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2,483,126

DELAY TIMER

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Fig. 1.

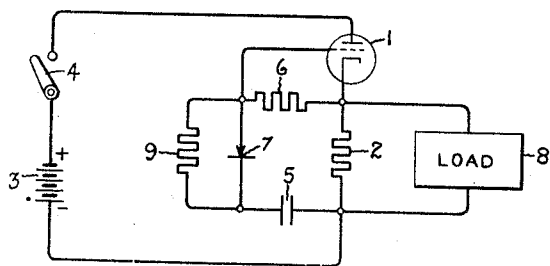


Fig. 2.

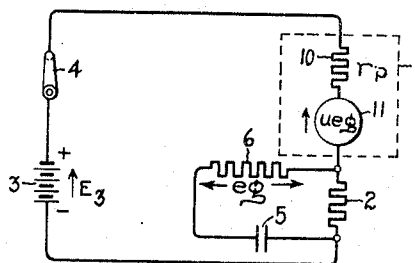


Fig. 3.

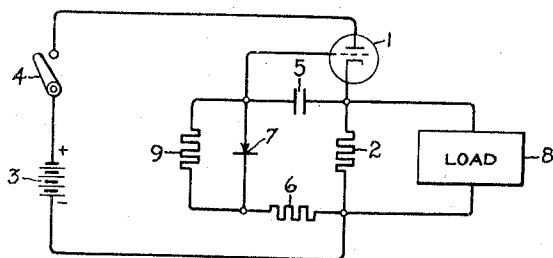
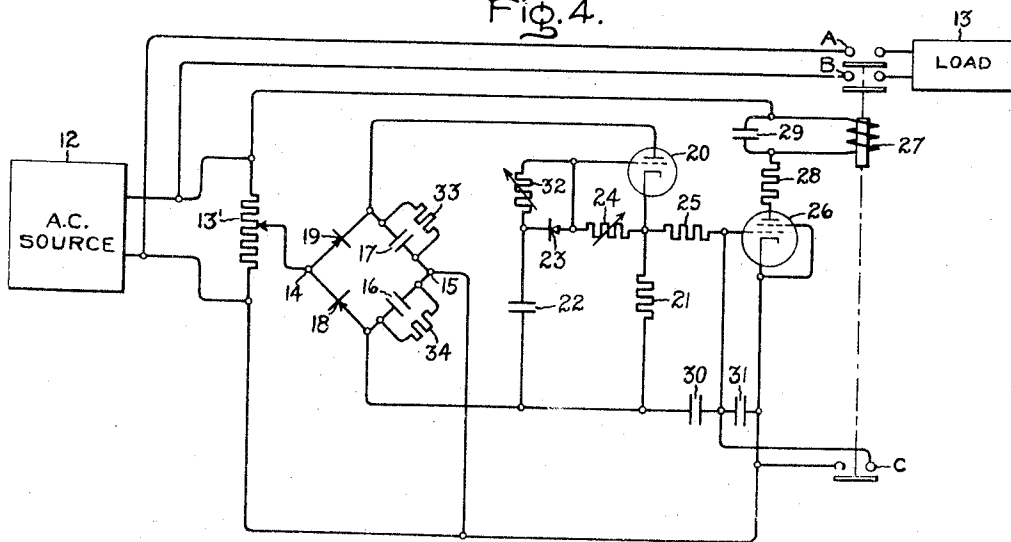


Fig. 4.



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DELAY TIMER

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4 Claims. (Cl. 175—320)

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This invention relates to electric circuits and more particularly to devices for producing electrical effects similar to those of inductances and capacitances. This invention further relates to time delay circuits wherein an event is caused to occur at a predetermined time after a first event.

It is an object of the invention to provide apparatus to produce a slowly increasing voltage or current after application of a constant voltage or current.

Another object of this invention is to provide an electrical circuit having a very long time delay but which does not require use of conventional RC or RL circuits having large time constants.

A further object of this invention is to provide a circuit having a very large and adjustable time delay when operating in one direction and a similarly large but independently adjustable time delay when operating in the reverse direction.

Still another object of this invention is to provide a relay system which connects a utilization circuit to a source of power at a predetermined time after the power is applied and in the event of a power interruption reconnects the utilization circuit to the source of power after a time delay determined by the duration of the interruption.

Yet another object of this invention is to provide apparatus to produce a predetermined long and adjustable time delay in a manner that requires only standard, readily available, low cost, circuit components.

In addition to the above objects, it is the objection of this invention to provide, by means of simple circuits employing electron discharge devices, effective inductances and capacitances of very high value without the actual physical construction of such inductances and capacitances.

The novel features believed to be characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawing in which Fig. 1 illustrates an embodiment of the invention adapted for use in a time delay circuit; Fig. 2 is the approximate equivalent circuit of the embodiment of the invention shown in Fig. 1; Fig. 3 shows an embodiment of the invention suitable for produc-

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ing electrical effects similar to those of a capacitance; and Fig. 4 shows a complete time delay control system embodying the principles of the invention.

Referring now to Fig. 1 which shows a circuit diagram illustrating an embodiment of this invention, 1 is an electron discharge device having a cathode, anode, and control electrode. The cathode of device 1 is connected through resistance 2, source of unidirectional electromotive force 3, and switch 4 to the anode thereof, the voltage of source 3 being in a direction to make the anode of device 1 positive with respect to the cathode. Condenser 5, resistance 6, and rectifier 7 are connected in series circuit across resistance 2, rectifier 7 being arranged to conduct when voltage drop across resistance 2 is in the direction corresponding to conduction in device 1. A utilization circuit 8 is connected across resistance 2 thus to be responsive to the voltage drop thereacross. Resistance 9 is placed across rectifier 7 to provide a discharge path for condenser 5.

The operation of the circuit shown in Fig. 1 can best be understood with reference to Fig. 2 which shows the equivalent circuit of the system immediately after switch 4 is closed. In this figure the effect of device 1 is represented by resistance 10 and voltage source 11, these representing the internal resistance and voltage respectively of a source producing the same effects on external circuits as device 1. While this representation of device 1 is not exact, it is sufficiently accurate to provide a useful indication of the operation thereof. The voltage of source 11 is $-ue_g$ where e_g is the negative potential of the control electrode of device 1 with respect to the cathode. The resistance of resistance 10 is the effective space path resistance of device 1, generally designated by the term "plate resistance" or r_p .

Adding the voltages around the circuit comprising switch 4, device 1, resistance 2, and source 3, the following equation is obtained:

$$(1) \quad E_3 = ue_g + (r_p + R_2) i_1$$

where:

E_3 is the voltage of source 3 in volts,

R_2 is the resistance of resistor 2 in ohms,

i_1 is the current flow through device 1 in amperes.

The above equation is written on the assumption that the effect of current flow in the shunt path around resistance 2 is negligible as compared with space path current of device 1, a condition

that may be obtained by proper choice of circuit components.

The value of e_g can be determined by the current flow through resistance 6 inasmuch as it is the IR drop of this resistance that produces e_g . Neglecting the influence of this current on the voltage drop across resistance 2, there results:

$$(2) \quad i_2 = C \left(R_2 \frac{di_1}{dt} - R_6 \frac{di_2}{dt} \right)$$

where:

i_2 is the current flow in resistance 6 in amperes, C is the capacitance of condenser 5 in farads, R_6 is the resistance of resistor 6 in ohms.

Equation 2 may more conveniently be expressed in operational form (see Gardiner and Barnes, Transients in Linear Systems, Wiley, 1942) which is:

$$(3) \quad i_2(s) = CR_2 si_1(s) - CR_6 si_2(s)$$

for the case of i_1 and i_2 equal to zero at the instant of closing switch 4. Solving Equation 3 for the value of current i_2 and computing the IR drop of resistance 6, the value of e_g becomes:

$$(4) \quad e_g(s) = R_6 i_2(s) = \frac{CR_2 R_6 s i_1(s)}{1 + CR_6 s}$$

Equation 1, when placed in operational form, becomes:

$$(5) \quad E_3(s) = u e_g(s) + (r_p + R_2) i_1(s)$$

Solving Equations 4 and 5 for the current $i(s)$, there results:

$$(6) \quad i_1(s) = \frac{(1 + CR_6 s) E_3(s)}{r_p + R_2 + CR_6 [r_p + (1 + u) R_2] s}$$

Inasmuch as $E_3(s)$ is equal to E_3/s for the case of the unit voltage produced by closing switch 3, Equation 6 be retransformed to give:

$$(7) \quad i = \frac{E_3}{r_p + R_2} \left[1 + \left(\frac{r_p + R_2}{r_p + (u+1) R_2} - 1 \right) E - \frac{r_p + R_2}{CR_6 (r_p + (1+u) R_2)} t \right]$$

Equation 7 may be compared with the equation for the sudden increase of voltage to a series circuit containing a resistance and an inductance, this equation being:

$$(8) \quad i = \frac{E}{R} \left[1 + \left(\frac{I_0 R}{E} - 1 \right) E - \frac{Rt}{L} \right]$$

where:

E is the applied voltage,
 R is the series resistance in ohms,
 L is the series inductance in henries,
 i_0 is the initial current flow in amperes.

From comparison of Equations 7 and 8 it is evident that the performance of the circuit of Fig. 2 may be represented by a conventional LR series circuit having the following constants:

$$(9) \quad \text{Equivalent resistance} = r_p + R_2$$

$$\text{Equivalent inductance} = CR_6 [r_p + (1+u) R_2] = T_c [r_p + (1+u) R_2]$$

$$\text{Equivalent initial current} = \frac{E_3}{r_p + (u+1) R_2}$$

where T_c is the time constant of the circuit across resistance 2.

The effectiveness of the circuit of Fig. 1 in simulating the effects of large values of inductance can best be explained by consideration of an actual circuit component which might be used in Fig. 1. With a value of 180 volts at source 3 and a 6F5 type hi-mu triode electron discharge

device 1 ($u=100$, $r_p=60,000$ ohms), the following circuit components might be used:

$$\begin{aligned} R_2 &= 10^6 \text{ ohms} \\ C_5 &= 2 \text{ microfarads} \\ R_6 &= 2 \times 10^6 \text{ ohms} \end{aligned}$$

Substituting these values in the above equations, the equivalent circuit components are:

$$\begin{aligned} R_{\text{equiv.}} &= 1.06 \times 10^6 \text{ ohms} \\ L_{\text{equiv.}} &= 404 \times 10^6 \text{ henries} \end{aligned}$$

The time constant ($R_{\text{equiv.}}/L_{\text{equiv.}}$) then becomes 381 seconds. The initial current obtained by substituting in Equation 9 is 1.78×10^{-6} amperes, a negligible value compared to the final current of 170×10^{-6} amperes.

While the above values are based on approximations that do not exactly represent the performance of device 1 throughout its entire operating characteristic, it is evident that the effects of extremely high values of inductance may be simulated by the circuit of Fig. 1. To achieve such value of inductance by usual methods requires inductors of excessive size inasmuch as the resistance of the inductance must not be so great as to lower the time constant of the complete circuit. Viewed differently, the performance of the above embodiment of this invention can be obtained only with an inductance having an inherent time constant of the order of 400 seconds, a value far in excess of the time constants that can be economically obtained.

While the circuit of Fig. 1 acts as inductance in so far as voltage increase across load 8 is concerned, it differs from a conventional RL circuit in that no energy is stored in a magnetic field. This constitutes a further advantage of the circuit for the normal high voltage surges incident to opening an inductive circuit are avoided, thereby eliminating the need for special devices to prevent insulation failure and arcing at switch contacts. In addition, the lack of stored energy in the circuit permits use of simple control devices to establish the rate at which the system is restored to a quiescent condition after opening switch 4.

The purpose of rectifier 7 and resistance 9 in Fig. 1 is to provide a discharge path for condenser 5 in which a controllable time constant is obtained. If switch 4 is opened after condenser 5 is charged or partly charged, condenser 5 will discharge through resistance 9, device 1, and resistance 2. Relatively small current flow will take place through resistance 6 because the positive control electrode potential at device 1 associated with the charge on condenser 5 causes the control electrode-cathode space path resistance of device 1 to be much smaller than the ohmic resistance of resistance 6. By proper choice of resistance 9 the discharge of condenser 5 can be controlled to achieve any degree of time lag desired so that reclosure of switch 4 will restore current flow in resistance 2 having initial value of a desired relationship with the period of time during which switch 4 is opened. Since the time constant of discharge depends on the value of resistance 9 and the time constant of charge on the value of resistance 6, these values may be independently adjusted to achieve any desired value of these constants.

In Fig. 3 a modified form of this invention is shown. This circuit differs from that of Fig. 1 only in that condenser 5 and resistance 6 are transposed in position. From the standpoint of current flow through resistance 2 the circuit of Fig. 3 acts as a series RC circuit with a resistance

in shunt with the capacitor. Hence, the voltage transient across load 8 when switch 4 is closed resembles that across a resistor in series with a condenser when sudden voltage is applied to the combination.

Other modifications of the circuits of Figs. 1 and 3 will be apparent to those skilled in the art. If, for example, an inductance is substituted for the condenser 5, Fig. 1, the voltage transient across load 8 will correspond to that across a resistance when sudden voltage is applied through a condenser. Similarly, the circuit of Fig. 3 will give an effect similar to an inductance if condenser 5 is replaced by an inductance.

Application of the principles of the invention to a time delay relay circuit is illustrated in Fig. 4. The purpose of this circuit is to close relay contacts A and B at a predetermined time after alternating voltage is made available at source 12; to instantaneously open these contacts upon failure of voltage from source 12; and to reclose contacts A and B at a predetermined time after alternating voltage is reapplied from source 12, the reclosure time depending on the length of the period of no voltage. In a practical application of this circuit, contacts A and B might be in the circuit from source 12 to load 13, the latter comprising rectifier or other circuits leading to the anodes of mercury vapor type electron discharge devices such as might be used in the pulse generator of a remote object detecting system. By use of this control it is possible automatically to apply anode voltage to the rectifiers when the cathodes are sufficiently heated while at the same time avoid destruction of the tubes due to application of voltage when the cathodes are not yet heated. Provision of variable reclosure time depending on the duration of loss of voltage from source 12 permits automatic operation of the circuit with minimum loss of operating time when voltage from source 12 fails for an interval of time that does not permit the cathodes of the mercury vapor tubes to cool to room temperature.

Considering in detail the circuit of Fig. 4, voltage from source 12 is applied to potentiometer 13' and to terminals 14 and 15. This voltage causes rectifiers 18 and 19 to charge condensers 16 and 17 respectively. The charge on condenser 17 causes the anode of electron discharge device 20 to become positive with respect to point 15 whereas the charge on condenser 16, acting through resistance 21, causes the cathode of device 20 to become negative with respect to point 15. Hence, the circuit comprising potentiometer 13', rectifiers 18 and 19, and condensers 16 and 17 causes the anode of device 20 to become positive with respect to the cathode by an amount determined by the potential of source 12. The circuit comprising resistances 21, 24 and 32, rectifier 23, and capacitor 22 will be recognized as identical with that of Fig. 1. Hence, current flow through resistance 21 and device 20 will slowly increase after potential from source 12 is applied.

The control electrode of gaseous discharge device 26 is connected to the cathode of device 20 whereas the cathode of device 26 is connected to point 15. Hence, with device 20 in a non-conducting condition, the control electrode of device 26 is negative with respect to the cathode by an amount depending on the charge of condenser 16. However, as current flows through device 20, and hence through resistance 21, a voltage drop appears across that resistance which tends to make the cathode of device 20 less negative with re-

spect to point 15. The rate of this current and voltage change is dependent on the time delay action due to condenser 22 and, when the voltage across resistance 21 causes the control electrode of device 26 to become sufficiently positive with respect to the cathode, space current flows through that device, thereby operating relay 27. Operating voltage for device 26 is derived directly from A.-C. source 12 through resistance 28.

When current flow takes place through device 26, relay coil 27 is actuated, thereby causing contacts A and B to close and apply voltage to load 13. In addition contacts C are closed and the control electrode of device 26 caused to be of equal potential with the cathode. This causes the control electrode of device 26 to lose control and conduction continues therethrough independently of the voltage drop across resistance 21. It will be understood, of course, that contacts C are not essential to operation of the system but are considered desirable to avoid relay chatter.

It is the purpose of condenser 29 across relay coil 27 to smooth the current flow through that coil and thereby to reduce chattering of the relay armature. Condensers 30 and 31 prevent voltage surges which may appear when voltage from source 12 is reapplied to the circuit from instantaneously tripping device 26. Resistances 33 and 34 provide leakage paths for discharge of condensers 17 and 16 respectively.

As described above with relation to Fig. 1, the time constant of voltage build-up across resistance 21, Fig. 4, depends on the time constant of the circuit comprising resistance 24 and capacitor 22. Hence, by adjustment of the value of resistance 24, the time interval between application of voltage from source 12 and the operation of relay 27 can be adjusted at will.

If voltage from source 12 fails, operating voltage is no longer available across device 26 and relay 27 drops out, thereby disconnecting load 13 and opening contacts C. In addition, condenser 22 commences to discharge through resistance 32 and the control electrode-cathode space path of device 20. If the voltage from source 12 is off for a long period of time before it is reapplied, the charge on condenser 22 is completely lost and full time delay between the subsequent application of voltage and operation of device 26 is obtained. On the other hand, if the voltage from source 12 is reapplied before condenser 22 discharges, the time required to build up voltage thereacross is reduced and device 26 operates after a shorter interval of time. Hence the time required to apply voltage to load 13 varies in accordance with the time during which voltage is lost across source 12.

If load 13 consists of the anode potential source to be applied to mercury vapor rectifier tubes, the time constant of discharge of condenser 22 through resistances 32 and 21 and the control electrode-cathode space path of device 20 is chosen with respect to the cooling characteristics of the mercury vapor tube heaters, thus causing relay 27 to operate just as soon as the anode voltage may be safely applied. The value of this time delay may be chosen without influencing the time delay between application of voltage from source 12 and operation of relay 27 by varying the value of resistance 32.

From the above discussion it is evident that the circuit of Fig. 4 provides the following time-delay action:

1. Upon initial application of voltage from

source 12, voltage is applied to load 13 after a predetermined time interval which may be adjusted by varying the value of resistance 24.

2. On loss of voltage from source 12, load 13 is immediately disconnected from source 12.

3. On reapplication of voltage from source 12, voltage is applied to load 13 after a time delay depending on the time period during which no voltage is applied from source 12, the value of this delay being independently adjustable by varying the value of resistance 32.

While I have shown and described certain particular embodiments of my invention, it will of course be understood that I do not wish to be limited thereto since various modifications both in the circuit arrangement and the instrumentalities employed may be made and I contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

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

1. A time delay circuit comprising an electron discharge device having an anode, a cathode, and a control electrode, means for selectively applying a positive potential to said anode relative to a fixed reference point, a first impedance connecting said cathode to said reference point, a timing circuit connected across said first impedance, said timing circuit serially comprising a second impedance, said rectifier being poled to conduct in the direction towards said reference point, a discharge impedance connected across said rectifier, said control electrode being connected to a point on said timing circuit which is rendered negative with respect to said cathode in response to flow of charging current in said capacitor, the time constant of said timing circuit being such that application of said potential to said anode causes an increasing current to flow in said device until said capacitor charged to a predetermined maximum potential, a load device energized in response to rise in current in said first impedance above a predetermined minimum value, and means including said discharge impedance and the grid-to-cathode path of said device for discharging said capacitor at a predetermined rate upon interruption of said potential.

2. A time delay circuit comprising an electron discharge device having an anode, a cathode, and a control electrode, means for selectively applying a positive potential to said anode relative to a fixed reference point, a first resistance connected from said cathode to said reference point, a timing circuit also connected from said cathode to said reference point and serially comprising, in the order named, a second resistance, a rectifier, and a capacitor, said rectifier being poled to conduct in the direction towards said reference point, a third resistor connected in shunt across said rectifier, said control electrode being connected to the common junction point of said second and third resistors and said rectifier, the time constant of said second resistor and said capacitor being such that application of said potential to said anode causes an increasing current to flow in said device until the charge on said capacitor rises to a predetermined maximum value, a load device energized in response to rise in current in said first resistance above a predetermined minimum value, and means including said third resistor and the grid-to-cathode path of said device for discharging said capacitor at a predetermined rate upon interruption of said potential.

3. A time delay circuit comprising an electron discharge device having an anode, a cathode, and a control electrode, means for selectively applying a positive potential to said anode relative to a fixed reference point, a first resistance connecting from said cathode to said reference point, a timing circuit also connected from said cathode to said reference point and serially comprising, in the order named, a capacitor, a rectifier, and a second resistance, said rectifier being poled to conduct in a direction towards said reference point, a third resistor connected in shunt across said rectifier, said control electrode being connected to the common junction point of said capacitor, said third resistor and said rectifier, the time constant of said second resistor and said capacitor being such that upon application of said potential to said anode causes an increasing current to flow in said device until the charge on said capacitor rises to a predetermined maximum value, a load device energized in response to rise in current in said first resistance above a predetermined minimum value, and means including said third resistor and the grid-to-cathode path of said device for discharging said capacitor at a predetermined rate upon the interruption of said potential.

4. A time delay circuit comprising an electron discharge device having an anode, a cathode, and a control electrode, means for selectively applying a positive potential to said anode relative to a fixed reference point, a first resistance connected from said cathode to said reference point, a timing circuit also connected from said cathode to said reference point and serially comprising, in the order named, a second resistance, a rectifier, and a capacitor, said rectifier being poled to conduct in the direction towards said reference point, a third resistor connected in shunt across said rectifier, said control electrode being connected to the common junction point of said second and third resistors and said rectifier, the time constant of said second resistor and said capacitor being such that application of said potential to said anode causes an increasing current to flow in said device until the charge on said capacitor rises to a predetermined maximum value, a normally-open load control relay having an operating coil energized in response to the current in said first resistance, said relay being operated to close load-controlling contacts when the current in said first resistance rises above a predetermined minimum value, and means including said discharge impedance and the grid-to-cathode path of said device for discharging said capacitor at a predetermined rate upon interruption of said potential.

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