Aug. 31, 1965 G. E. KERSEY 3,204,151

FAST-ACTING RELAY CONTROLLED CIRCUIT

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FIG. 1

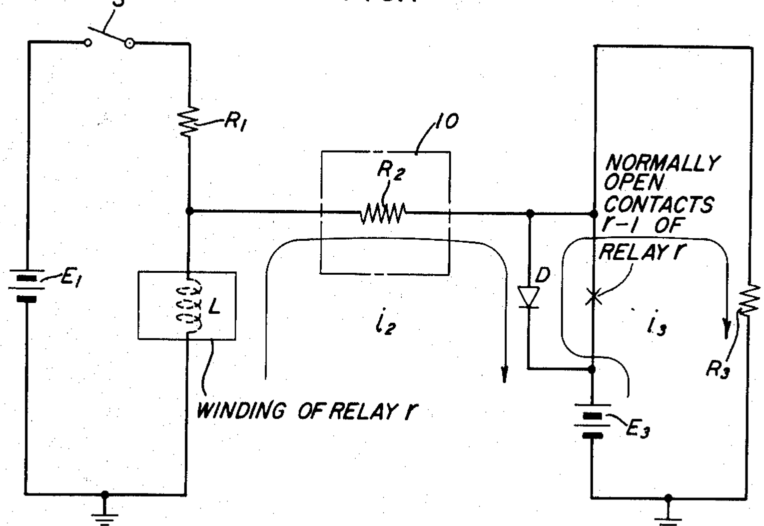
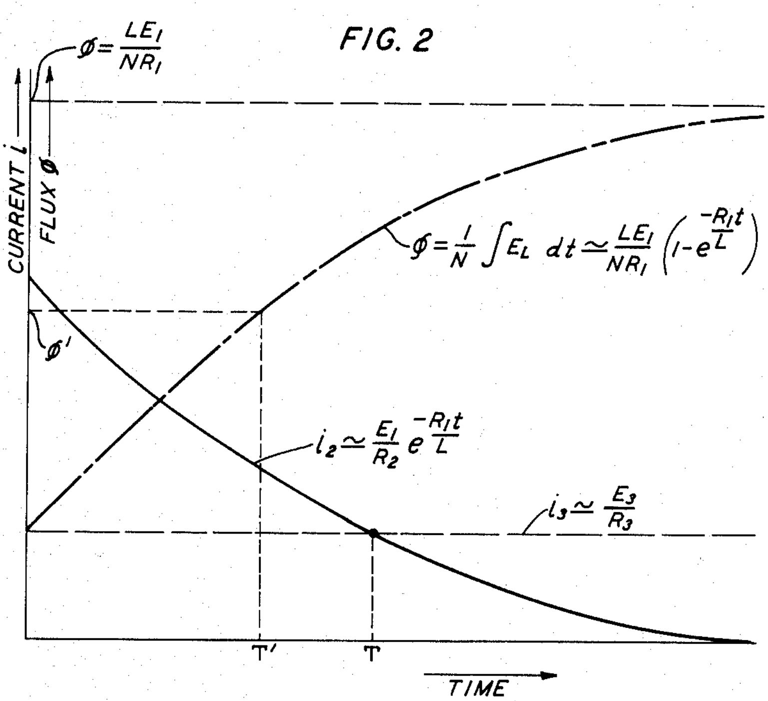


FIG. 2



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FAST-ACTING RELAY CONTROLLED CIRCUIT

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This invention relates to relay-controlled circuits, and more particularly to the rapid operation of such circuits employing electromechanical relays.

An electromechanical relay is often used to either establish or disestablish a connection from one circuit element to another. In such a case a winding associated with the relay is energized to create a magnetic field which acts upon a set of contacts that link the circuit elements. Where the contacts are normally separated, the field serves to draw them together and establish a conduction path between the elements, but where the contacts are normally closed, the field causes their separation and disrupts the path.

While an electromechanical relay is simple and reliable, it is subject to several disadvantages. In the first place the electrical inertia of its winding prevents a rapid change in the magnetic field that acts upon the contacts, thus delaying their closure, when open, and their separation, when closed. In addition, the motion of the contacts produced by the field often results in undesirable vibration, i.e., chatter.

Accordingly it is an object of the invention to reduce the extent of the delay interval that conventionally exists between the energizing of a relay winding and the operation of associated relay contacts. A related object is to eliminate the vibration that often accompanies the operation of the contacts.

To accomplish the foregoing and related objects the invention provides for shunting the contacts by a unidirectionally conductive device which is coupled to the winding, i.e., coil, of the relay through a resistor of appreciable resistive magnitude.

As a result, when a load is to be energized through the contacts from a work source, and a control source, producing an output level of greater magnitude, energizes the coil, the unidirectionally conductive device becomes operated and the load is clamped to the signal level of the work source so long as the current supplied to the device by the control source is greater than that drawn by the load.

It is a feature of the invention that the coupling resistor is readily proportioned to allow the coil energy to build up to a level which operates the contacts slightly before the current through the device falls below the level required to maintain the clamping action.

In effect, the unidirectionally conductive device is rendered conductive by the control source until a control signal attributable to it decays exponentially, substantially according to the relation $K_1e^{-\alpha_1 t}$ to a cut-off point K_1' at the time T. Simultaneously, the control source energizes the relay winding by a control signal that increases monotonically, substantially according to the relation $K_2-K_2e^{-\alpha_2 t}$ until the contacts are operated at a time T′, which occurs earlier than the cut-off time T. Hence, one circuit element is initially connected to another through the unidirectionally conductive device and subsequently through the relay contacts.

Other aspects of the invention will become apparent after the consideration of an illustrative embodiment taken in conjunction with the drawings in which:

FIG. 1 is a schematic diagram of a fast acting relay circuit according to the invention; and

FIG. 2 is a graphical diagram explanatory of the operation of the circuit in FIG. 1.

As shown in FIG. 1, an electromechanical relay r is used for controlling a work circuit that includes a source E_3 and a load R_3. The relay r is represented by a pair of normally open contacts r–1 in the work circuit and a winding, i.e., coil, in an operate circuit. The winding is characterized by an impedance with a reactive constituent of inductance L. In the operate circuit, the coil is energized from a source E_1 through a resistor R_1 by the closure of a switch S. The resistor may expressly limit the flow of current through the coil after the switch S has been operated, or it may represent the impedance of another device employed in conjunction with the relay r. When the operate circuit is activated, the contacts in the work circuit are brought together after a duration determined by the time required for a sufficient buildup of magnetic field energy in the coil.

To apply the source voltage E_3 to the load R_3 within the delay interval that normally attends relay operation, a unilaterally conductive device, such as a rectifying diode D, shunts the contacts r–**1** and is connected to the operate circuit through an isolating element **10**. The isolating element is desirably a resistor of appreciable resistance magnitude R_2 and the signal strength of the operate source E_1 is proportioned to be greater than the corresponding strength of the work source, i.e., $E_1>E_3$.

When the switch S is operated the inductive inertia of the coil L prevents the immediate flow of current through it so that the shunt diode, being subjected to greater voltage at its anode than at its cathode, is rendered conductive and the work voltage E_3 is directly applied to the load as desired. As long as the loop current flow i_2 through the isolating resistor R_2 is greater than the loop current flow i_3 in the load the diode will be maintained in a forward-biased condition and the work voltage E_3 will continue to be applied at the load R_3.

The current i_2 through the isolator resistor, neglecting the coil resistance, is

$$\frac{E_L-E_3}{R_2}$$

where E_L, the inductor voltage, is an exponentially decaying function given in Expression 1

$$E_L=\frac{E_1R_2+E_3R_1}{R_1+R_2}e^{-\left(\frac{R_1R_2}{R_1+R_2}\right)\frac{t}{L}} \tag{1}$$

Usually $R_2>R_1$ and, since $E_1>E_3$, E_L is approximately

$$E_L\simeq E_1e^{-\frac{R_1t}{L}}$$

and the isolating resistor current i_2 becomes

$$i_2\simeq\frac{E_1}{R_2}e^{-\frac{R_1t}{L}}-\frac{E_3}{R_2} \tag{2}$$

At the same time, the current i_3 flowing through the load R_3 because of the work voltage is E_3/R_3. The work voltage E_3 will continue to be applied through the diode D as long as $i_2>i_3$ or

$$\frac{E_1}{R_2}e^{-\frac{R_1t}{L}}-\frac{E_3}{R_2}>\frac{E_3}{R_3} \tag{3}$$

If $R_2>R_3$, Expression 3 becomes

$$\frac{E_1}{R_2}e^{-\frac{R_1t}{L}}>\frac{E_3}{R_3} \tag{4a}$$

or

$$K_1e^{-\alpha_1 t}>K_1'$$

where

$$K_1=\frac{E_1}{R_2}$$

$$K_1'=\frac{E_3}{R_3}$$

and

$$\alpha_1=\frac{R_1}{L}$$

The left-hand and right-hand sides of Expression 4*a*, which substantially give the currents i_2 and i_3 flowing through the diode D due respectively to the voltage of the coil L and the work source E_3, are plotted in FIG. 2. When the two currents are equal, at time T given by Expression 4*b*

$$T=\frac{L}{R_1}\ln\left(\frac{R_3}{R_2}\cdot\frac{E_1}{E_3}\right) \quad (4b)$$

the diode D is no longer able to clamp the load R_3 at the work voltage E_3.

Hence the circuit elements, whose parameters form Expressions 4*a* and 4*b*, are proportioned so that time T occurs after the closure of contacts *r*–1 (FIG. 1). The time of closure depends upon the buildup of magnetic field flux φ in the coil substantially according to Expression 5, which is plotted in FIG. 2,

$$\varphi=\frac{1}{N}\int E_L dt\simeq\frac{LE_1}{NR_1}\left(1-e^{-\frac{R_1t}{L}}\right) \quad (5)$$

where:

N is the number of turns in the coil,
E_L is the voltage of the coil, and
L is the inductance of the coil.

At time T′, the flux φ reaches a preassigned magnitude φ' (FIG. 2) that is of sufficient strength to operate the relay contacts and

$$\varphi'\simeq\frac{LE_1}{NR_1}\left(1-e^{-\frac{R_1T'}{L}}\right) \quad (6)$$

or

$$K_2'\simeq K_2-K_2e^{-\alpha_2T'}$$

where

$$K_2{}^1=\varphi^1$$

$$K_2=\frac{LE_1}{R_1}$$

and

$$\alpha_2=\frac{R_1}{L}$$

For a typical relay, the coil inductance is on the order of 240 henries and the operate time is on the order of 7 milliseconds. Thus, when R_1 is 24,000 ohms, and of a smaller magnitude than R_2, the relationship among the parameters of Expression 4*b* is

$$\frac{2R_2}{R_3}=\frac{E_1}{E_3}$$

In the event that the restrictions imposed upon R_1, R_2, and R_3 do not apply, i.e., $R_2 \ngtr R_1$ or R_3, Expression 4*b* becomes

$$T=\frac{L(R_1+R_2)}{R_1R_2}\ln\left[\frac{(E_1R_2R_3+E_3R_1R_3)}{E_3(R_1+R_2)(R_2+R_3)}\right] \quad (7)$$

from which appropriate resistive magnitudes can be determined in the manner previously described.

Consequently as long as the circuit parameters are adjusted so that the contacts close before the expiration of the clamping interval, operation of the switch S associated with the source E_1 results in the rapid application

of a work voltage E_3 to a load R_3, unaccompanied by contact chatter. When the contacts *r*–1 ultimately close the work voltage is then applied through them until the coil is deenergized, at which time the diode D is prevented from interfering with the disengagement of the contacts *r*–1 by being further back-biased by the voltage induced in the coil through the collapse of its magnetic field.

Other adaptations of the invention will occur to those skilled in the art.

What is claimed is:

1. Apparatus comprising
a relay having a pair of normally open contacts, and a control winding characterized by electrical inertia,
a source connectable to a load through said contacts,
means for energizing said control winding to close said contacts and establish a conduction path therethrough after a delay interval governed by the electrical inertia of said control winding,
a unidirectionally conductive diode connected in shunt with said contacts and poled in its direction of nonconduction with respect to said source, and
a path, whose impedance is greater than that of said load, interconnecting said diode with said winding, whereby energy applied to said winding by said energing means is able to establish a conduction path from said source to said load through said diode before the closure of said contacts.

2. Apparatus comprising
a relay with a control winding and a pair of normally open contacts,
means, including a first source and a resistor, for energizing said control winding,
a first path including said contacts for connecting a second source to a load by the closure of said contacts,
and a second path in shunt with the first and responsive to said energizing means for connecting said second source to said load.

3. Apparatus comprising
a relay,
means, including a first source, for energizing said relay,
means controlled by the energized relay for connecting a second source to a load after a time delay T,
and means controlled by the energizing means for clamping said second source to said load for a preassigned interval commencing before the lapse of said time delay T and terminating thereafter.

4. A fast-acting relay controlled circuit comprising
a relay having a pair of normally open contacts and a winding characterized by electrical inertia,
a source connectable to a load through said contacts,
means for energizing said winding to close said contacts and connect said source to the said load through the closed contacts after a time delay governed by said electrical inertia,
a unidirectionally conductive device connected in shunt directly with said contacts,
and a path extending from said winding to said device,
thereby to clamp said source to said load through said device for a preassigned interval commencing before the lapse of said time delay and terminating thereafter.

5. A fast-acting relay controlled circuit comprising
a relay having a winding and a pair of contacts,
a source connectable to a load through said contacts,
a diode connected in shunt with said contacts, a resistor connecting said winding to said diode, and
means for energizing said winding.

6. Apparatus responsive to energizing means for connecting a source with a load, comprising
first means energized from the energizing means substantially according to the relation $K_1e^{-\alpha_1t}$ for clamping the source to the load as long as $K_1e^{-\alpha_1T}<K_1'$, where K_1 is the initial signal level of said first means,

α_1 is the exponential factor by which such signal level changes during time t, and K_1' is the signal level at which said first means fails to operate, and second means energized from said energizing means substantially according to the relation $K_2-K_2e^{-\alpha_2 t}$ for establishing a through path from said source to said load as long as $K_2-K_2e^{-\alpha_2 T}>K_2'$, where K_2 is the ultimate signal level of said second means, α_2 is the exponential factor by which the signal level of said second means changes during time t, K_2' is the level which said second means operates, and T is its operate time,

whereby said source is initially connected to said load by said first means and subsequently connected to said load by said second means.

7. Apparatus responsive to energizing means capable of supplying increasing and decreasing signals, for connecting a source with a load, comprising

means controlled by an asymptotically increasing signal supplied by the energizing means for connecting the source to the load after a preassigned interval,

and means controlled by a exponentially decreasing signal supplied by said energizing means for connecting said source to said load before said preassigned interval.

8. Apparatus responsive to energizing means for connecting a source to a load, comprising

means energized by a steadily increasing signal supplied by the energizing means for connecting the source to the load after a delay time T, and

means energized by a steadily decreasing signal supplied by said energizing means for connecting said source to said load until the attainment of a time T′ after said delay time T.

9. A relay-controlled circuit comprising

a relay having a winding with first and second terminals and a pair of contacts with first and second terminals, said winding being characterized by an inductance L,

a first resistor having first and second terminals and being characterized by a resistance R_1, the first terminal of said first resistor being connected to the first terminal of said winding,

a switchable source characterized by a voltage E_1 and interconnecting the second terminal of said first resistor with the second terminal of said winding,

a second resistor having first and second terminals and characterized by a resistance R_2, the first terminal of said second resistor being connected to the junction of said first terminal of said first resistor with said first terminal of said winding and the second terminal of said second resistor being connected to the second terminal of said pair of contacts,

a diode having a cathode and an anode, said anode being connected to said second terminal of said pair of contacts and said cathode being connected to the first terminal of said pair of contacts,

a third resistor having first and second terminals and characterized by a resistance R_3, the second terminal of said third resistor being connected to said second terminal of said pair of contacts, and

a source characterized by a voltage E_3 interconnecting the first terminal of said third resistor with said first terminal of said pair of contacts.

10. Apparatus as defined in claim 9 wherein said contacts operate after a time delay T from the energizing of said winding from said switchable source; and

said winding, said first resistor, said second resistor, said third resistor, said switchable source, and said second named source are proportioned according to the relation

$$T=\frac{L}{R_1}\ln\left(\frac{R_3}{R_2}\cdot\frac{E_1}{E_3}\right)$$

11. Apparatus as defined in claim 9 wherein said contacts operate after a time delay T from the energizing of said winding from said switchable source; and

said winding, said first resistor, said second resistor, said third resistor, said switchable source, and said second named source are proportioned according to the relation

$$T=\frac{L(R_1+R_2)}{R_1R_2}\ln\left[\frac{(E_1R_2R_3+E_3R_1R_3)}{E_3(R_1+R_2)(R_2+R_3)}\right]$$

12. In combination with a relay having a control winding and a pair of normally open contacts,

an operate circuit including the winding of the relay and means for energizing it,

a work circuit including the contacts of said relay and a source connectable to a load therethrough,

a clamping path conected in shunt with said contacts, and

a control path extending from said operate circuit to said clamping path.

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SAMUEL BERNSTEIN, *Primary Examiner.*