Dec. 4, 1951

F. K. LOW

2,577,137

TIME DELAY CIRCUIT

Filed Sept. 9, 1947

FIG. 1

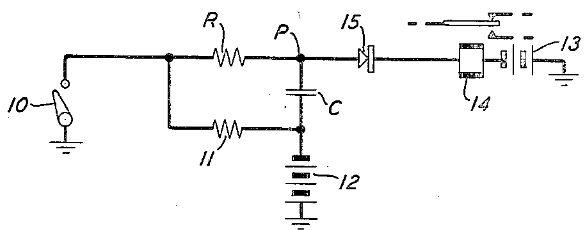


FIG. 2

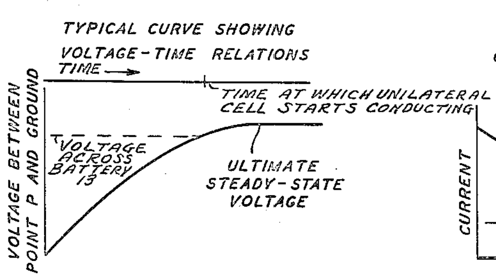


FIG. 3

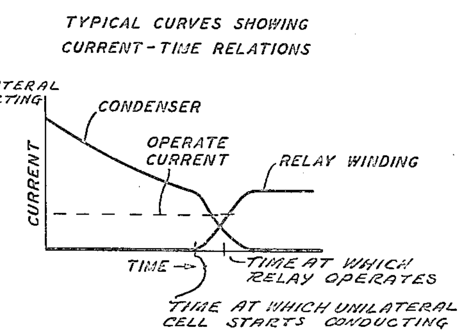


FIG. 4

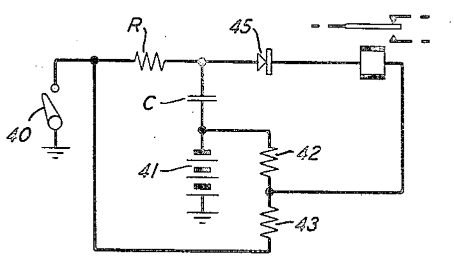
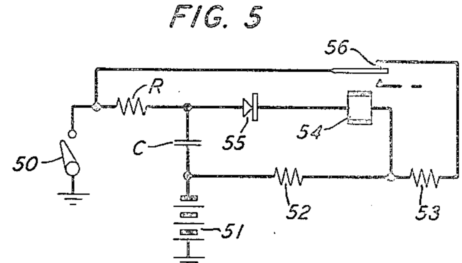


FIG. 5



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TIME-DELAY CIRCUIT

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2 Claims. (Cl. 175—320)

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This invention relates to timing apparatus and more particularly to circuits for delaying the energization of a current-responsive device and thereby, in the case of a relay, delaying the attraction of its armature for a certain period of time after the circuit is established.

The usual means employed for delaying the operation of a relay involves a short-circuited winding or copper slug on the relay core or a special construction of the relay. Another means sometimes used comprises a gas filled break-down tube or vacuum tube in combination with a condenser-resistance combination which causes the relay to operate when the condenser becomes charged to a given voltage by current flowing through the resistance. Arrangements of the first type give more or less variable operation and those of the second type are rather expensive. An object of this invention is to provide a simplified and inexpensive means for operating a relay after a definite and controllable interval, whereby the relay may be of standard and simple construction. Another object of this invention is to provide a means for operating a relay after a controllable interval, whereby variations in the relay operate time are a relatively small part of the over-all time thereby permitting precise control over the time-delay interval. A further object of this invention is to provide a means for accelerating the movement of the relay armature whereby increased pressure for the contacts may be obtained. Other objects and advantages of the invention are within the scope of the invention as will appear from the appended claims.

A complete understanding of the invention will be derived from the detailed description that follows taken in conjunction with the appended drawings, wherein:

Fig. 1 is the basic circuit diagram of the invention;

Fig. 2 is a graph showing in qualitative manner typical voltage-time relations for the apparatus;

Fig. 3 is a graph showing in qualitative manner typical current-time relations for the apparatus;

Fig. 4 is a modification of the basic circuit permitting the use of a single source of potential; and

Fig. 5 is a modification of the basic circuit whereby increased pressure for the relay contacts may be obtained.

The basic circuit of the invention as shown in Fig. 1 comprises a unidirectional device such as unilateral cell 15 connected to two sources of potential 12 and 13, and the positive terminals of these sources of potential are grounded. The potential of source 13 is substantially less than that of source 12. One side of the unilateral cell 15 is connected to source of potential 12 through timing resistor R and bleeder resistor 11. Condenser C is connected across resistors R and 11. The other side of the unilateral cell 15 is connected to source of potential 13 through the winding of relay 14. Contacts 10 are connected to the junction between resistors R and 11 and to ground.

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Unilateral cell 15 will conduct current only when the left-hand terminal of the cell, as shown in the drawings, is of positive polarity with respect to the right-hand terminal of the cell. When switch 10 is open no current is supplied to the circuit by either battery, and, since there is no potential drop across the resistors, the magnitude of the potential across cell 15 equals the difference in potential between batteries 12 and 13. Since the potential across battery 12 is larger than the potential across battery 13 and since the negative terminal of each battery is connected to cell 15, it follows that the left-hand terminal of cell 15 is of negative polarity with respect to the right-hand terminal of the cell and the cell is in a non-conducting condition. Thus, neglecting leakage currents, no current flows in the circuit and the biasing potential across cell 15 is equal to the difference in potential between batteries 12 and 13. While the contacts 10 are open the potential across timing condenser C is normally zero since there is no current flowing through resistors 11 and 12. When contacts 10 are closed current flows from the grounded pole of battery 12 through contacts 10 and resistor 11 to the negative pole of battery 12. The potential drop across resistor 11 which is caused by this current equals the potential across battery 12 and it is applied to condenser C through timing resistor R. Condenser C begins to charge, and the potential across the condenser increases exponentially as governed by the time-constant of serially connected resistor R and condenser C. Considering the potential between point P and ground, battery 12 supplies a fixed potential of negative polarity which is partially counteracted by the potential across condenser C. The sum of these two potentials at any instant equals the potential between point P and ground. The potential across the condenser C rises exponentially, as governed by the characteristics of the time-delay network comprising resistor R and condenser C, until the potential from point P to ground is less than the potential applied to the right side of the unilateral cell by battery 13.

When the potential from point P to ground just equals the potential of battery 13, there is no bias across cell 15 since there is no potential difference between the right side and the left side of the cell. Therefore unilateral cell 15 becomes conducting and the resistance which it offers to the flow of current from battery 13 is negligible. Current now flows to the negative terminal of battery 13 through the winding of relay 14, cell 15, resistor R, and switch 10 from the positive terminal of battery 13. The current through this branch of the circuit increases rapidly to its steady state value, and the rate of increase is governed by the impedance of the series circuit comprising the winding of relay 14, cell 15, and resistor R. When the current has increased to the magnitude required to operate the relay (designated "Operate Current" in the drawing), the armature of relay 14 operates. As soon as cell 15 becomes conducting both batteries 12 and 13 cause current to pass to switch 10 from ground and the potential then applied to condenser C equals the potential drop across resistor 11 less the potential drop across resistor R caused by the sum of the charging current supplied by battery 12 and the current flowing from battery 13. The potential drop caused by the sudden current which flows from battery 13 through resistor R reduces the potential applied to condenser C since the potential drop across resistor R is of opposite polarity to the potential applied to the condenser across resistor 11. The potential now applied to condenser C is less than the potential applied before cell 15 became conducting, therefore, the rate of charging condenser C is decreased and the charging current decreases rapidly to zero in an exponential manner. Typical curves showing the current and voltage relationships after contacts 10 are closed are indicated in Fig. 2 and Fig. 3. From an inspection of the curves in Fig. 2 and Fig. 3 it may be seen that the ability of the circuit to cause an abrupt rise in current in the relay branch, following a precisely timed interval, makes variations in relay operate time a relatively small part of the over-all time thereby permitting precise control over the time-delay interval. When contacts 10 are opened condenser C discharges through resistors R and and 11 and unilateral cell 15 is again biased so that no current is permitted to flow through the relay branch of the circuit. The time required for discharging condenser C and thereby restoring the bias to the unilateral cell 15 can be reduced by shunting the timing resistor R with an additional unilateral cell poled in the opposite direction to cell 15.

The time which elapses between the operation of switch 10 and the operation of the armature of relay 14 is determined by the time-constant of serially connected resistor R and condenser C, by the difference in potential between batteries 12 and 13, and by the impedance of the series circuit comprising the winding of relay 14, cell 15, and resistor R. The time-constant of serially connected resistor R and condenser C and the difference in potential between batteries 12 and 13 determine the time at which cell 15 becomes conducting. The impedance of the series circuit comprising the winding of relay 14, cell 15, and resistor R determines the rate at which the current through the winding of relay 14 increases after cell 15 becomes conducting. It will be observed that variations in time between the instant

relay winding is energized and the instant the relay armature is operated can be made a relatively small part of the over-all time delay so that precise control over the operation of the relay may be obtained.

The electrical values of the time-delay network are determined by the potential difference between batteries 12 and 13, the potential of battery 12, and the time-delay desired. During the time interval between the operation of switch 10 and the time when cell 15 becomes conducting the potential across condenser C is determined by the following equation:

$$E=V_{12}\left(1-\frac{1}{e^{t/RC}}\right)$$

where E is the potential across condenser C, V_{12} is the potential across battery 12, e is the base of natural logarithms, t is the elapsed time, R is the resistance of resistor R, and C is the capacitance of condenser C. Cell 15 becomes conducting when

$$E=V_{12}-V_{13}$$

where V_{13} is the potential across battery 13.

The value of resistance 11 is not critical. If the resistance is large, the current drain on battery 12 is small but the time required to discharge condenser C and restore the circuit is large. If the resistance is small, the current drain on battery 12 is large and the time required to discharge condenser C and restore the circuit is small.

As pointed out above, the impedance of the series circuit comprising the winding of relay 14, cell 15, and resistor R determines the interval of time between the instant cell 15 becomes conducting and the instant the relay armature operates. The inductance of the winding of relay 14 is usually the only important element which must be considered. It is desirable to minimize the interval of time between the instant that cell 15 becomes conducting and the instant the relay armature operates so as to minimize any variations in the time-delay which may be introduced during that portion of the total time. Thus, the inductance of the winding of relay 14 should be minimized in order to obtain precise control over the timing action.

Fig. 4 indicates a circuit using a single source of potential 41 and a voltage divider made up of resistors 42 and 43 to achieve the same result as the basic circuit. The operation of this circuit differs from that of the basic circuit in that when contacts 40 are open there is no biasing potential applied to unilateral cell 45; however, the instant contacts 40 are closed bias is applied to unilateral cell 45 from the voltage divider comprising resistors 42 and 43, and the circuit then functions in the same manner as the basic circuit. The circuit is restored by opening contacts 40 thereby opening the potential circuit and permitting timing condenser C to discharge through timing resistor R and the two elements 42 and 43 of the voltage divider.

Fig. 5 shows the circuit indicated in Fig. 4 modified so that the connection between resistors 53 and R is made through contacts 56 which are an armature and back contact of relay 54. When bias is removed from unilateral cell 55 by the build-up of sufficient potential across condenser C a sudden current is permitted to flow through the winding of relay 54 as described for the basic circuit. When relay 54 operates and opens contacts 56 the circuit branch comprising resistor

53 and contacts 56 is opened thereby eliminating resistor 53 as a shunt across the relay winding branch of the circuit. The removal of shunting resistor 53 suddenly increases the flow of current through the winding of relay 54 thereby accelerating the movement of the relay armature which results in increased pressure of the armature against the front contacts of relay 54. In particular, after capacitor C has charged sufficiently to cause relay 54 to operate, the potential of the relay terminal connected to the junction of resistors 52 and 53 assumes an abrupt change of potential in the negative direction by the opening of contact 5 inasmuch as resistor 53 "floats" potentialwise, and in view of the fact that the other terminal of winding 54 is maintained at substantially the same potential with respect to ground, the opening of contact 56 impresses an increased potential across winding 54 thereby immediately accelerating the armature motion. When contacts 50 are opened the flow of current from battery 51 is interrupted, the armature of relay 54 is restored to the back contacts due to the action of the armature spring, and contacts 56 are closed. The closure of contacts 56 establishes a discharge path for condenser C comprising resistors 52, 53 and R.

Although it is apparent that the circuit parameters will be selected in accordance with the available voltage sources and the desired time delay, the circuit of Fig. 1, for example, has been demonstrated properly to operate with the following parameters: Resistor R, 10,000 ohms; resistor 11, 500 ohms; condenser C, 12 microfarads; battery 12, negative 50 volts; battery 13, negative 20 volts; winding of relay 14, 8,450 ohms.

As a further example, the circuit of Fig. 4 has been demonstrated properly to operate with the following parameters: Resistor R, 10,000 ohms; resistors 42 and 43, 250 ohms; condenser C, 12 microfarads; battery 41, negative 50 volts; winding of the relay, 8,450 ohms.

What is claimed is:

1. A time-delay circuit comprising a voltage divider, a serially connected circuit comprising a unilateral cell, relay, first element of said voltage divider, and timing condenser, a second element of said voltage divider connected to the junction between said first element and said relay, a timing resistor connected in series with said second element of the voltage divider and connected to the junction between said timing condenser and said unilateral cell, a source of potential connected to ground and to the junction between the timing condenser and the first element of the voltage divider, and a set of contacts connected to ground and the junction between the second element of the voltage divider and the timing resistor whereby bias is applied to the unilateral cell from the voltage divider the instant said contacts are closed, and, due to the action of the timing resistor and condenser, said bias is removed a timed interval thereafter thereby permitting a sudden current to pass through the unilateral cell and operate said relay.

2. A time-delay circuit comprising a voltage divider, a serially connected circuit comprising a unilateral cell, relay, first element of said voltage divider, and timing condenser, a serially connected timing resistor and set of contacts circuit connected to ground and to the junction between the unilateral cell and timing condenser, a second element of said voltage divider connected to the junction between said first element and said relay, a back contact and armature of said relay connected in series with said second element of the voltage divider and connected to the junction between the timing resistor and the set of contacts which are connected to ground, and a source of potential connected to ground and to the junction between the timing condenser and the first element of the voltage divider whereby bias is applied through the timing resistor to the unilateral cell the instant said serially connected timing resistor and set of contacts circuit is closed, and, due to the action of the timing condenser and resistor, said bias is removed a timed interval thereafter thereby permitting a sudden current to pass through the unilateral cell and operate said relay, the operation of said relay serving to open said back contact and armature thereby suddenly increasing the voltage applied to said relay and accelerating the movement of the relay armature.

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