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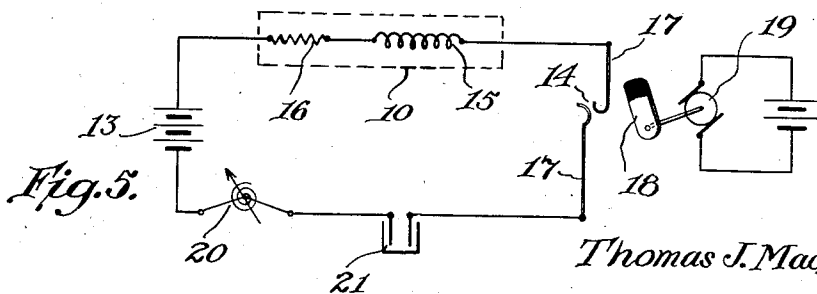
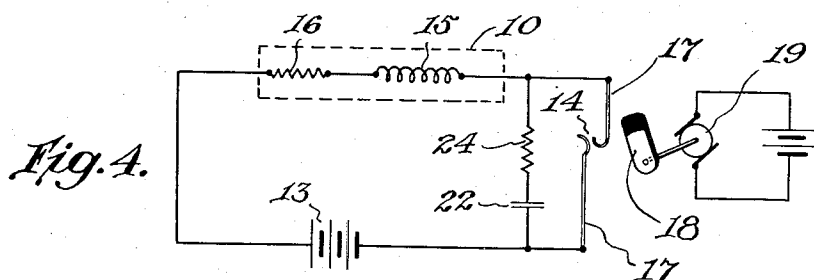
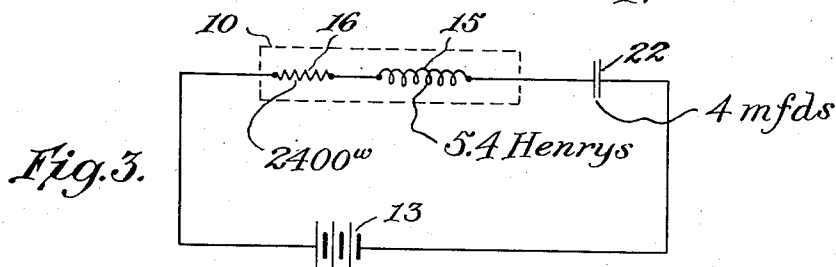
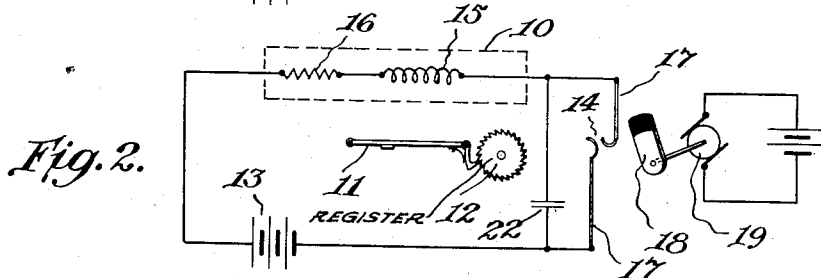
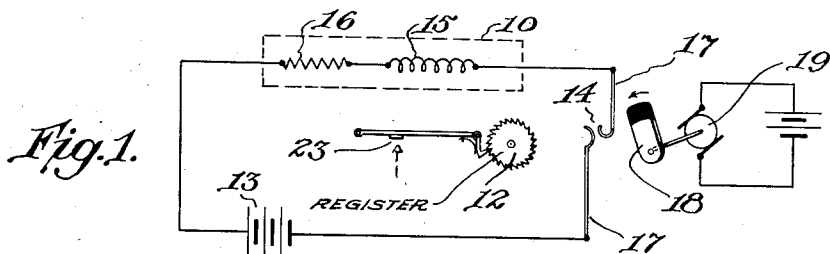
T. J. MacKAVANAGH

2,267,986

FOLLOW-THROUGH ELECTRIC CIRCUIT

Filed May 25, 1939

2 Sheets-Sheet 1



Inventor

Thomas J. MacKavanagh

By *Charles H. Hills*

Attorney

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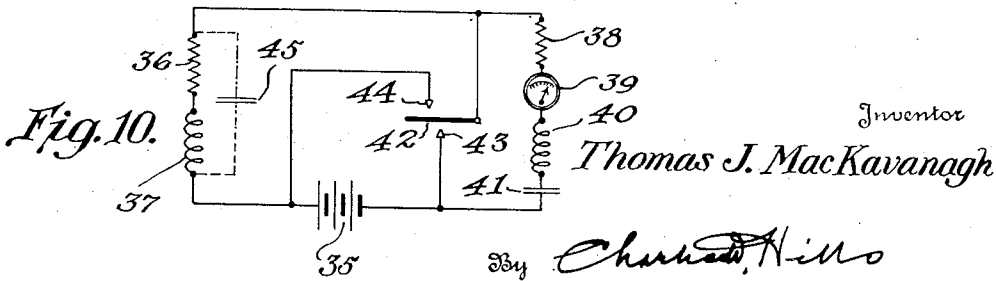
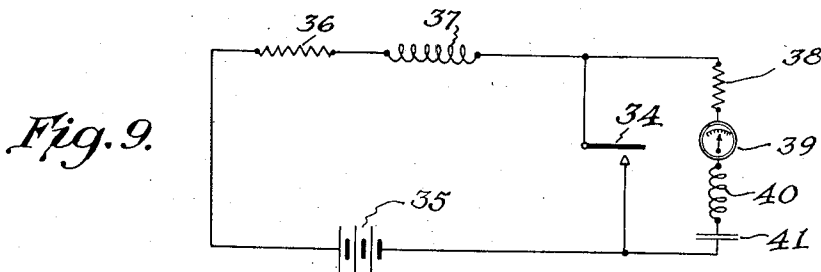
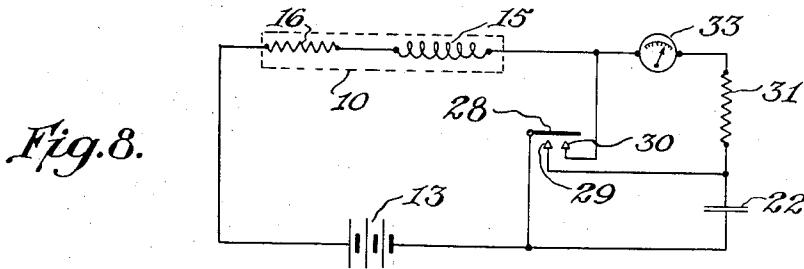
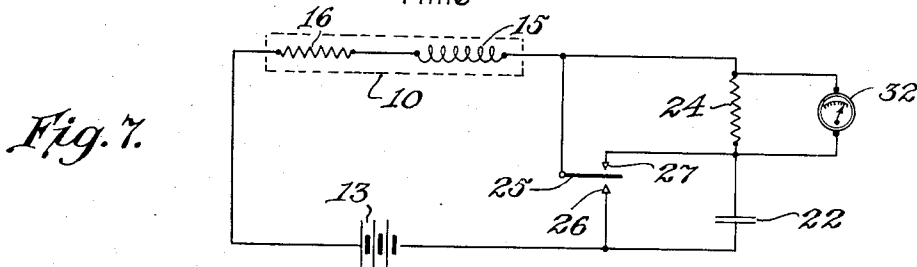
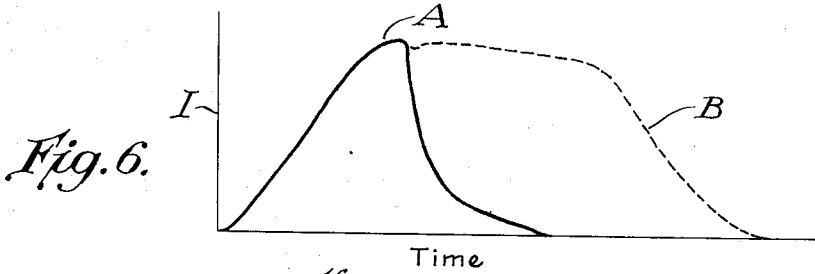
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FOLLOW-THROUGH ELECTRIC CIRCUIT

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2 Sheets-Sheet 2



Inventor

Thomas J. MacKavanagh

By *Charles H. Hill*

Attorney

UNITED STATES PATENT OFFICE

2,267,986

FOLLOW-THROUGH ELECTRIC CIRCUIT

Thomas J. MacKavanagh, Washington, D. C.

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13 Claims. (Cl. 235—92)

The present invention is related to signalling and like electric circuits comprising a source of current, a current-operated electromagnetic relay, counter or registering device, and a circuit-closing switch for controlling current flow to the device.

The present invention has for its object the provision of means to sustain current flow in a circuit including an inductive winding of a relay or the like, having a relatively high inherent resistance, for a predetermined period after the circuit-controlling switch has opened.

It is an important object of the present invention to provide means to make possible an appreciable gain in speed of electrically operated registers, relays, or the like inductive apparatus without an increase in battery voltage over that necessary to obtain a lower operating speed when the invention is not employed.

It is a further important object of this invention to provide means for the satisfactory and uniform operation of electrically operated registers, relays, and the like inductive apparatus when the touch of the associated circuit-closing switch varies within predetermined limits.

It is a further important object of this invention to provide means for ensuring a current flow through electrically operated registers, relays, and the like inductive apparatus for a period substantially independent of the momentary closing period of associated circuit-closing switches.

It is a further object of this invention to provide means for ensuring a sustained current of a predetermined mean value through a relay and like inductive apparatus although the associated circuit-closing switch is repeatedly opened during the period of sustained mean current.

It is a further important object of this invention to provide a pair of circuits having their terminals in connected relation, with switch means adapted to alternately place said circuits in parallel and in series circuit association, respectively, and to provide for reverse unidirectional current flow for a predetermined period in one of said circuits.

It is a further important object of this invention to provide a pair of circuits having their terminals in connected relation, with switch means adapted to place said circuits alternately in parallel and in series circuit association, respectively, and to modify one of said circuits as the relationship of the circuits is changed from parallel to series.

Other and further important objects of this

invention will be apparent from the disclosures in the specification and the accompanying drawings.

This invention is illustrated in the drawings and hereinafter more fully described.

Figure 1 is a diagrammatic showing of a conventional circuit which includes a battery, a switch, means to operate the switch, and a current-operated registering or counting device which includes a registering element engageable by a movable armature to actuate it, when the switch is closed.

Figure 2 is a diagrammatic showing of the circuit of Figure 1 modified to include a condenser to provide a follow-through current to the winding of the register after the winding has been initially energized by the closing of the switch for a predetermined period of time.

Figure 3 is a showing of the equivalent circuit of the arrangement shown in Figure 2 when the switch is open.

Figure 4 shows a modified form of the circuit of Figure 2.

Figure 5 is an explanatory showing of a circuit such as that of Figure 1 with additional current-responsive means in the circuit.

Figure 6 is an explanatory graph of current flow in the circuit of Figure 1 and as modified in the circuit of Figure 2.

Figures 7, 8, 9, and 10 show diagrammatically modifications of the circuit of Figure 2 by the inclusion of current-responsive means other than the winding of the register.

In the drawings:

In Figure 1 there is illustrated diagrammatically a conventional circuit comprising a current-operated counter or register 10 of conventional construction, a battery 13, and a switch 14. The counter is provided with an armature 11 suitably connected to a registering mechanism, indicated generally at 12, to register the closing of the circuit.

The actuating winding of the counter has inductance and resistance, indicated by the numerals 15 and 16 respectively, and when the circuit is closed the current in the winding will increase gradually because of the counter voltage generated in the winding as the magnetic flux in the magnetic circuit of the device increases. The current will finally reach a value equal to the steady impressed voltage divided by the resistance of the circuit, but since, theoretically, the time taken to reach this value is infinite, we usually concern ourselves only with the time that must elapse between the closing of the switch and

the growth of the current to such a value as to result in positive operation of the register by the movable armature 11.

In a circuit set up for test purposes, the register 10 was a conventional high-speed register having an actuating winding of a measured inductance of 5.4 henrys and a measured resistance of 2400 ohms. The voltage of the battery 13 was 128 volts.

The switch 14 was formed of two phosphor bronze strips 17, and the circuit was momentarily closed by striking one of the strips to bring them into contact by a revolving blade 18 of insulating material and driven by a motor 19.

When the switch was held closed by hand, it was found that a minimum steady current of 16.5 milliamperes was necessary in the actuating winding of the counter device to positively actuate the registering mechanism 12.

With a battery voltage of 128 volts and the switch closed by the revolving blade 18, the register would not positively register more than 220 closings of the circuit per minute with the switch contacts being closed for $\frac{1}{16}$ of each revolution of the revolving blade 18.

In a relay, a counter, or a similar current-operated device having actuating coils, a certain minimum value of current must flow through the coils for a certain minimum period of time to effect satisfactory operation of the movable armature of the device, the current value being determined by the design of the magnetic circuit of the device, the inertia of the movable parts, and the tension of controlling springs. When an attempt is made to cause the device to operate faster—to have the counter register more circuit-closing operations per minute—the “time constant” of the circuit becomes of first importance because it may, for a given voltage applied to the circuit, prevent the current building up to a value necessary to operate the device satisfactorily during the period of circuit closing.

If the circuit of Figure 1 is completed by the closing of the switch 14, the equation for instantaneous current is:

$$i = Ke^{-\frac{Rt}{L}} + \frac{E}{R} \quad (1)$$

At the instant of closing of the switch, $t=0$, $i=0$, and

$$K = -\frac{E}{R}$$

The current equation now becomes

$$i = \frac{E}{R} \left(1 - e^{-\frac{Rt}{L}} \right) \quad (2)$$

and this equation indicates that the current is an exponentially growing function of time.

It should now be obvious that if we would increase the operating speed of the device 10 of Figure 1—would reach a desired value of operating current in less time—we must increase the battery voltage. If we would do no more than deliver the same amount of energy to the device at each closing of the switch, it is obvious that we must increase the intensity of current flow at each closing as the period of closing becomes shorter and shorter, and must progressively increase the battery voltage.

Should the circuit contain elements such as a heat-responsive device indicated at 20, or an electro-chemical cell indicated at 21 in Figure 5, they may be injuriously affected by the increased current, and the moving parts of the device 10

may also be injuriously affected by the sudden rush of current of abnormal value.

Again, when operating with an increased voltage great care must be taken to keep the period of switch closing within narrow limits, for if the closing period is extended slightly the current becomes abnormal and destructive heating of the actuating coils results.

In telegraphing, for instance, some operators close the sending key or switch with a “heavy” touch, and others with a “light” touch, and the operator at the receiving station of a telegraph circuit must usually adjust the travel of the armature of the relay or sounder for proper operation of the receiving device as the “style” of sending is varied. A certain sending operator may change his touch as he becomes fatigued or nervous, and his speed of sending may vary for several reasons.

Mechanically or electrically operated switches may also operate erratically for many reasons, contacts become dirty or irregular in surface, springs become fatigued, and the operating current of relays may vary over wide limits as the result of improper functioning of their control switches.

The voltage at the contacts of a fast-operating switch is many times that of the battery voltage in circuits having appreciable inductance, and this high voltage tends to maintain current flow through the opening contacts of the switch with resulting arcing between the contacts, and destruction of the contact surfaces. Therefore, condensers have heretofore been connected to shunt the opening contacts to protect the contacts and to very materially hasten the opening of the circuit, and in fact, when shunting the opening contacts of the vibrating switch of a spark coil, to make possible a rapid “break” of the circuit and a definite gain in the voltage at the terminals of the secondary of the coil.

The present invention was conceived to sustain the current flow through the actuating coil of a relay, counter, or other current-operated device possessing inductance and a relatively high inherent resistance after the switch opens, and particularly to ensure positive operation of the device when its operation would otherwise be erratic because of improper functioning of the circuit-closing switch.

It was also conceived as a means to make possible an increase in the operating speed of a counter, relay, or similar device without necessitating an increase in operating voltage above that necessary to operate the device at a much lower speed without the invention. An increase in operating speed in the ratio of 890 to 220, without increase in battery voltage, is hereinafter described.

It was also conceived as a means to make possible an increase in operating speed of a counter, relay, or similar device without necessitating the use of currents of progressively increasing intensity, and of increasing battery voltage, as the switch closed period became progressively shorter, within predetermined limits, and so avoid the injurious effect of abnormal currents in circuit elements, and without necessitating the extreme care necessary when abnormal currents are used to avoid “overshooting” when the “touch” of the closing switch becomes heavier than intended.

The present invention was also conceived as a means to make possible a rate of change of energy flow best suited to satisfactory operation

of circuit elements in making possible a period of current flow greater than that possible during momentary switch closing. And, when it is possible to sustain the current for a period greater than that of switch closing, it becomes possible to maintain a circuit in substantially closed position, to maintain a relay in circuit-closing condition, while the line switch repeatedly and rapidly opens and closes, and without necessitating a special relay structure.

In Figure 2, there is shown a circuit embodying the present invention and in which the actuating winding of the device 10 has an inductance of 5.4 henrys, and a resistance of 2400 ohms, and a condenser 22, shunting the closing contacts of the switch 14, has a capacitance of 4 microfarads.

The addition of the condenser 22 of predetermined capacitance in the circuit resulted in a positive increase in the operating speed of the register in the ratio of 890/220 without any change in the battery voltage, and despite the fact that conditions were unfavorable due to the relatively light touch of the contacts of the switch when jarred at the higher operating speed.

An inspection of Figure 2 will disclose that the circuit is initially similar to that of Figure 1 when the switch closes, but when the switch opens the circuit takes the form shown in Figure 3. In other words, the device 10 is initially subjected to the current that would flow when the device is connected directly to the battery, and is next subjected to the follow-through current that flows when it is connected in series with the charging condenser.

Referring now to Figure 3, if the circuit shown is supplied by a source of constant voltage E, and L and C are considered constant, the equation for instantaneous current is:

$$i = K_1 e^{-mt} + K_2 e^{-nt} \quad (3)$$

in which

$$m = \frac{RC - \sqrt{R^2 C^2 - 4LC}}{2LC} \quad (4)$$

and

$$n = \frac{RC + \sqrt{R^2 C^2 - 4LC}}{2LC} \quad (5)$$

An analysis of the equations for m and n indicates that the constants R, L, and C may be of such relative values that the term

$$\sqrt{R^2 C^2 - 4LC}$$

may be either real, imaginary, or zero.

Further analysis indicates that

- (a) It is real when R is greater than two times the square root of the inductance divided by the capacitance, i. e.,

$$2\sqrt{\frac{L}{C}}$$

- (b) It is imaginary when R is less than two times the square root of the inductance divided by the capacitance; and

- (c) It is zero when R is equal to two times the square root of the inductance divided by the capacitance.

When the circuit satisfies the equation of case (a), the current-time relation is aperiodic; when it satisfies the equation of case (b), the current-time relation is oscillatory; and when the equation of case (c) is satisfied, the current-time relation is aperiodic, but the circuit is critical, for

if R decreases for any reason, the circuit becomes oscillatory and the device 10 tends to chatter and produce false registrations.

- In setting up a circuit to satisfy case (c), we have

$$2400 = 2\sqrt{\frac{5.4}{C}}$$

- and we find $C = 3.75$ microfarads as the minimum value of capacitance to make the current-time relation of the circuit aperiodic. Obviously, an increase in the value of the capacitance above this value will satisfy the equation of case (a), so a value of 4 microfarads was adopted in the test circuit.

- In the counter device 10 under test, movement of the armature did not appreciably affect the measured inductance, but it will be obvious to those familiar with the art that weighted values of L and R may be used for the actual inductance and the effective resistance when movement of the armature appreciably affects the magnetic circuit and the losses incidental to change in the magnetism of the magnetic material.

It will be obvious that the invention is not limited to a circuit employing a switch of the specific type described.

- It will now be appreciated that the operation of the device 10, or the like, is, to a great extent, uninfluenced by the "touch" of the closing switch.

- From an inspection of Figure 2, it will be evident that the switch 14 discharges the condenser 22 when it closes to connect the device 10 directly to the battery. As shown in Figure 4, a resistance 24 may be connected in series with the circuit arrangement which discharges the condenser to limit the short-circuit current and to dissipate the energy stored in the condenser. The inclusion of this resistance will, of course, in some instances, necessitate its being considered in the equations of cases (a), (b), and (c), but it was found that the addition of enough resistance 24 in Figure 4 to limit the current flowing when the condenser was shunted to a satisfactory low value did not measurably affect the operation of the register of Figure 2 with the value of capacitance used. A value of ten ohms in the resistance 24 was found satisfactory.

- The conventional device 10 under test was also provided with circuit-closing contacts 23 so that it could be used as a relay, as a registering device, or as both. It will be evident that the task of ensuring positive operation of the device as a register was more onerous than that of securing positive closing of relay contacts, because of the greater friction and inertia of the registering mechanism, but the more onerous duty of operating it as a register was accepted because the register gave means of positively comparing register operation with switch closing operations, and of checking the validity of the used constants of the circuit within reasonable limits.

- An increase in the operating speed of the register from 220 to 890 without any increase in battery voltage was considered satisfactory under the known conditions of switch performance, and while it appears reasonable to expect a greater increase in speed with improved switch construction, the test was not concerned with maximum gain in operating speed, but with gain under unfavorable switch operating conditions. It is also reasonable to assume that the increased operating speed of 890 could have been obtained at a lower battery voltage with an improved switch,

but it was found that the circuit could be conveniently protected by a fuse to protect the device 10 in the event of the sticking together or "freezing" of switch contacts should another form of switch be employed.

It should be evident that the switch illustrated in the drawings is merely for illustrative purposes, and that others making use of a similar switch should guard against vibrations of the switch contacts due to mechanical resonance of the springy elements thereof. It will also be obvious to those familiar with the art that the function of the line switch 10 may be performed by other types of switches, whether mechanically or electrically operated.

In review, it may be repeated that the circuit embodying the invention is one in which the current is purposely sustained for a period of time greater than that of the period of switch closing by interposing a condenser of predetermined capacitance, as the switch opens, to maintain current flow for a substantially long period after the switch closes. This is directly opposed to the use of a condenser for the purpose of ensuring a rapid "break" of the circuit as the switch opens and to substantially limit the period of current flow to that of the period of switch closing. Resistors and condensers have been used heretofore to suppress sparking at the contacts of opening switches, as opposed to the purposes of the present invention, in which a condenser of predetermined capacitance is interposed upon opening of the line switch to maintain the circuit in closed condition for current flow for a predetermined period of time and so make possible the functioning of a relay, or the like, and produce a result impossible by momentarily closing the circuit by a line switch under the same circuit conditions as to battery voltage. While non-inductive resistors and condensers are not strictly interchangeable, yet, in practice, opening contacts have been shunted by resistors or condensers to suppress sparking at the contacts, in one case to dissipate rapidly the energy of a decaying field, and in the other to absorb or store that energy or to produce rapid reversals of current in the circuit. In both cases they were conceived as means to suppress sparking, to permit a sudden cessation of current flow, and not as means to add to the initial current a follow-through current to maintain current flow, and in effect to maintain the circuit closed for current flow for a substantially long and predetermined period of time after the switch opens.

It will be obvious that sufficient time must be allowed between successive closings of the switch 14 to permit the current to be sustained long enough to effect positive operation of the device 10 when the device 10 is to register the closings of the switch when used as a register, or to close a local circuit as often as the switch 14 is closed when it is used as a circuit-closing device.

However, the present invention makes it conveniently possible to superimpose current impulses due to the closing of the switch 14 upon charging current impulses to delay opening of the relay circuit-closing contacts when this is desired.

In Figure 6, the solid curve A is typical of current growth and current decay in the circuit of Figure 1, while the dotted curve B is typical of current flow, with the same battery voltage, in the circuit of Figure 2 under the conditions of resistance, inductance, and capacitance given in connection with the conventional device 10

The curves were observed while an oscilloscope indicated the current flow during the tests.

At a given operating speed of the blade 18 and with a given battery voltage, a milliammeter in the circuit of Figure 1 would give a "kick" reading of about 4 milliamperes, but when the circuit was changed to that of Figure 2, and without any change having been made in the operating speed of the blade 18, and without any change in the battery voltage, the "kick" reading of the milliammeter was around 20 milliamperes. These readings are given merely to indicate roughly how the relay is affected when the circuit of Figure 2 is in use, although, after all, the gain in speed from 220 to 890, already referred to, is the best evidence of how the circuit affects the relay performance.

In Figure 7, there is illustrated diagrammatically a circuit arrangement in which a switch 25 is provided with front and back contacts 26 and 27, so that when the switch closes, it will cause current to flow through the device 10 while at the same time discharging the condenser 22 through the resistance 24, but upon opening will engage the back contact 27 and will short-circuit the resistance 24.

Another circuit element may, of course, be substituted for the resistance 24 to be affected by the discharge current of the condenser 22 without being affected by the charging current that flows when the switch opens, or a device 32, responsive to the current in the resistor 24, may be connected as shown.

In Figure 8, there is shown diagrammatically a circuit arrangement in which a switch 28 engages a pair of contacts 29 and 30 to cause current flow through the device 10 while short-circuiting the condenser 22, and which switch 28, upon opening, automatically inserts a resistor 31 to delay the charging of the condenser 22, and so that the resistance-capacitance relation of the circuit may be of any desired value above that determined by the resistance of the coil winding alone during the period of charge.

The circuit of Figure 8 may also include a current-responsive device 33 which would be only responsive to the charging current of the condenser 22.

In a circuit in which a relay employs a movable coil in a magnetic field, as in a D'Arsonval galvanometer, and is provided with a switch blade movable with the coil to engage a contact and close a local circuit, the circuit arrangement of Figures 9 and 10 may be employed.

In the circuit shown diagrammatically in Figure 9, a switch 34 is closeable to connect a battery 35 through a resistor 36 and an inductance 37, while also closing another circuit comprising a resistor 38, a current-responsive device 39, such as a relay of the D'Arsonval type, having inductance 40, and a capacitor 41. It will be evident that when the switch 34 is closed, current flows through the circuit elements 36 and 37 in one direction, and that when the switch 34 is opened, current flows through the same elements in the same direction and also through the circuit comprising the elements 38, 39, 40, and 41 to charge the capacitor at a rate determined by the capacitance of the capacitor, and the resistances 36 and 38. Then, when the capacitor 41 has been charged and the switch 34 again closed, there will be a reversed unidirectional current through the relay 39 to assist the

moving coil thereof in opening the local circuit switch controlled by it.

The switch 34 would be closed momentarily with the resistor 36 and the inductance 37 limiting current flow, and the device 39 becomes energized when the switch opens. The constants of the circuit are arranged to result in unidirectional current flow in both directions through the device 39; that is, the circuit is aperiodic.

In the circuit shown diagrammatically in Figure 10, a switch 42 is closeable through a contact 43 to close the two circuits already referred to in discussing Figure 9, but upon the opening of the switch 42 the contact 44 is engaged to short-circuit the resistor 36 and the inductance 37 so as to eliminate their effect in determining the rate of current growth through the device 39 as the capacitor is charged. Thus, the resistance and inductance values of the elements 36 and 37, respectively, may be chosen to limit the current therethrough to any desired low value when the switch 42 is closed without affecting the time constant of the circuit containing the device 39. Since the function of the elements 36 and 37 is then to limit current flow through their circuit when the switch 42 is closed, it is obvious that a capacitor 45 may be substituted for them, as indicated in dotted lines.

It will be evident that in the discussion of the test circuit of Figure 2 it was disclosed that the "open" period of the switch was great enough to allow the follow-through current to operate the relay. In general, the switch should be held open long enough to allow the follow-through current to operate whatever device is in series with the capacitor, but it is appreciated that it may be desirable to shorten the switch open period in certain use situations to hold the relay in closed condition for a desired period of time by superimposing one follow-through impulse on another with such frequency as to produce the effect of a sustained current of an average value sufficient to hold the relay closed.

I am aware that many changes may be made and numerous details of construction may be varied through a wide range without departing from the principles of this invention, and I, therefore, do not purpose limiting the patent granted hereon otherwise than as necessitated by the prior art.

I claim as my invention:

1. A circuit comprising in series circuit association a relay or the like having inductance and a relatively high inherent resistance relative to said inductance in its winding, a source of unidirectional current, and a switch, means in circuit association with said circuit to sustain unidirectional current flow through said circuit for a predetermined period of time after the switch opens the circuit, said means comprising a capacitor of predetermined capacitance in relation to said resistance and said inductance connected shunting the switch contacts.

2. In combination, a relay or the like having inductance and a relatively high inherent resistance relative to said inductance, a source of unidirectional current, a capacitor of predetermined capacitance in relation to said resistance and said inductance, and switch means operable upon closing to connect said relay in series with said battery and upon opening to connect said relay and said battery and said capacitor in series to cause a follow-through unidirectional

current to flow for a predetermined period of time after the switch opens.

3. A circuit comprising in series circuit association a relay or the like having inductance and a relatively high inherent resistance relative to said inductance in its winding, a source of unidirectional current, switch means operable to open and close said circuit, respectively, and a capacitor of a predetermined capacitance in relation to said resistance and said inductance automatically interposable in series in said circuit upon opening of said switch means to cause follow-through unidirectional current to flow in said circuit for a predetermined period of time after said switch opens.

4. A circuit comprising in series circuit association a relay or the like having inductance and a relatively high resistance relative to said inductance in its winding, a capacitor of predetermined capacitance in relation to said resistance and said inductance, and a source of unidirectional current, switch means arranged upon closing to short-circuit said condenser and cause current flow through said relay, and upon opening to condition said circuit for follow-through unidirectional current through said circuit for a predetermined period of time.

5. A circuit comprising in series circuit association a relay or the like having inductance and a relatively high inherent resistance relative to said inductance in its winding, a source of unidirectional current, and a switch operable to open and close said circuit, a resistor and a capacitor in series and connected shunting said switch and being automatically connected in series with said relay upon opening of said switch, said capacitor being of predetermined capacitance in relation to said winding resistance and said resistor and said inductance and adapted to cause unidirectional follow-through current flow through said relay for a predetermined period of time after said switch opens.

6. A circuit having in series circuit association an inductance, a resistor, a capacitor, and a source of unidirectional current, switch means arranged momentarily closable to discharge said capacitor and initiate current flow through said inductance, said capacitor being of predetermined capacitance in relation to said inductance and said resistor and being adapted to cause a unidirectional follow-through current to flow through said inductance for a predetermined period of time after said switch opens.

7. A circuit comprising in series circuit association a relay or the like having inductance, a resistor, a source of unidirectional current, and a switch to open and close said circuit, respectively, means adapted to sustain flow of unidirectional current through said relay for a predetermined period of time after the switch opens and substantially longer than a momentary switch closed period, said means comprising a capacitor arranged automatically insertable in said circuit as said switch opens and having a predetermined capacitance in relation to said inductance and said resistor such as to render the circuit aperiodic.

8. A circuit comprising in series circuit association a relay or the like having inductance, a resistor, a capacitor, and a source of unidirectional current, said resistor having an ohmic resistance not less than two times the square root of the inductance divided by the capacitance of said capacitor, and switch means connected with said circuit to close and open, re-

spectively, a circuit shunting said capacitor whereby to initiate current flow through said relay upon momentary closing of said switch and to cause a follow-through unidirectional current to flow through said relay to maintain current flow through said relay for a predetermined period of time upon said switch being opened following the momentary closing thereof.

9. In combination with a device including a movable element and motor means including an armature connected operable to drive said element, and a winding having resistance and inductance, a battery, a switch, circuit means connecting said battery and said switch in series with said winding, means connected to repeatedly close said switch to cause rapidly succeeding impulses of current to flow through said winding without effecting a predetermined desired movement of said element, and means operable immediately upon each opening of said switch following an impulse to cause the flow of a follow-through unidirectional current through said winding to effect the predetermined desired movement of said element, said means comprising a capacitor having a predetermined capacitance in relation to said resistance and said inductance and connected in a circuit in parallel with said switch.

10. In combination with a device including a movable armature and including a winding having resistance and inductance, a battery, a switch, a first circuit means connecting said battery and said switch in series with said winding, a second circuit means including a capacitor, a resistor, and current-responsive means in series, said second circuit being arranged to be closed by said switch when said switch is in closed position and being inserted in series with said battery and said winding when said switch is open, said resistance in said first circuit and said resistor in said second circuit, respectively, having values of resistance in relation to the capacitance of said capacitor to condition said circuits for aperiodic flow of current therein.

11. In combination with a current-responsive device including a movable armature and including a winding having resistance and inductance, a switch, a battery, circuit means connecting said battery and said switch in series with said winding, said switch being closable a predetermined maximum number of times per minute to cause impulses of current to flow through said winding to cause a similar number of effective movements of said armature, and means enabling a higher frequency of effective armature movement to

be obtained without necessitating an increase in battery voltage, said means comprising a capacitor of a predetermined capacitance in relation to said resistance and inductance to cause flow of a unidirectional follow-through current through said winding at each opening of said switch following a closing thereof, and connected in a circuit in parallel with said switch.

12. In combination with a current-responsive device including a movable armature and including a winding having resistance and inductance, a switch, a battery, circuit means connecting said battery and said switch in series with said winding, said switch being closable a predetermined maximum number of times per minute to cause impulses of current to flow through said winding to cause a similar number of effective movements of said armature, the upper limit of the frequency of switch closing to produce effective movements of said armature depending upon factors including the resistance and inductance of said circuit and upon irregular contact resistance of the closed switch, means enabling a higher predetermined maximum frequency of switch closing and a higher frequency of effective armature movement to be obtained without necessitating an increase in battery voltage while making the circuit less sensitive to contact resistance irregularities, said means comprising a capacitor of a predetermined capacitance in relation to the resistance and inductance of said circuit to cause flow of unidirectional follow-through current through said winding at each opening of said switch following a closing thereof, and connected in a circuit in parallel with said switch.

13. In combination, a movable armature, a movable element in driven connection with said armature, an actuating coil for said armature and having resistance and inductance, a battery, a capacitor, means connecting said coil, said battery, and said capacitor in series circuit association in a first circuit, a switch movable to open and to closed positions, respectively, means connecting said switch in parallel with said capacitor in a second circuit, said capacitor being shunted by said second circuit for discharging when said switch is closed, and being charged by said battery when said switch is open, said capacitor having a predetermined capacitance in relation to the resistance and inductance of said first circuit for unidirectional current flow in that circuit while the capacitor is being charged.

THOMAS J. MacKAVANAGH.