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QUICK-RESET TIME-DELAY ELECTRONIC CONTROL SYSTEM

Filed Aug. 29, 1944

2 Sheets-Sheet 1

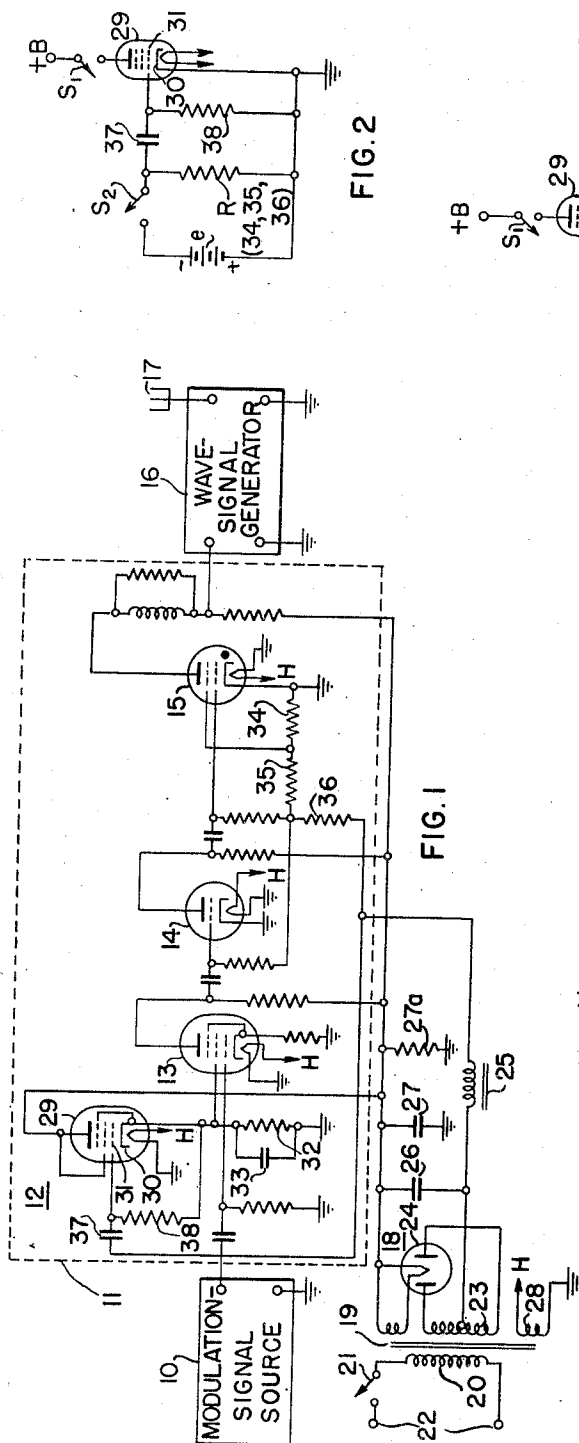


FIG. 1

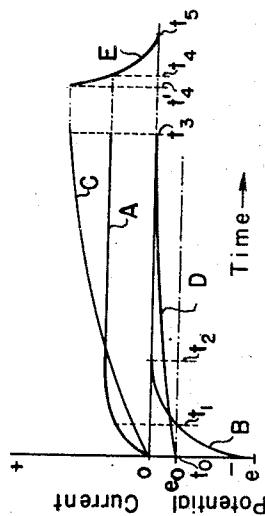


FIG. 3

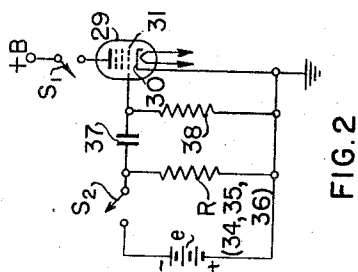


FIG. 2

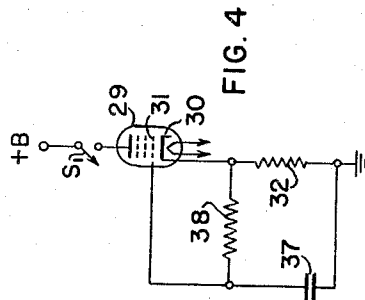


FIG. 4

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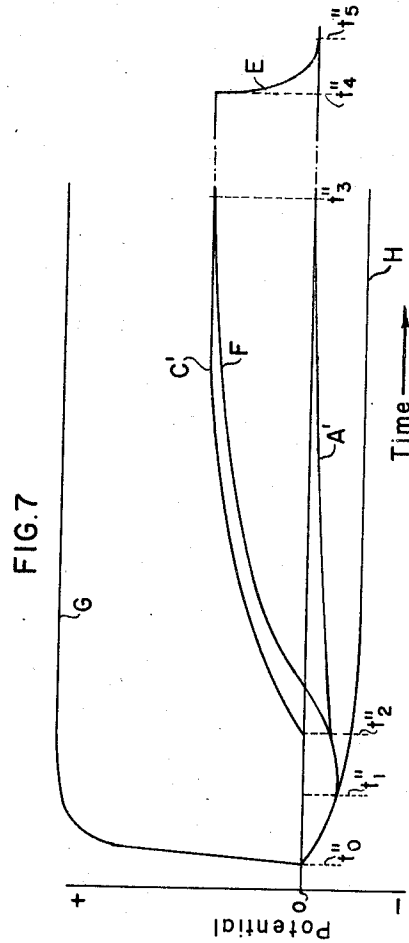
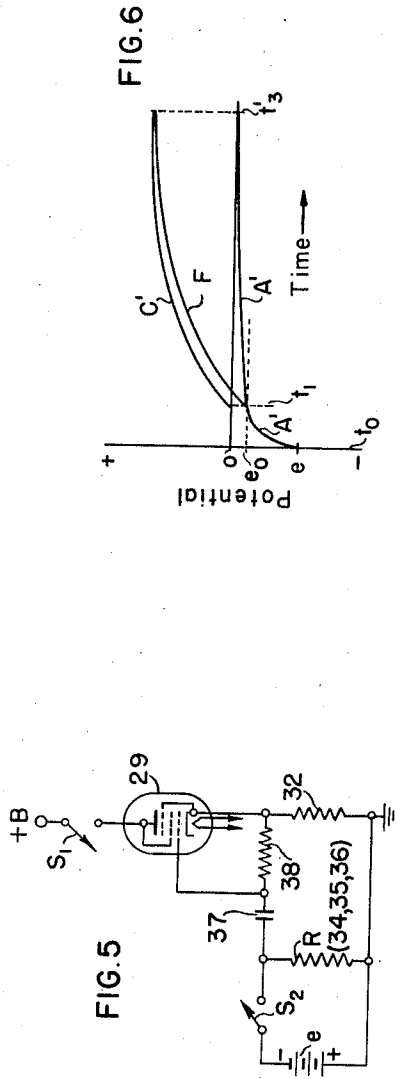
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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

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QUICK-RESET TIME-DELAY ELECTRONIC
CONTROL SYSTEM

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8 Claims. (Cl. 250-27)

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The present invention relates to quick-reset time-delay electronic control systems and, particularly, to such systems which automatically reset themselves after each cycle of delayed control. While the control system of the present invention is of general application, it is particularly suited for use in a protective system for electrical equipment and will be described in that connection.

There are many applications where it is desirable or necessary that electrical equipment be placed in service only after the lapse of a certain time interval following the initial energization thereof. A delay of this character may be necessary, for example, to enable either the equipment itself or auxiliary equipment or both to reach a normal safe operating temperature prior to subjecting the equipment to normal load conditions. Illustrative of equipment of this class is the conventional cathode-ray tube which includes a fluorescent screen adapted to be scanned by an electron beam. The energy delivered to the screen of the tube by the electron beam is sufficiently large that the screen is substantially damaged over any area thereof where the electron beam is allowed to rest for an appreciable short interval. This may occur, for example, during the normal warm-up period immediately following the energization of the cathode-ray tube and its associated scanning system, particularly where the cathode-ray tube and its associated power-supply system become fully operative before the vacuum tubes of the scanning system have warmed up sufficiently to generate scanning potentials or currents.

Of the numerous protective systems heretofore proposed for apparatus of the type mentioned, a substantial number involve the use of electromagnetic relays. Such relays necessarily utilize movable parts and include some form of electrical contact structure. These relays have numerous well-known disadvantages among the more important of which may be mentioned the prevalent tendency to fail due to sticking, dirty or burned contacts, to insulation breakdown, or to failure of their moving mechanical parts or the supporting bearings therefor. These relays have the additional disadvantage that their usefulness is usually restricted to those applications where the relay is not subjected in operation to shocks or vibration. Where it is necessary that the relay consume a minimum of power from its energizing control circuit, the relay must be so delicately constructed that its field of application is greatly limited.

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To avoid the numerous disadvantages inherent in electromagnetic relays, it has been proposed that the desired control be effected electronically by the use of vacuum tubes. Such electronic control systems of the time-delay type have not usually been capable of a rapid automatic reset such as would enable the control system to perform a successive time-delay control immediately following a cycle of its operation. A substantial number of these electronic control systems rely for their operation upon the time interval required for one or more vacuum tubes thereof to attain a temperature approximating their normal operating temperature. This latter type of system may be quite unreliable since the time-relay control provided thereby may change with the age or condition of the control tube and may be seriously affected by changes of energizing power. These systems are also not usually capable of a quick-reset action since the thermal energy stored in one or more vacuum tubes thereof may be quite substantial.

It is an object of the present invention, therefore, to provide a new and improved quick-reset time-delay electronic control system which avoids one or more of the disadvantages and limitations of prior control systems of the type described.

It is a further object of the invention to provide a new and improved quick-reset time-delay electronic control system, the delay operation of which may be readily rendered responsive to one or to several operating conditions of apparatus controlled thereby and one thus having a high degree of flexibility of application.

It is an additional object of the invention to provide a new and improved quick-reset time-delay electronic control system of simple and inexpensive circuit arrangement comprising a minimum of circuit components yet one possessing high stability and reliability of operation.

It is a further object of the invention to provide a new and improved quick-reset time-delay electronic control system, the operation of which enables the attainment of a precise and accurate delay interval of selected value and an automatic reset action requiring a reset interval of precise value short in relation to the delay interval.

In accordance with the invention, a quick-reset time-delay electronic control system comprises a vacuum tube having a first and a second operative state and including a control electrode which when energized maintains the vacuum tube in the first operative state, the vacuum tube in one of its operative states being adapted to provide a desired control effect. The system

includes means for concurrently energizing the vacuum tube and the control electrode to initiate the establishment of the second operative state of the tube, and means responsive to space current flow through the vacuum tube for additionally energizing the control electrode, the first-mentioned and second-mentioned energizing means including a common electrical time-constant circuit through which the control electrode is energized from each thereof for limiting to a selected value the time interval of the energization of the control electrode to delay for this interval the establishment of the second operative state of the vacuum tube. The control system additionally includes means effective upon the deenergization of the vacuum tube rapidly to restore the control of the time-constant circuit over the interval of energization of the control electrode.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

Referring now to the drawings, Fig. 1 is a circuit diagram, partly schematic, representing a complete radiant-energy transmitting system embodying the present invention in a particular form; Figs. 2, 4 and 5 represent simplified circuit diagrams of certain portions of the control system of Fig. 1 and are used to explain certain features of the control system and simplify an explanation of the operation thereof; and Figs. 3, 6 and 7 graphically represent operating characteristics of the control system in its simplified and complete forms.

Referring now more particularly to Fig. 1 of the drawings, there is represented a circuit diagram, partly schematic, of a complete radiant-energy transmitting system which includes a quick-reset time-delay electronic control system embodying the present invention in a particular form. The transmitter includes a modulation-signal source 10 which generates a modulation signal of periodic-pulse wave form. The output circuit of the unit 10 is coupled to an input circuit of a unit 11 which includes a quick-reset time-delay electronic control system 12, presently to be described in greater detail, a modulation-signal amplifier 13 having a signal-translating characteristic controlled by the control system 12, a second signal amplifier 14, and a modulator 15 having an output circuit coupled to a modulation input circuit of a wave-signal generator 16. The output circuit of the generator 16 is coupled to an antenna system 17.

The transmitter is energized from a power-supply system 18 which includes a power transformer 19 having a primary winding 20 coupled through a switch 21 to a source of alternating potential 22. The center-tapped secondary winding 23 of the transformer 19 is connected to a rectifier tube 24 in a conventional full-wave rectifier system which includes a series filter choke 25, shunt filter condensers 26, 27, and a bleeder resistor 27a. The transformer 19 includes a low-voltage secondary winding 28 which is coupled to the heaters of the several vacuum tubes of unit 11, as indicated by the reference character H in the drawing.

It will be understood that the transmitter just described is, with the exception of the control system 12 of unit 11 presently to be described, of conventional construction and operation, the

details of which are well understood in the art rendering further detailed description thereof unnecessary. Considering briefly, however, the operation of the transmitter as a whole, and neglecting for the moment the operation of the control system 12 of unit 11, a modulation signal is supplied by the signal source 10 to an input circuit of the unit 11. The signal amplifiers 13 and 14 translate the applied signal to the modulator 15 which operates to apply a modulation signal of large current amplitude to the modulation input circuit of the wave-signal generator 16. The applied modulation signal modulates a wave signal generated by the unit 16 and the modulated wave signal is applied to the antenna system 17 for radiation therefrom. The operation of the power-supply system 18 is conventional, the transformer 19 being used to transform the relatively low-voltage alternating potential applied to the input terminals 22 to a high-voltage alternating potential which is rectified by the rectifier 24 and applied through the filter elements 25, 26 and 27 to the anode circuits of the vacuum tubes of unit 11. The winding 28 of the transformer 19 energizes the heaters of the latter vacuum tubes.

In order that the modulation signal applied to the modulation input circuit of the generator 16 shall have large current amplitude, the modulator 15 of unit 11 is a gaseous vacuum tube, for example a grid-controlled mercury-vapor tube marketed under the trade name "Thyratron." The characteristics of this tube are such that the tube may be seriously damaged or its life appreciably shortened if a modulation signal is applied to its control electrode before its cathode has reached a normal operating temperature. A time interval of approximately twenty seconds is required between the moment when the power switch 21 of the power supply 18 is initially closed and the moment when the modulation signal may safely be applied to the control electrode of the vacuum tube 15. It is the purpose of the quick-reset time-delay electronic control system 12 of unit 11 so to control the characteristics of the signal amplifier 13 as to prevent the application of the modulation signal to the vacuum tube 15 for an interval sufficient to allow the cathode of the latter to reach a normal operating temperature after the switch 21 of the power-supply system 18 is closed to energize the transmitter.

Considering now the portion of the system embodying the present invention, the quick-reset time-delay electronic control system 12 includes a vacuum tube 29 having a substantially inoperative state, or state of low conductivity, and an operative state or state of relatively high conductivity. This vacuum tube, which in its conductive state is adapted to provide a desired control effect for the signal amplifier 13 to control the amplification of the latter, includes input electrodes comprising a cathode 30 and a control electrode 31 which when biased negatively to a predetermined value maintains the vacuum tube 29 in its inoperative or nonconductive state. The control system includes means for concurrently energizing the vacuum tube 29 and its control electrode 31 to initiate the establishment of the second or conductive operative state of this tube. This means comprises the power-supply system 18, which provides a high unidirectional potential for the anode of tube 29, and a cathode resistor 32 included in the cathode circuit of vacuum tube 29. The cathode resistor 32 has a small filter condenser 33 connected in shunt thereto. As will

be more fully explained hereinafter, the cathode resistor is responsive to the space current flow through the vacuum tube 29 for energizing the control electrode 31 upon initiation of space current through this tube. The energizing circuit for the control electrode 31 includes, in addition to the cathode resistor 32 and in series therewith between the cathode 30 and the filter choke 25, three series-connected resistors 34, 35 and 36 which are included in the negative-return lead of the power-supply system 18 and thus are common to the cathode circuits of all of the vacuum tubes of unit 11.

The energizing circuit last mentioned includes an electrical time-constant circuit for limiting to a selected value the time interval of energization of the control electrode 31 to delay for this interval the establishment of the second operative state, or conductive state, of the vacuum tube 29 by the energizing means comprising the power-supply system 18. This time-constant circuit includes a condenser 37 for coupling the control electrode 31 of vacuum tube 29 to the junction of the filter choke 25 and resistor 36, thus to couple the resistors 32, 34, 35 and 36 in series between the input electrodes 30 and 31 of the vacuum tube 29, and includes a resistor 38 connected in shunt to the input electrodes 30, 31. As thus arranged, the resistors 32, 34, 35 and 36 essentially comprise a source of energizing potential for the control electrode 31 of vacuum tube 29 and the condenser 37 is included in series between the control electrode 31 and this source of energizing potential.

The control system also includes means, comprising the condenser 37 and resistor 38, effective upon the deenergization of the vacuum tube 29 rapidly to restore the control of the time-constant circuit over the interval of energization of the control electrode 31. This means comprises the series-connected resistors 32, 34, 35 and 36 which effectively connect the condenser 37 across the input electrodes 30 and 31 of vacuum tube 29 and which form with the condenser 37 a second time-constant circuit having a time constant much shorter than that of the condenser 37 and resistor 38.

The screen electrode of vacuum tube 29 is connected directly to the cathode 30 of tube 29 so that the potential developed across the cathode resistor 32 when the vacuum tube 29 becomes conductive is applied as a positive energizing potential to the screen electrode of vacuum tube 13 to control the amplification of the latter. In particular, the vacuum tube 13 has little or no amplification during periods when its screen electrode has only a small or no potential applied thereto, as during the intervals when the vacuum tube 29 is nonconductive, but has high amplification during those intervals when the vacuum tube 29 becomes fully conductive to develop a substantial positive potential across the cathode resistor 32.

In considering the operation of the control system just described, it may be mentioned at the outset that the control action is divided into three general categories; namely, a control action responsive to the space current of all of the vacuum tubes 13, 14, 15 and 29, a control action responsive to the space current of the vacuum tube 29 without regard to that of the other vacuum tubes, and a control action which may be independent of the space current of any of the vacuum tubes. The simplified circuit diagrams of Figs. 2, 4 and 5 are used as an aid in explain-

ing these several types of control action, the curves of Figs. 3, 6 and 7 graphically representing the operating characteristics of the control system in its several simplified forms and in the form shown in Fig. 1.

Fig. 2 is a simplified circuit diagram of a portion of the control system 12 of Fig. 1, similar circuit elements being designated by similar reference numerals, and is used as an aid in explaining one type of control action effected by the control system. In this simplified arrangement, the energizing circuit of the control electrode of tube 29 is shown as including a source of unidirectional energizing potential comprising a battery e . In the actual system of Fig. 1, no such battery is used but rather, as will be explained more fully hereinafter, the potential source e represents the voltage developed across the resistor R which is comprised by the resistors 34, 35 and 36 of Fig. 1. The anode of vacuum tube 29 is shown as energized through a switch S_1 from a source of anode potential, indicated as $+B$, and the time-constant circuit 37, 38 is represented as coupling the input electrodes 30, 31 of tube 29 through a switch S_2 to the source of unidirectional energizing potential e . The switches S_1 and S_2 , while they do not appear as such in the Fig. 1 system, represent the equivalent control effected by the power switch 21 of Fig. 1. If the switches S_1 and S_2 are closed simultaneously, and if it be assumed that the cathode 30 of the tube 29 is at normal operating potential, the condenser 37 will immediately begin to charge through the resistor 38 from the source of potential e and, by virtue of the polarity of the potential source, will produce across the resistor 38 a potential having negative polarity with respect to ground. This potential is applied to the control electrode 31 of vacuum tube 29 and is effective to maintain the latter biased to anode current cutoff. As the condenser 37 becomes charged, its charging current begins to decrease, thus decreasing the voltage developed across the resistor 38. This continues until the condenser 37 is fully charged after a short interval. At the end of this interval, no voltage is developed across the resistor 38 and, there then being no bias upon the control electrode 31 of vacuum tube 29, the latter becomes fully conductive.

Curve A of Fig. 3 represents the exponential manner in which the condenser 37 charges from the source of potential e and curve B represents the manner in which the negative potential developed across the resistor 38 varies with time. The bias e_0 at which the vacuum tube 39 just becomes conductive is represented in Fig. 3 by the horizontal broken line. It will be apparent that the vacuum tube 29 is maintained in a nonconductive state by the action of the time-constant circuit 37, 38 during the interval t_0-t_1 and that this tube becomes fully conductive at time t_2 . If the switches S_1 and S_2 are opened at time t_4 , the condenser 37, which now biases the control electrode 31 positively with respect to the cathode 30, is rapidly discharged during a relatively short interval t_4-t_5 through a discharge path which includes the control electrode 31, the cathode 30 and the resistor R . This rapid reset characteristic is represented by curve E.

The value of the resistor 38 is sufficiently large with relation to the capacitance of the condenser 37 that the latter requires several seconds to charge. The conductive resistance of the control electrode-cathode path of vacuum tube 29 and the resistance of the resistor R is sufficiently

small, on the other hand, that the condenser 37 discharges much more rapidly, for example within a second or less.

Fig. 4 is a simplified circuit diagram representing another portion of the control system 12 of Fig. 1, similar circuit elements being designated by similar reference numerals, and is used as an aid in explaining a second type of control action effected by the control system. If it be assumed that the cathode of the vacuum tube 29 is at normal operating potential at the moment the switch S_1 is closed, the initial space current of the tube 29 flows through the cathode resistor 32 to develop thereacross a potential, positive with regard to ground. This initial space current remains small, however, since the potential developed across the resistor 32 immediately begins to charge the condenser 37 through the resistor 38, thus to develop across the latter a bias potential of negative polarity which is applied to the control electrode 31 of the vacuum tube 29 and is sufficiently large that it maintains the latter near anode current cutoff. As the condenser 37 charges, the charging current through the resistor 38 decreases so that the negative bias applied to the control electrode 31 also decreases to permit a slight increase in the space current of vacuum tube 29. This action continues until the condenser 37 becomes fully charged, at which time no potential is developed across the resistor 38 and the vacuum tube 29 is fully conductive.

In this type of control action, however, an appreciable time interval elapses before the vacuum tube 29 becomes fully conductive since the cathode resistor 32 effectively provides a degenerative control between the input and output electrodes of vacuum tube 29. Thus, as shown by curve C of Fig. 3, which represents the charging characteristic of the condenser 37 in the Fig. 4 arrangement, the condenser 37 requires a relatively long interval t_0-t_3 within which to receive its full charge. Curve D of Fig. 3 represents the variation of voltage across the resistor 38. The Fig. 4 arrangement, like that of Fig. 2, also possesses the rapid reset feature. Thus, when switch S_1 is opened at time t_4' , the condenser 37 rapidly discharges, as represented by curve E, through a series circuit of relatively low resistance comprising the control electrode-cathode resistance of tube 29 and the cathode resistor 32. The control system is thus rapidly conditioned for another cycle of the operation described.

It can be shown mathematically that, during the charging interval of the condenser 37, the variation of potential of the cathode 30 of tube 29 may be expressed by the following relation:

$$E_{30} = \frac{E_B R_{32}}{R_p + R_{32}} \left(1 - \frac{\mu}{1 + \mu + \frac{R_p}{R_{32}}} e^{-\frac{t}{\beta}} \right) \quad (1)$$

where

E_B = potential of source +B

R_{32} = resistance of resistor 32

R_p = plate resistance of tube 29

μ = amplification factor of tube 29

t = time

$$\beta = CR_{32} \left(\frac{1 + \mu + \frac{R_p}{R_{32}}}{1 + \frac{R_p}{R_{32}}} \right)$$

C = capacitance of condenser 37

R_{38} = resistance of resistor 38

Equation 1 is premised upon the assumptions that the value of the resistor 38 is very much larger than that of the cathode resistor 32 and, secondly, that the plate resistance R_p of tube 29 remains constant during the interval when the condenser 37 is receiving its charge. In connection with the second assumption, it will be evident that the value of potential drop developed across the cathode resistor 32 at any instant is dependent upon the plate resistance R_p of the tube 29, since it is the plate resistance of tube 29 and the resistance of the resistor 32 which determine the value of space current flowing through the latter. That the second assumption is a reasonable one, however, will be apparent when it is considered that the value of resistance of the cathode resistor 32 is preferably at least eight to ten times larger than the plate resistance of the tube 29, so that variations of the latter become inappreciable in relation to the sum of the plate resistance and the resistance of resistor 32. Since the value of the resistor 32 is preferably many times larger than that of the plate resistance of vacuum tube 29, and since the amplification factor of tube 29 may be easily made to be of the order of 50 or more, Equation 1 may be simplified to the following approximate relation:

$$E_{30} = E_B \left(1 - e^{-\frac{t}{CR_{32}\mu}} \right) \quad (2)$$

It will be apparent that the first term of Equation 2 represents the steady-state condition of the tube 29 following the interval required for the condenser 37 to charge. Similarly, the second term of Equation 2 represents a transient condition which governs during the interval when the condenser 37 is receiving its charge. It will be at once evident from this transient term that the degenerative control of tube 29 is effective to prolong the charging interval of the condenser 37 by the amplification factor μ of tube 29. The time delay effected by the portion of the control system represented by Fig. 4 is thus 50 or 100 times that obtainable simply by the use of a time-constant circuit alone, as in Fig. 2, and not arranged to utilize the degenerative feature of the Fig. 4 arrangement.

Equation 1 shows that it is not only desirable to utilize a value of resistance for the resistor 32 large in comparison with the plate resistance of the vacuum tube 29 to render the ratio

$$\frac{E_p}{E_{32}}$$

small, in that this ratio appears in the denominator of β , but additionally that a large value of cathode resistance is desirable to enable the attainment of a large potential drop across the cathode resistor 32 during the steady-state condition of operation of the vacuum tube 29 after the condenser 37 has received its maximum charge, since the value of cathode potential is then almost equal to the potential of the source +B. Additionally, the larger the value of the cathode resistor 32, the larger will be the range of values over which the potential of the cathode 30 changes. This is of particular importance in the control system of Fig. 1 where the potential drop across the cathode resistor 32 is utilized to control the repeating ratio or gain of the controlled amplifier 13. Thus, with a large value of cathode resistor, the relatively small value of the potential developed across the cathode resistor 32 at the moment when the switch S_1 is closed may

be readily ascertained from Equation 2 to have the following approximate value:

$$E'_{so} = \frac{E_B}{\mu} (t=0) \quad (3)$$

In the simplified circuit diagram of Fig. 4, the source of potential +B and the switch S₁ together with the cathode resistor 32 comprise means for concurrently energizing the vacuum tube 29 and the control electrode 31 thereof to initiate the conductive state of operation of the vacuum tube. The condenser 37 and resistor 38 comprise an electrical time-constant circuit included in the last-mentioned means for limiting to a selected value the time interval of energization of the control electrode 31 to delay for this interval the establishment of the conductive state of the vacuum tube by the energizing means. The resistor 32 and the electrodes 30, 31 of vacuum tube 29 comprise means effective upon the deenergization of the vacuum tube 29, as upon opening of the switch S₁, rapidly to restore the control of the time-constant circuit 37, 38, by rapid discharge of the condenser 37, over the interval of energization of the control electrode 31.

Fig. 5 is a simplified circuit diagram in which the circuits of Figs. 2 and 4 are combined. The operation of this arrangement will be in general apparent from the foregoing described operation of Figs. 2 and 4. Referring to Fig. 6, the portion of the curve A' between the time t₀ when the switches S₁ and S₂ are closed and the time t₁ represents the control electrode-to-cathode voltage of the vacuum tube 29 produced by the potential drop across the resistor 38 due to the charge of the condenser 37 from the potential source e. At time t₁, the control electrode has insufficient bias to prevent the initiation of space current in the vacuum tube 29. A potential is thus developed across the cathode resistor 32, as represented by curve C'. The bias applied to the control electrode of tube 29, considered with relation to ground potential, thus varies as represented by curve F during the interval t₁—t₃'. The control electrode-to-cathode potential of vacuum tube 29 is equal to the difference at every instant between the values of curves C' and F and, hence, varies during the interval t₁—t₃' as represented by curve A'. From this, it will be evident that the Fig. 2 portion of the instant arrangement is effective to provide an initial time delay during the interval t₀—t₁, while the Fig. 4 portion of the instant arrangement is effective to provide a much longer time relay extending from t₁ to t₃'.

In the control system 12 of Fig. 1, the potential developed across the resistors 34, 35 and 36 has been represented in the simplified circuit diagrams of Figs. 2, 4 and 5 as the potential e. A potential is developed across these resistors as soon as the rectifier tube 24 becomes conductive after closure of the switch 21, this potential being produced by the charging current of the filter condenser 27 and the current of the bleeder resistor 27a. Curve G of Fig. 7 represents the manner of variation of the potential developed across the resistor 27a beginning at the moment t₀' when the rectifier 24 becomes conductive and curve H represents the manner of variation of the potential developed across the resistors 34, 35 and 36.

The remaining curves A', C', E and F of Fig. 7 apply to the operation of the control system 12 of Fig. 1 and correspond to curves bearing the same designation in Figs. 3 and 6. The several types of time delay provided by the control sys-

tem of the Fig. 1 arrangement will now be readily apparent from the curves of Fig. 7. Thus, the condenser 37 receives increasing values of charge during the time interval t₀'—t₁' to maintain tube 29 biased to anode current cutoff as explained in regard to the simplified arrangement of Fig. 2, this action continuing until the moment t₂' when the vacuum tube 29 becomes slightly conductive. During the interval t₂'—t₃', the control action is of the type explained hereinbefore in regard to the simplified circuit arrangement of Fig. 4. The control action during the entire interval t₀'—t₃' is also dependent, at any given moment, to some extent upon the space currents of all of the vacuum tubes 13, 14, 15 and 29 since this affects the potential developed across the resistors 34, 35 and 36, the contribution of this factor to the control action depending in large extent upon the rapidity with which the cathodes of these tubes reach their normal operating temperatures after the power-supply switch 21 is closed. Thus, the length of the interval t₀'—t₂' is dependent both upon the rapidity with which the vacuum tubes reach normal operating temperature and upon the time constant of the condenser 37 and the resistor 38. The length of the time interval t₂'—t₃' depends, on the other hand, primarily upon the degenerative control of the tube 29 effected by the cathode resistor 32 and upon the time constant of the condenser 37 and resistor 38.

When the switch 21 is open to deenergize the power-supply system 18 as at time t₄' of Fig. 7, the condenser 37 rapidly discharges through the control electrode-to-cathode path of the vacuum tube 29 and through the resistors 32, 34, 35 and 36 rapidly to reset the control system 12 at time t₅' to condition it for a subsequent cycle of time-delay control action, this rapid reset action being represented by curve E of Fig. 7. The rapidity of reset is determined, of course, by the value of capacitance of condenser 37, the value of the conductive resistance of the control electrode 31 and cathode 30 of tube 29, and by the values of the resistors 32, 34, 35 and 36. The values of resistance of these elements are so selected that the total resistance of the discharge path is only a small fraction of the value of resistance of resistor 38 so that the reset action requires an interval quite short with relation to the total time-delay interval provided by the control system upon energization of the latter.

While applicant does not intend to be limited to any particular circuit values in the embodiment of the invention described, there follows a set of circuit values which have been found to be particularly suitable for a control system of the type shown in Fig. 1:

60 Resistor 27a	75,600 ohms (approximately)
Resistor 32	220,000 ohms
Resistor 34	27 ohms
65 Resistor 35	470 ohms
Resistor 36	470 ohms
Resistor 38	3.3 megohms
Condenser 33	0.01 microfarad
Condenser 37	0.5 microfarad
70 Vacuum tube 13	Type 6AG5
Vacuum tube 14	Type 6J6
Vacuum tube 15	Type 2D21
Vacuum tube 29	Type 6AG5

From the above description of the invention, it will be apparent that a control system embody-

ing the invention may be readily rendered responsive to one or to several operating conditions of an apparatus to be controlled by the system and is one thus having a high degree of flexibility of application. It will further be apparent that the control system of the invention is of simple and inexpensive circuit arrangement involving a minimum of circuit components and yet is one possessing a high degree of stability and reliability of operation. The control system of the invention has the additional advantage that its time-delay and reset operations are controlled by electrical time-constant circuits which are so inherently stable as to enable the attainment of a precise and accurate delay interval of any selected value and an automatic reset action requiring a reset interval of precise value which is quite short in relation to the delay interval provided by the control system.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A quick-reset time-delay electronic control system comprising, a vacuum tube having a first and a second operative state and having a plurality of electrodes including a control electrode which when energized maintains said vacuum tube in said first operative state, said vacuum tube in one of its operative states being adapted to provide a desired control effect, means for concurrently energizing the electrodes of said vacuum tube including said control electrode to initiate the establishment of said second operative state, means responsive to space current flow through said vacuum tube for additionally energizing said control electrode, said first-mentioned and second-mentioned energizing means including a common electrical time-constant circuit through which said control electrode is energized from each thereof for limiting to a selected value the time interval of said energization of said control electrode to delay for said interval the establishment of said second operative state of said vacuum tube, and means effective upon the deenergization of said vacuum tube rapidly to restore the control of said time-constant circuit over the interval of energization of said control electrode.

2. A quick-reset time-delay electronic control system comprising, a vacuum tube having a first and a second operative state and having a plurality of electrodes including a control electrode which when energized with a bias potential of predetermined polarity and magnitude maintains said vacuum tube in said first operative state, said vacuum tube in one of its operative states being adapted to provide a desired control effect, means for energizing the electrodes of said vacuum tube to initiate the establishment of said second operative state and for concurrently energizing said control electrode by applying thereto a bias potential having said predetermined polarity and at least said predetermined magnitude, means responsive to space current flow through said vacuum tube for additionally energizing said control electrode with a bias potential having said predetermined polarity, said first-mentioned and second-mentioned en-

energizing means including a common electrical time-constant circuit through which said control electrode is energized from each thereof for limiting to a selected value the time interval of said energization of said control electrode to delay for said interval the establishment of said second operative state of said vacuum tube, and means effective upon the deenergization of said vacuum tube rapidly to restore the control of said time-constant circuit over the interval of energization of said control electrode.

3. A quick-reset time-delay electronic control system comprising, a vacuum tube having a substantially inoperative state and an operative state and having a plurality of electrodes including a control electrode which when biased negatively to a predetermined value maintains said vacuum tube in said inoperative state, said vacuum tube in one of its operative states being adapted to provide a desired control effect, means for energizing the electrodes of said vacuum tube to initiate the establishment of said operative state and for concurrently energizing said control electrode by applying thereto a negative bias having said predetermined value, means responsive to space current flow through said vacuum tube for additionally energizing said control electrode with a negative bias potential, said first-mentioned and second-mentioned energizing means including a common electrical time-constant circuit through which said control electrode is energized from each thereof for limiting to a selected value the interval of application of said bias to said control electrode to delay for said interval the establishment of said operative state of said vacuum tube, and means effective upon the deenergization of said vacuum tube rapidly to restore the control of said time-constant circuit over the interval of energization of said control electrode.

4. A quick-reset time-delay electronic control system comprising, a vacuum tube having a first and a second operative state and having a plurality of electrodes including a control electrode which when energized maintains said vacuum tube in said first operative state, said vacuum tube in one of its operative states being adapted to provide a desired control effect, means for energizing the electrodes of said vacuum tube to initiate the establishment of said second operative state and including a source of bias potential for concurrently energizing said control electrode to maintain said vacuum tube in said first operative state, means responsive to space current flow through said vacuum tube for additionally energizing said control electrode, said first-mentioned and second-mentioned energizing means including a common electrical time-constant circuit comprising a condenser in series with each of said energizing means and said control electrode and a resistor connecting said condenser across each of said energizing means for limiting to a selected value the interval of said energization of said control electrode to delay for said interval the establishment of said second operative state of said vacuum tube, and means effective upon the deenergization of said vacuum tube rapidly to restore the control of said time-constant circuit over the interval of energization of said control electrode.

5. A quick-reset time-delay electronic control system comprising, a vacuum tube having a first and a second operative state and having a plurality of electrodes including input electrodes which when energized maintain said vacuum

tube in said first operative state, said vacuum tube in one of its operative states being adapted to provide a desired control effect, means for energizing the electrodes of said vacuum tube to initiate the establishment of said second operative state and including an energizing circuit coupled between said input electrodes for concurrently energizing said input electrodes, said energizing circuit including a first and a second source of energizing potential of which said second source has a value of potential varying with the value of space current flow through said vacuum tube and including an electrical time-constant circuit having a resistor in shunt with said input electrodes and a condenser in series between each of said sources and said resistor for limiting to a selected value the interval of said energization of said input electrodes to delay for said interval the establishment of said second operative state of said vacuum tube, and means effective upon the deenergization of said vacuum tube rapidly to restore the control of said time-constant circuit over the interval of energization of said input electrodes.

6. A quick-reset time-delay electronic control system comprising, a vacuum tube having a first and a second operative state and having a plurality of electrodes including input electrodes which when energized maintain said vacuum tube in said first operative state, said vacuum tube in one of its operative states being adapted to provide a desired control effect, means for energizing the electrodes of said vacuum tube to initiate the establishment of said second operative state and including an energizing circuit coupled between said input electrodes for concurrently energizing said input electrodes, said energizing circuit including a first and a second source of energizing potential of which said second source has a value of potential varying with the value of space current flow through said vacuum tube and including an electrical time-constant circuit having a resistor in shunt with said input electrodes and a condenser in series between each of said sources and said resistor for limiting to a selected value the interval of said energization of said input electrodes to delay for said interval the establishment of said second operative state of said vacuum tube, and a second time-constant circuit effective upon the deenergization of said vacuum tube rapidly to restore the control of said first-mentioned time-constant circuit over the interval of energization of said input electrodes.

7. A quick-reset time-delay electronic control system comprising, a vacuum tube having a first and a second operative state and having a plurality of electrodes including input electrodes which when energized maintain said vacuum tube in said first operative state, said vacuum tube in one of its operative states being adapted to provide a desired control effect, means for energizing the electrodes of said vacuum tube to initiate the establishment of said second operative state and including an energizing circuit coupled between said input electrodes for con-

currently energizing said input electrodes, said energizing circuit including a first and a second source of energizing potential of which said second source has a value of potential varying with the value of space current flow through said vacuum tube and including an electrical time-constant circuit having a resistor in shunt with said input electrodes and a condenser in series between each of said sources and said resistor for limiting to a selected value the interval of said energization of said input electrodes to delay for said interval the establishment of said second operative state of said vacuum tube, and a resistor coupling said condenser across said input electrodes and effective upon the deenergization of said vacuum tube rapidly to restore the control of said time-constant circuit over the interval of energization of said input electrodes.

8. A quick-reset time-delay electronic control system comprising, a first vacuum tube having a first and a second operative state and having a plurality of electrodes including input electrodes which when energized maintain said vacuum tube in said first operative state, a second vacuum tube coupled to said first vacuum tube to have an operating characteristic thereof controlled by one of the operative states of said first vacuum tube, means for energizing the electrodes of said first vacuum tube to initiate the establishment of said second operative state, means including a resistor in the cathode circuit of said first vacuum tube and a resistor common to the cathode circuits of both of said vacuum tubes for energizing said input electrodes, said last-mentioned energizing means including an electrical time-constant circuit having a condenser coupling said resistors in series between said input electrodes and having a resistor connected in shunt to said input electrodes for limiting to a predetermined value the interval of said energization of said input electrodes to delay for said interval the establishment of said second operative state of said first vacuum tube by said energizing means, and means effective upon the deenergization of said first vacuum tube rapidly to restore the control of said time-constant circuit over the interval of energization of said control electrode.

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