjustment of the value of resistor 53 also has a further effect on the time at which the thyatron is extinguished in each cycle, since said resistor affects the resultant phase of the voltage which is applied by the winding 54 to the grid during firing of the thyatron. Increasing the value of said resistor retards the phase of the alternating voltage component applied to the grid during the firing of the thyatron, which as hereinbefore described has

the effect of lengthening the firing periods. The result is, therefore, that increasing the value of resistor 53 increases the percentage time of firing of the thyatron.

It will be understood that the resistor 53 can in the application of the invention just above described be varied in any desired manner, automatically or otherwise in response to a desired controlling quantity, and may furthermore be a resistor which varies inherently in response to said quantity, such as for example in response to the magnitude of a controlled temperature.

Of the two effects of the variation in resistor 53 producing variation of the percentage time of firing, namely, the effect on the voltage to which capacitance 51 is charged and the effect of the phase shift of the alternating component of grid voltage, one or the other can be caused to predominate as desired by suitable selection of the circuit parameters. Where the change in resistance of the resistor 53 is small in relation to the average value of said resistance over the required range of variation of the controlling quantity therefor, said resistor may be included in a suitable bridge or like arrangement which will render the grid circuit of the thyatron desirably sensitive to the required small variation of the resistor 53. Fig. 9 shows one such arrangement, applied to a case where the variation of percentage time of firing is determined mainly by the phase shift of alternating grid voltage component by the resistor 53.

In the arrangement of Fig. 9, the transformer 18 is provided with a further secondary winding 60 having connected thereacross a potentiometer 61 and capacitance 62 in series with one another. The variable tapping point of this potentiometer is connected with the control resistor 53 and one end of the potentiometer resistance is connected with the lower end of the winding 54 in the manner shown. The winding 60 produces a voltage in anti-phase to the anode voltage and the potentiometer injects into the grid circuit a component leading on said anode voltage and adjustable in magnitude by the setting of the potentiometer 61, whereby the level of controlled quantity about which the apparatus operates may be adjusted at will.

It will be understood that arrangements of the kind illustrated by Fig. 9 are applicable also in connection with the arrangement of Fig. 1.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electronic relay arrangement comprising a gaseous conduction discharge device having an anode, a cathode and a control electrode, a control circuit for said control electrode including a capacitance and a discharge path for said capacitance, a charging circuit for said capacitance having rectifying means therein connected across the anode and cathode of said device for charging said capacitance during positive half-cycles of anode voltage to apply to said control electrode a voltage subject to time lag tending to cause anode conduction, a second capacitance in said control circuit in series with means for applying to said control electrode an alternating voltage of a phase tending to prevent anode conduction of said discharge device, said second capacitance being chargeable during non-conduction of said device to tend to produce on said control electrode a unidirectional negative voltage tending to maintain non-conduction after extinction of the anode current, the voltage produced in response to anode conduction on the

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first said capacitance falling during conduction so as to produce on said control electrode a change of voltage resulting in extinction of anode current, and means for producing in said control circuit a controlling voltage component governing the anode conduction in said device in accordance with the magnitude of an input quantity, whereby periodically to initiate and continue anode conduction during a number of cycles of anode voltage dependent upon the magnitude of said input quantity.

2. An electronic relay arrangement comprising a gaseous conduction discharge device having an anode, a cathode and a control electrode, a control circuit for said control electrode including a capacitance and a discharge path for said capacitance, a charging circuit for said capacitance having rectifying means therein connected across the anode and cathode of said device for charging said capacitance during positive half-cycles of anode voltage to apply to said control electrode a voltage subject to time lag tending to cause anode conduction of said device, said control circuit also including a second capacitance in series with means for applying to said control electrode an alternating voltage of a phase tending to prevent anode conduction of said device, said second capacitance being chargeable during non-conduction of said device to tend to produce on said control electrode a unidirectional negative voltage tending to maintain non-conduction after extinction of the anode current, and the voltage produced in response to anode conduction on the first said capacitance falling during conduction so as to produce on said control electrode a change of voltage resulting in extinction of anode current, and means responsive to the extent of departure of a regulated quantity from a desired value connected with said control circuit for producing in said control circuit a controlling voltage component governing the anode conduction in said device in accordance with said departure, whereby periodically to initiate and continue anode conduction during a number of cycles of anode voltage dependent upon the extent of said departure.

3. An electronic relay arrangement comprising a gaseous conduction discharge device having an anode, a cathode and a control electrode, a control circuit connected to said control circuit and including a capacitance and a discharge path for said capacitance, a charging circuit for said capacitance having rectifying means therein connected across the anode and cathode of said device for charging said capacitance during positive half-cycles of anode voltage to apply to said control electrode a voltage subject to time lag tending to cause anode conduction, said control circuit also including a second capacitance in series with means for applying to said control electrode an alternating voltage of a phase tending to prevent anode conduction of said device, said second capacitance being chargeable during non-conduction of said device to tend to produce on said control electrode a unidirectional negative voltage tending to maintain non-conduction after extinction of the anode current, and the voltage produced in response to anode conduction on the first said capacitance falling during conduction so as to produce on said control electrode a change of voltage resulting in extinction of anode current, and control apparatus connected with said control circuit for superimposing on said alternating voltage tending to prevent

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alternating voltage having a large phase displacement with respect to said voltage tending to prevent anode conduction, whereby periodically to initiate and continue anode conduction during a number of cycles of anode voltage dependent on the magnitude of said controlling component of voltage.

4. An electronic relay arrangement comprising a gaseous conduction discharge device having an anode, a cathode and a control electrode, a control circuit connected to said control electrode including a capacitance and a discharge path for said capacitance, a charging circuit for said capacitance having rectifying means therein connected across the anode and cathode of said device for charging said capacitance during positive half-cycles of anode voltage to apply to said control electrode a voltage subject to time lag tending to cause anode conduction, said control circuit also having a second capacitance connected therein in series with means for applying to said control electrode an alternating voltage of a phase tending to prevent anode conduction in said device, said second capacitance being chargeable during non-conduction of said device to tend to produce on said control electrode a unidirectional negative voltage tending to maintain non-conduction after extinction of the anode current, and the voltage produced in response to anode conduction on the first said capacitance falling during conduction so as to produce on said control electrode a change of voltage resulting in extinction of anode current, and control apparatus responsive to the extent of departure of a regulated quantity from a desired value connected with control circuit for superimposing on said alternating voltage tending to prevent anode conduction a controlling component of alternating voltage dependent in magnitude on said departure and having a large phase displacement with respect to said voltage tending to prevent anode conduction, whereby periodically to initiate and continue anode conduction during a number of cycles of anode voltage dependent upon the extent of said departure.

5. An electronic relay arrangement comprising a gaseous conduction discharge device having an anode, a cathode and a control electrode, a control circuit connected to said control electrode including a capacitance and a discharge path for said capacitance, a charging circuit for said capacitance having rectifying means therein connected across the anode and cathode of said device for charging said capacitance during positive half-cycles of anode voltage to apply to said control electrode a voltage subject to time lag tending to cause anode conduction, said control circuit also having a second capacitance connected therein in series with means for applying to said control electrode an alternating voltage of a phase tending to prevent anode conduction, said second capacitance being chargeable during non-conduction of said device to tend to produce on said control electrode a unidirectional negative voltage tending to maintain non-conduction after extinction of the anode current, and the voltage produced in response to anode conduction on the first said capacitance falling during conduction so as to produce on said control electrode a change of voltage resulting in extinction of anode current, and an input impedance in said control circuit, whereby periodically to initiate and continue anode conduction during a number of cycles of anode voltage

dependent upon the magnitude of a control voltage applied across said impedance.

6. An electronic relay arrangement comprising a gaseous conduction discharge device having an anode, a cathode and a control electrode, a control circuit connected to said control electrode and including a capacitance and a discharge path for said capacitance, a charging circuit for said capacitance having rectifying means therein connected across the anode and cathode of said device for charging said capacitance during positive half-cycles of anode voltage to apply to said control electrode a voltage subject to time lag tending to cause anode conduction, a second capacitance in said control circuit in series with means for applying to said control electrode an alternating voltage of a phase tending to prevent anode conduction of said device, said second capacitance being chargeable during non-conduction of said device to tend to produce on said control electrode a unidirectional negative voltage tending to maintain non-conduction after extinction of the anode current, and the voltage produced in response to anode conduction on the first said capacitance falling during conduction so as to produce on said control electrode a change of voltage resulting in extinction of anode current, and a variable impedance in said control circuit, whereby periodically to initiate and continue anode conduction during a number of cycles of anode voltage dependent upon the value of said impedance.

7. An electronic relay arrangement comprising a gaseous conduction discharge device having an anode, a cathode and a control electrode, a control circuit connected to said control electrode and including a capacitance and a discharge path for said capacitance, a charging circuit for said capacitance having rectifying means therein connected across the anode and cathode of said device for charging said capacitance during positive half-cycles of anode voltage to apply to said control electrode a voltage subject to time lag tending to cause anode conduction, a second capacitance in said control circuit in series with means for applying to said control electrode an alternating voltage of a phase tending to prevent anode conduction of said device, said second capacitance being chargeable during non-conduction of said device to tend to produce on said control electrode a unidirectional negative voltage tending to maintain non-conduction after extinction of the anode current, and the voltage produced in response to anode conduction on the first said capacitance falling during conduction so as to produce on said control electrode a change of voltage resulting in extinction of anode current, and control apparatus including a resonant circuit having a reactive element connected with the said control circuit to apply to said control circuit an alternating voltage dependent on a controlling quan-

tity applied to said control apparatus, the last said voltage having a large phase displacement with respect to said alternating voltage tending to prevent anode conduction, whereby periodically to initiate and continue anode conduction during a number of cycles dependent upon said controlling quantity.

8. An electronic relay as defined in claim 7, wherein said reactive element comprises the primary winding of a transformer of low resistance and a capacitative element in series circuit relation therewith, and a circuit having the secondary winding of said transformer connected therein and controlling the voltage in the control electrode of said gaseous conduction discharge device.

9. An electronic relay arrangement comprising a gaseous conduction discharge device having an anode, a cathode and a control electrode, a control circuit for said control electrode including a capacitance and a discharge path for said capacitance, a charging circuit for said capacitance having rectifying means therein connected across the anode and cathode of said device for charging said capacitance during positive half-cycles of anode voltage to apply to said control electrode a voltage subject to time lag tending to cause anode conduction of said device, a second capacitance in said control circuit in series with means for applying to said control electrode an alternating voltage of a phase tending to prevent anode conduction, said second capacitance being chargeable during non-conduction of said device to tend to produce on said control electrode a unidirectional negative voltage tending to maintain non-conduction after extinction of the anode current, and the voltage produced in response to anode conduction on the first said capacitance falling during conduction so as to produce on said control electrode a change of voltage resulting in extinction of anode current, and a bridge circuit having a control impedance responsive to a controlling quantity connected therein, said bridge circuit being connected in said control circuit for producing in said control circuit a controlling voltage component governing the anode conduction in said device and dependent on the extent of departure of said quantity from a prescribed value, whereby periodically to initiate and continue anode conduction during a number of cycles of anode voltage dependent on said departure.

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The following references are of record in the file of this patent:

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