

Oct. 2, 1945.

W. L. SMITH

2,386,149

ELECTROMAGNETIC CONTROL

Filed Aug. 9, 1943

2 Sheets-Sheet 1

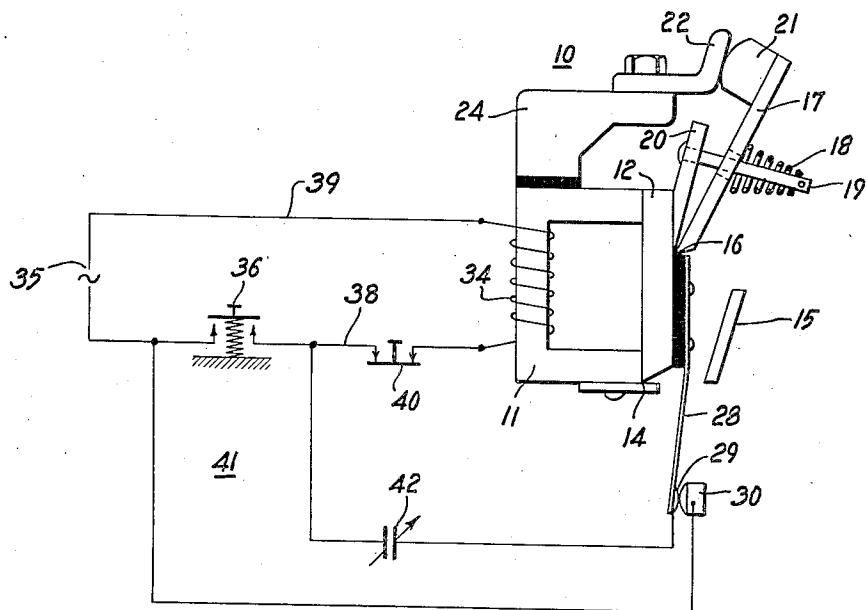


Fig.-1

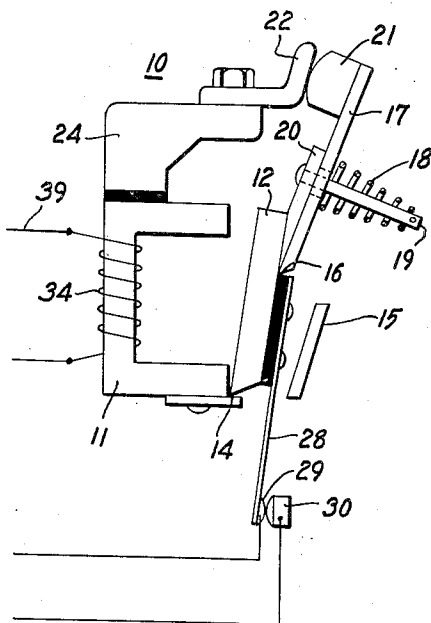


Fig.-2

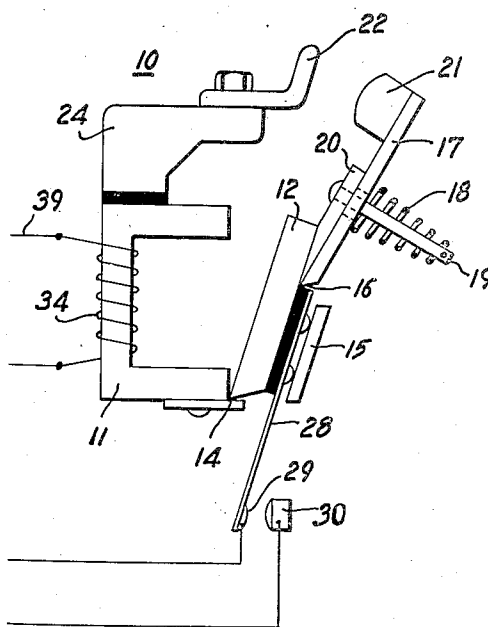


Fig.-3

INVENTOR.
WARD L. SMITH

BY *John L. Leonard* &
Harold J. Rathbun
ATTORNEYS

Oct. 2, 1945.

W. L. SMITH

2,386,149

ELECTROMAGNETIC CONTROL

Filed Aug. 9, 1943

2 Sheets-Sheet 2

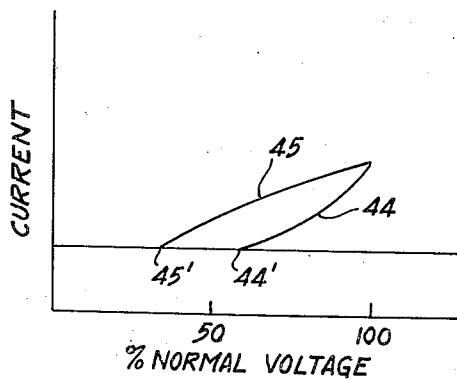
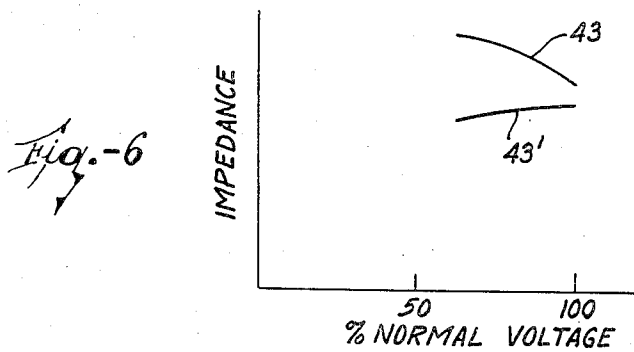
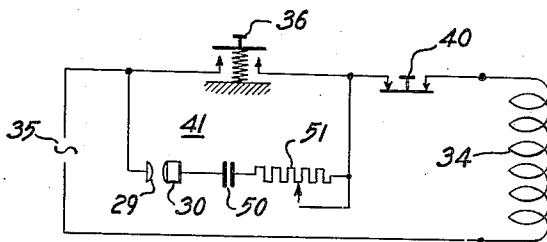
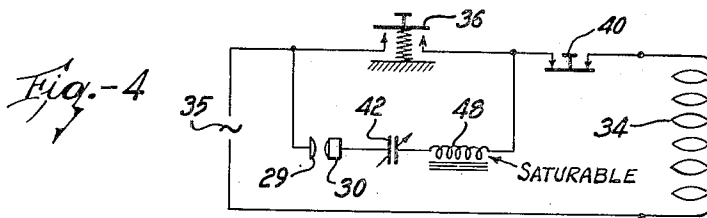


Fig.-7

INVENTOR.
WARD L. SMITH
BY *John Leonard & Harold J. Rathbun*
ATTORNEYS

UNITED STATES PATENT OFFICE

2,386,149

ELECTROMAGNETIC CONTROL

Ward L. Smith, Hudson, Ohio, assignor to The
Electric Controller & Manufacturing Company,
Cleveland, Ohio, a corporation of Ohio

Application August 9, 1943, Serial No. 497,941

10 Claims. (Cl. 175—375)

This invention relates to improvements in electro-magnetic control and more particularly to improvements in the control of electromagnetic devices energized by alternating current and having movable armatures such as, for example, relays, switches and the like, and the principal object of my invention is to improve the drop-out characteristics of such devices.

The minimum values of supply voltage, voltage drop across the operating winding, current in the operating winding, or magnetic flux in the iron path which are sufficient to retain an electromagnetic device in operated position, hereinafter referred to as the drop-out values of the respective quantities, are an important factor in the design of electrical apparatus embodying such devices.

For example, a disadvantage in the operation of a common type of electromagnetic device energized by alternating current, e. g. alternating current switches and relays having a spring biased contact arm pivoted to a movable armature, heretofore has been the tendency of the armatures of such devices to remain in an intermediate position consequent upon a reduction in the supply voltage to a value slightly below the drop-out value or to hesitate in such intermediate position during an opening cycle caused by such a decrease in voltage. Momentary voltage variations of this magnitude without substantial change in frequency occur frequently in many installations due to the sudden application of a large load to the supply system or due to other causes resulting in a temporary current demand in excess of the normal circuit capacity. The undesirable operation results from the fact that the contact spring which, when the switch or relay is closed, provides a uniform pressure at the contact surfaces, assists the opening movement of the armature only during the initial stage of the opening cycle. At the instant when the contacts start to separate, the assisting force of the contact spring suddenly reduces to zero, and the remaining force or forces tending to cause opening movement of the armature are, in many instances, insufficient to effect such additional opening movement unless the supply voltage is further reduced.

It is thus seen that when the supply voltage is within a range slightly below the drop-out value that the armature of an alternating current switch or relay may open only partially or hesitate during its opening cycle. While the armature is in the intermediate position, the contacts are but lightly touching each other, and the contact surfaces therefore tend to become

overheated and may weld together. An important object of this invention is to provide an improved electromagnetic control for causing the armature of an alternating current electromagnetic device to move quickly and steadily to its fully open position consequent upon a decrease in the supply voltage to a value within a range but slightly below the drop-out value or consequent upon a gradual decrease in the supply voltage through said range.

Another disadvantage in the operation of electromagnetic devices having movable armatures and energized by alternating current is the inability of such devices to remain in operated position consequent upon a reduction in the supply voltage to values in the neighborhood of 60% of normal.

For example, to prevent needless deenergization of electrical apparatus controlled by an alternating current electromagnetic relay due to opening of the relay as a result of a temporary decrease in the supply voltage to a value below the drop-out value of the relay, special low voltage protective devices equipped with time delay mechanisms have been used. The time delay mechanisms serve to maintain the control relay contacts in closed position for an interval after the voltage falls below the drop-out value, so that, if the voltage increases again before the expiration of the time interval, the control relay does not operate to shut down the controlled apparatus. In many instances these time delay mechanisms could be dispensed with if the control relay armature did not tend to move to its deenergized position until the supply voltage reached a very low value. It is an object of this invention to provide an electromagnetic control for preventing opening movement of the armature of an alternating current electromagnetic device unless the voltage of the circuit supplying said device is reduced to a small percentage of its normal value.

One of the functions of a low-voltage protective relay of the time delay described above or of the more common type having no time delay feature is to control the deenergization of all of the electromagnetic switches in a control system so that, under conditions of reduced voltage, all of the switches open simultaneously. In order to accomplish this result the low-voltage protective relay must open before any of the switches or other relays in the system. Because of the smaller inertia of the moving parts of the low-voltage protective relay, the relay opens before the switches consequent upon a very sudden reduction in the supply voltage to zero, but diffi-

culty has been experienced in designing low-voltage protective relays which open before the other switches of the system consequent upon less sudden reductions in voltage or under conditions wherein the voltage remains constant at some reduced value. An important factor here involved is the fact that the heavier moving parts of the electromagnetic switches tend to cause the switches to start to open at values of supply voltage higher than the drop-out voltage of the low-voltage protective relay, i. e. the switches have a higher drop-out voltage than the relay. A further object of this invention is to provide means operable to cause the drop-out voltage of an alternating current low-voltage protective relay to be higher than that of the electromagnetic switches or other relays in the same control system.

Another object is to provide an alternating current electromagnetic control for causing unhesitating opening movement of the armature of an alternating current switch or relay when a predetermined reduced value of supply voltage is reached which predetermined value is selectable from a wide range of voltage values.

A specific object is to provide an alternating current electromagnetic control for preventing movement of an armature to an open position except when the supply voltage is close to zero.

A further object is to provide an electromagnetic control for changing the drop-out voltage value of an alternating current electromagnetic device.

Yet another object is to provide an alternating current electromagnetic control which operates to cause an armature to move quickly and steadily to its open position regardless of the nearness of the supply voltage to the drop-out value of the device comprising the armature.

A more detailed object is to provide a means in the energizing circuit of the operating winding of an electromagnetic device having a member movable to change the inductance of said winding which means causes the impedance of said energizing circuit to increase as said member moves to decrease the inductance of said winding.

In accordance with this invention a negative or capacitive reactance means such as a condenser is connected in series with a positive or inductive reactance means such as the operating winding of an alternating current electromagnetic device having a movable armature. The condenser is proportioned relative to the inductive reactance of the winding so that the impedance of the supply circuit of the operating winding increases as the armature of the device opens, whereas without the condenser the supply circuit impedance decreases, and consequently there is a positively decreasing force rather than a substantially constant force tending to prevent the armature of the device from moving to its open position. In a modification a saturable inductance and a condenser connected in series with each other and with the operating winding of an electromagnetic device are relatively proportioned so as to maintain the current through the winding at a substantially constant value even though the supply voltage decreases greatly from its normal value and so that when the armature of the device moves toward its open position the attracting force steadily decreases. In another modification, an adjustable resistor and a condenser connected in series with each other and with the operating winding of an electromagnetic device are proportioned

so as to increase the resistance component of the impedance of the supply circuit to thereby increase the drop-out voltage above that existing when the condenser and winding alone are used.

By means of this invention it is possible to either increase the drop-out voltage of the low-voltage protective relay of an alternating current control system or to decrease the drop-out voltage of the larger electromagnetic switches involved in the system or both, and by virtue of the same electromagnetic control arrangement which accomplishes the change or changes in the drop-out voltages, to cause a quick and unhesitating drop-out action of both the relay and the switches when the respective new values of drop-out voltage are reached. That is, the electromagnetic control of this invention not only permits the designer to select almost any voltage below the maximum for the drop-out value of a switch or relay, but also causes the relay or switch to move to its open position without hesitation when the drop-out voltage selected for that relay or switch is reached.

Other objects and advantages will become apparent from the following description wherein reference is made to the drawings, in which

Fig. 1 illustrates the invention as applied to the control of an electromagnetic switch shown in its closed position;

Figs. 2 and 3 show the switch of Fig. 1 in an intermediate and the open positions, respectively;

Fig. 4 is a wiring diagram of a modification;

Fig. 5 is a wiring diagram of a further modification; and

Figs. 6 and 7 are graphs showing impedance and current variations, respectively, which occur when the present invention is used as compared with prior art arrangements.

Referring to Figs. 1, 2 and 3, one type of electromagnetic device to which this invention may be applied is shown as a switch 10 representative of a well-known construction and having a C-shaped magnetic frame 11 and a clapper-type armature 12 which is pivoted at a knife edge 14 so as to be movable from a fully closed position bridging the open end of the frame 11 as shown in Fig. 1 to a fully open position against a suitable stop 15 as shown in Fig. 3. Pivoted to the armature 12 at a knife edge 16 is a movable contact arm 17 biased in a counter-clockwise direction about the knife edge 16 by a helical spring 18 interposed between the contact arm 17 and a suitable stop near the outer end of a spring post 19. The post 19 is secured to an upwardly extending bracket 20 of the armature 12 and passes loosely through an opening in the arm 17. In both the intermediate and the open positions of the switch 10 shown in Figs. 2 and 3, respectively, the spring 18 is extended and the contact arm 17 is thereby forced counterclockwise against the bracket 20, and in the closed position of the switch 10 shown in Fig. 1, the spring 18 is compressed and biases a contact 21 on the contact arm 17 against a stationary contact 22 suitably attached to an insulated support 24 extending upwardly from the frame 11.

The switch 10 is preferably provided with a normally open auxiliary contact mechanism for a purpose to be hereinafter described. An illustrative auxiliary contact mechanism may comprise a flat-spring 25 having one end suitably attached to but insulated from the lower end of the armature 12 and having at its free end a movable auxiliary contact 26. When the arma-

ture 12 is in the closed and intermediate positions of Figs. 1 and 2, respectively, the movable auxiliary contact 29 is in circuit completing engagement with a suitably supported stationary auxiliary contact 30, and when the armature 12 is in the open position of Fig. 3, the contacts 29 and 30 are disengaged.

The construction of the switch 10 has not been described in detail since its construction forms no part of the present invention and is merely illustrative of one type of electromagnetic device with which this invention may be used.

The armature 12 is moved from the open position of Fig. 3 to the closed position of Fig. 1 and is held in the closed position by magnetic flux produced by energization of an operating winding 34 on the frame 11, is moved from the closed position to the intermediate position of Fig. 2 due to the combined action of the spring 18 and gravity consequent upon a reduction in the amount of magnetic flux, and is moved from the intermediate position to the open position of Fig. 3 due to gravity alone. It is obvious to those skilled in the art that the switch 10 may include an additional spring or other means augmenting the force of gravity throughout the opening cycle or replacing the force of gravity entirely.

The winding 34 is arranged to be energized from a source 35 of alternating current upon closure of a normally open, momentary contact type push button 36 through a pair of conductors 38 and 39 and the contacts of a normally closed push button 40 interposed in the conductor 38. Connected in parallel with the stationary contacts of the push button 36 is a holding circuit 41 comprising a capacitive reactance means such as a variable condenser 42 and the auxiliary contacts 29 and 30 of the switch 10, which holding circuit is described more in detail hereinafter. Closure of the push button 36 causes energization of the winding 34 from the source 35 through the conductors 38 and 39 and consequent movement of the armature 12 to the closed position of Fig. 1 wherein the contacts 21 and 22 and the auxiliary contacts 29 and 30 are closed. Opening of the push button 36 does not effect deenergization of the winding 34 since the winding continues to be supplied with current through the holding circuit 41 which is completed upon closure of the auxiliary contacts 29 and 30. Opening of the push button 40, however, causes complete deenergization of the winding 34 and the armature 12 consequently moves quickly to its open position.

In order to facilitate the description of the function of the condenser 42, an explanation of the operation of Figs. 1, 2 and 3 is given here with the assumption that the condenser 42 is short circuited. With this assumption, which renders the circuit of Fig. 1 the same as the usual prior art circuits, and with the push button 36 open and the armature 12 in the closed position, the impedance Z of the energizing circuit 41 for the winding 34 is given by

$$(1) \quad Z = \sqrt{R^2 + X_L^2}$$

where R is the resistance and X_L is the inductive reactance of the circuit. Due to the substantially closed iron flux path in the magnetic circuit of the switch 10 when the armature 12 is closed, the inductive reactance of the energizing circuit is so very much larger than the resistance that the resistance may be neglected in deter-

mining the impedance. Thus equation (1) may be considered approximately to be

$$(2) \quad Z = X_L$$

The magnitude of the current through the winding 34 is inversely proportional to the impedance of the energizing circuit, and consequently a decrease in the impedance results in a proportional increase in the current through the winding 34 if the voltage of the source 35 remains constant. Since the introduction of an air gap into the magnetic circuit of the switch 10 causes the inductive reactance of the winding 34 to decrease, the impedance of the energizing circuit under the assumed conditions decreases in accordance with Equation 2, and consequently a current of larger magnitude flows through the winding 34 upon movement of the armature 12 toward its open position. Although the introduction of the air gap has increased the reluctance of the magnetic circuit, the increase in current tends to maintain a substantially constant flux irrespective of the position of the armature 12.

Assume now that the armature 12 is held in the closed position of Fig. 1 by flux produced by the winding 34 (the condenser 42 still being short circuited) and that the voltage of the source 35 decreases while the frequency remains substantially constant. As the voltage of the source 35 decreases, the current in the winding 34 decreases, and consequently the flux holding the armature 12 decreases. At a predetermined reduced value of voltage (the drop-out value) the armature 12 starts to move toward its open position due to the fact that the holding force of the flux becomes less than the combined forces of the spring 18 and gravity. However, a slight opening movement of the armature 12 causes the current in the winding 34 to increase from its reduced value since the introduction of the air gap in the magnetic circuit reduces the inductive reactance and hence the impedance of the energizing circuit. Assuming that the voltage now remains constant at the drop-out value or slightly below, the increasing current tends to maintain a constant flux in the magnetic circuit irrespective of the position of the armature 12, but the flux is slightly less effective in its attraction on the armature 12 due to increased leakage and "fringing" at the air gap. The armature 12, therefore, continues to move toward its open position due to the difference between the pull of the flux and the combined forces of gravity and of the spring 18. However, when the armature 12 reaches the intermediate position of Fig. 2, the contacts 21 and 22 are just barely in contact with each other and the opening force of the spring 18 is consequently zero and the force of gravity only remains to oppose the pull of the flux. When the armature 12 is in the intermediate position it is desirable for proper closing action of the switch 10 that the force of gravity on the armature 12 be as small as possible. Consequently, there is a very strong tendency under the assumed conditions of reduced voltage for the armature 12 to remain in the intermediate position, and, since the contacts 21 and 22 are very lightly in contact with each other over a small area, undue heating of the contacts occurs and the possibility of the contacts welding together exists. Reduced values of supply voltage throughout a range immediately below the minimum drop-out value which are insufficient to maintain the armature 12 in its closed position thus are sufficient to prevent the

force of gravity from moving the armature 12 to the fully open position of Fig. 3.

In order to prevent the foregoing undesirable operation of prior art structures and in accordance with this invention, the condenser 42 is included in the holding circuit 41 of Fig. 1 and is adjusted to have a capacity such that the capacitive reactance of the holding circuit is considerably greater than the inductive reactance of the circuit when the armature 12 is closed. With the condenser 42 in the holding circuit 41, the push button 36 open, and the armature 12 in its closed position, the impedance Z of the energizing circuit for the winding 34 is given by

$$(3) \quad Z = \sqrt{R^2 + (X_L - X_C)^2}$$

where R and X_L refer to the same quantities as before and X_C is the capacitive reactance of the condenser 42. Since the inductive reactance of the energizing circuit is very much greater than the resistance, and the capacitive reactance is considerably greater than the inductive reactance when the armature 12 is closed, the difference between the inductive reactance and the capacitive reactance is also much greater than the resistance (the negative sign of the difference being of no consequence). If the capacitive reactance introduced into the energizing circuit is approximately twice the inductive reactance of the energizing circuit when the armature 12 is closed, the impedance of the circuit has not been changed materially by the inclusion of the condenser 42 therein so long as the armature 12 is in its closed position, as is clear from a comparison of Equations 1 and 3.

Assume now that the voltage of the source 35 decreases to or slightly below a value at which the armature 12 starts to move toward its open position. (As will be explained subsequently, this value of drop-out voltage is not necessarily the same as the drop-out voltage without the condenser 42 in the circuit.) When the armature 12 now starts to move toward its open position, the inductive reactance of the winding 34 decreases as before, but the impedance Z of the energizing circuit increases as is clear from an examination of Equation 3. Consequently, instead of the current through the winding 34 increasing as before, the current decreases as the armature 12 moves toward its open position. Since the flux varies as the current, the flux also decreases and the armature 12 moves rapidly and steadily to the open position of Fig. 3 and the contacts 21 and 22 separate quickly and fully without hesitation at the intermediate position of Fig. 2.

It is thus seen that with a condenser of suitable capacity connected in series with the operating winding of an alternating current electromagnetic device, a decrease in the supply voltage to values slightly below the drop-out value permits a rapid and unhesitating opening movement of the armature. However, if the condenser has a capacitive reactance approximately twice the inductive reactance of the operating winding 34 when the armature 12 is closed, the drop-out voltage is much lower than it would be if the condenser were not present. Without a condenser connected in series with the winding 34, a reduction in the voltage of the source 35 causes a decrease in current through the winding 34 since the current I is given by

$$(4) \quad I = \frac{E}{X_L}$$

the resistance being neglected, but, since the re-

duced current causes a reduction of flux, the inductive reactance and consequently the impedance generally increase at lower flux densities as indicated by the curve 43 of Fig. 6 so that there is not a proportional drop in current with decreased voltage. In Fig. 6, wherein impedance of the energizing circuit is plotted against percentage of normal supply voltage, the curve 43 indicates the variation in impedance of the energizing circuit for the operating winding 34 with the condenser 42 short circuited and the curve 43' indicates the variation in impedance of the energizing circuit when the condenser 42 is not short circuited. The rate of decrease in current with declining voltage when the capacitive reactance of the energizing circuit is zero is shown by the curve 44 of Fig. 7 wherein current in the energizing circuit is plotted against percentage of normal supply voltage.

With a condenser of proper value in accordance with this invention in the energizing circuit the current in the winding 34 also decreases with the voltage since the current is then given by

$$(5) \quad I = \frac{E}{X_L - X_C}$$

the resistance R being neglected. This reduced current causes a reduction in the flux, and since the inductive reactance of the circuit generally increases due to the increased permeability of the iron at low flux densities, the impedance of the circuit decreases, in accordance with Equation 3 and as indicated by the curve 43' Fig. 6, and the current falls less rapidly with declining voltage. The rate of decrease in current through the operating winding 34 with declining voltage when the capacitive reactance of the energizing circuit is approximately twice the inductive reactance is shown by the curve 45 of Fig. 7. From Fig. 7 it will be noted that a point 44' on the curve 44 which point is at the drop-out current value occurs at a higher value of voltage than a similar point 45' on the curve 45.

Thus the addition of the condenser 42 in series with the winding 34 not only causes a rapid and unhesitating opening operation of the switch 10 consequent upon a reduction in the supply voltage, but also affects the drop-out voltage of the switch 10. In some applications it may be desirable to reduce greatly the value of the drop-out voltage and in other applications it may be desirable to have a steady and unhesitating drop-out at a relatively high value of reduced voltage.

To further reduce the value of the drop-out voltage, a circuit such as Fig. 4 may be used, wherein a saturable reactor 48 is connected in series with the condenser 42 in the holding circuit 41. Due to the non-linear characteristics of the reactor 48 the inductive reactance of the energizing circuit increases greatly as the voltage decreases, so that the impedance decreases very rapidly, and substantially constant current flows through the winding 34 until extremely low voltages are reached. If the resistance of the energizing circuit is made very small and the electrical constants of the inductances and the condenser are properly selected so that a condition of series resonance is approached at low values of supply voltage, the switch 10 can be held closed even though the supply voltage is decreased to 10% of normal or lower. For proper opening operation it is important that resonance not be actually reached since it is necessary that the capacitive reactance be greater than the inductive reactance at the instant the armature starts to open

in order for the consequent decrease in inductive reactance to cause an increase in the impedance.

To increase or to maintain the drop-out voltage of the switch 10 at its usual value, but to provide for unhesitating opening movement of the armature 12 consequent upon a decrease in the supply voltage below the drop-out value, the condenser 42 may be adjusted to have a capacitive reactance greater than twice the inductive reactance of the winding 34 when the armature 12 is closed, or the circuit of Fig. 5 may be used, wherein an adjustable resistor 51 is connected in series with a fixed condenser 50 in the holding circuit 41. When the voltage of the source 35 is at its normal value, the resistor 51 is so adjusted that the current in the winding 34 is at a value slightly greater than the drop-out value. Under these conditions, the impedance of the energizing circuit is maintained substantially constant throughout slight decreases in voltage, that is, the resistance term in Equation 2 is no longer negligible and small changes in inductive reactance do not affect greatly the impedance of the circuit. However, if the supply voltage decreases slightly and to such an extent that the current and flux fall below the drop-out values, the armatures 12 starts to open and the impedance of the energizing circuit increases considerably due to the decrease in the inductive reactance caused by the introduction of an air gap in the magnetic circuit. The resulting decrease in current through the winding 34 permits the armature 12 to drop unhesitatingly to its open position.

I claim:

1. In combination with an electromagnetic device having a winding, a member movable to change the inductance of said winding, an alternating current energizing circuit for said winding, and means in said energizing circuit for causing the impedance of said energizing circuit to increase as said member moves to decrease the inductance of said winding.

2. In combination with an electromagnetic device arranged to be operated by alternating current and having an operating winding, a member movable to change the inductance of said winding, an energizing circuit for supplying alternating current to said winding, and capacitive reactive means connected in said energizing circuit for causing an increase in the impedance of said energizing circuit as said member moves to decrease the inductance of said winding.

3. In combination with an electromagnetic device having a winding arranged to be energized from a source of alternating current, a member movable to change the inductance of said winding, an energizing circuit for supplying alternating current to said winding, and capacitive reactive means connected in said energizing circuit in series with said winding for causing an increase in the impedance of said energizing circuit as said member moves to decrease the inductance of said winding.

4. The combination with an electromagnetic device having a winding arranged to be energized from a source of alternating current of variable voltage and having an armature movable consequent upon said voltage reaching a predetermined reduced value, of a capacitance connected in series with said winding and said source of current and having a reactance greater than the reactance of said winding when said armature is in its closed position with said voltage at a value slightly above said predetermined value.

5. In combination with an electromagnetic device having a magnetic circuit and a winding, a member movable to change the air gap of said magnetic circuit, an alternating current energizing circuit for said winding, and a capacitance connected in said energizing circuit in series with said winding, said capacitance being so proportioned in relation to the inductance of said winding when the air gap of said magnetic circuit is substantially zero that the impedance of said energizing circuit increases as said member moves to increase the air gap of said magnetic circuit.

6. The combination with an electromagnetic device having a movable armature and a winding arranged to be energized from a source of alternating current, of a capacitance connected in series with said winding and said source of current and having a reactance approximately twice the reactance of said winding when said armature is in its closed position.

7. The combination with an alternating current electromagnetic switch having an operating winding, a condenser, means for connecting said winding to a source of alternating current independently of said condenser until said switch is closed, and means operable upon closure of said switch to interpose said condenser in a circuit between said winding and said source, said condenser having a capacitive reactance greater than the inductive reactance of said winding when said switch is closed.

8. In combination with an electromagnetic device having a magnetic circuit and a winding, a member movable to change the inductance of said winding, an energizing circuit for supplying alternating current to said winding, a saturable inductance and a capacitance connected in said energizing circuit in series with each other and with said winding, said capacitance being so proportioned in relation to the combined inductance of said saturable inductance and said winding when said magnetic circuit is closed that the impedance of said energizing circuit increases as said member moves to decrease the inductance of said winding.

9. In combination with an electromagnetic device having a magnetic circuit and a winding, a member movable to change the inductance of said winding, an alternating current energizing circuit for said winding, and a capacitance and a resistor connected in said energizing circuit in series with each other and said winding, said capacitance being so proportioned in relation to the inductance of said winding when said magnetic circuit is closed that the impedance of said energizing circuit increases as said member moves to decrease the inductance of said winding.

10. The combination with an electromagnetic switch of the type having a movable armature adapted to be held in a closed position by magnetic flux produced by a winding energized with alternating current, the holding force of said flux being in opposition to an opening force which suddenly decreases during and before completion of an opening cycle initiated upon reduction of said flux below a predetermined value, of a capacitance connected in series with said winding and so proportioned relative to the inductance of said winding that said flux decreases from its reduced value as a result of movement of said armature away from its closed position.

WARD L. SMITH.