

May 16, 1961

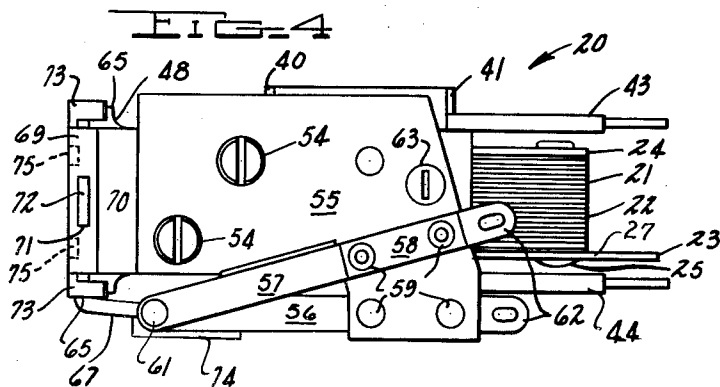
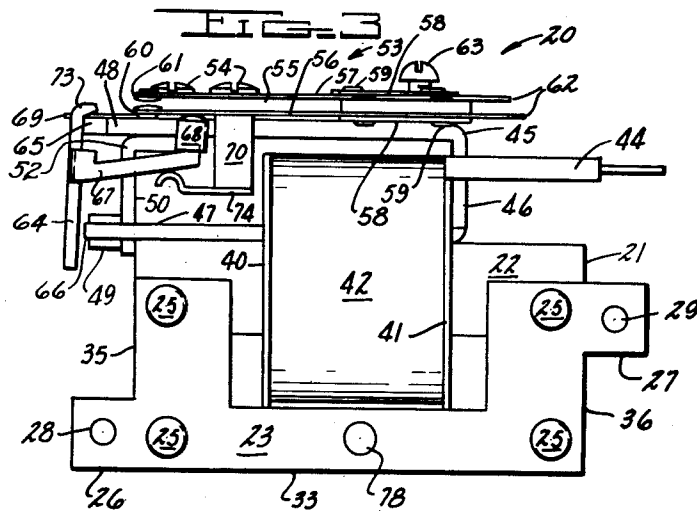
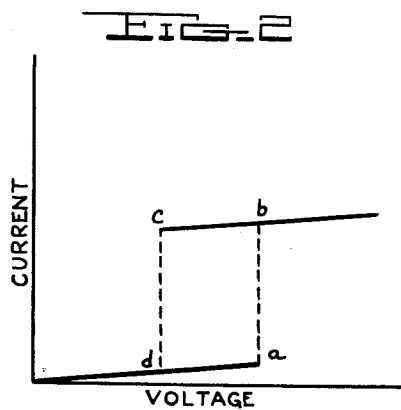
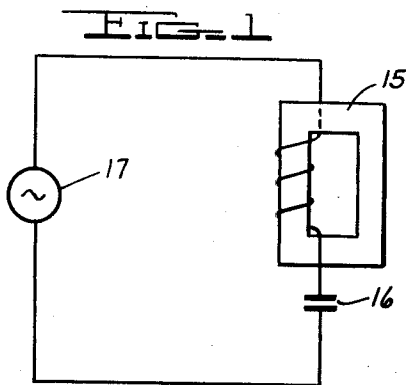
W. D. HENRY

2,984,772

FERRORESONANT INDUCTOR RELAY

Filed July 18, 1957

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG-5

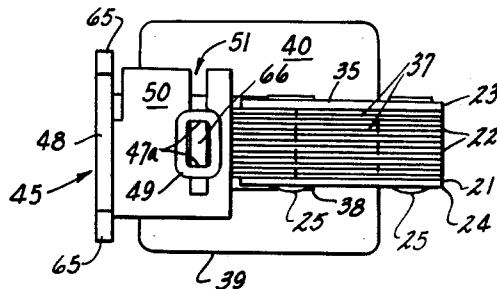


FIG-6

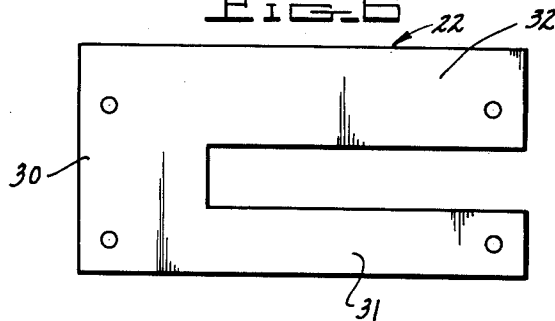


FIG-7

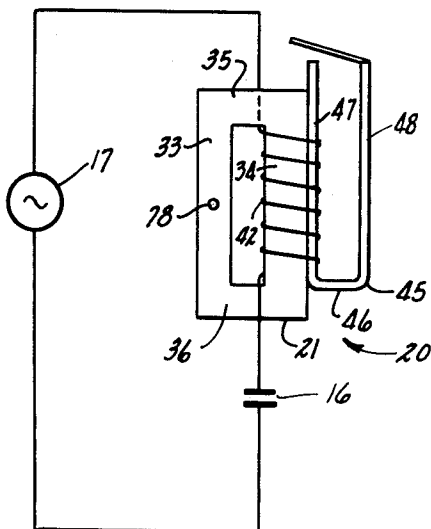
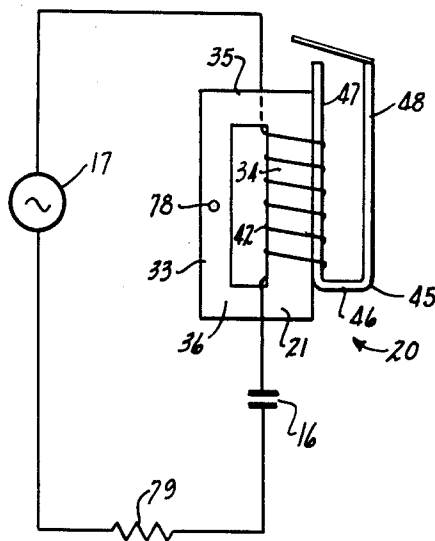


FIG-8



1

2,984,772

FERRORESONANT INDUCTOR RELAY

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1 Claim. (Cl. 317—193)

This invention relates to circuit control apparatus and more particularly to inductors and alternating current operated switches employing non-linear electromagnetic elements.

A principal object of this invention is to provide an inexpensive and sensitive control apparatus of small size and light weight.

Another object of this invention is to provide control apparatus which greatly increases the usefulness of ferroresonant circuits.

Another object of this invention is to provide an electromagnetic relay whose operating points can be readily and economically adjusted to close tolerances and which will remain precisely adjusted.

A further object of this invention is to provide an alternating current relay which will not overheat when operated continuously in excess of rated voltage or at just below the contact-operating voltage.

Another object is to provide an alternating current relay which is particularly free from vibration or hum.

Still another object is to provide an alternating current relay which is responsive to changes in voltage, current, frequency, or impedance and which is suitable for a wide variety of control functions.

Other objects and advantages, and a fuller understanding of the invention may be had by referring to the following description and claims, taken in connection with the accompanying drawings in which:

Figure 1 is a diagram of a simple ferroresonant circuit.

Figure 2 is a graph showing the voltage-current characteristics in a ferroresonant circuit.

Figure 3 is a front elevational view illustrating an electromagnetic relay embodying the principles of the present invention.

Figure 4 is a top plan view of the relay shown in Figure 3.

Figure 5 is an elevational view of the relay, with certain parts removed to show the construction, looking at the left hand side of Figure 3.

Figure 6 is a plan view showing one of the laminations before being assembled in the relay shown in Figure 3.

Figures 7 and 8 show schematic circuit diagrams of embodiments of the invention.

Ferroresonant circuits such as that of Figure 1 have been known for many years. Examples of such ferroresonant circuits are described and claimed in U.S. Letters Patent No. 1,725,022, granted to L. J. Stacy et al. on August 20, 1929, and in U.S. Letters Patent No. 1,921,788, granted to C. G. Suits on August 8, 1933. The characteristics of the ferroresonant circuit shown in Figure 1 are briefly described to provide a better understanding of the present invention.

The simple ferroresonant circuit of Figure 1 comprises a saturable core inductor 15 connected in series with a capacitor 16. When such a circuit is connected to a

2

constant-frequency alternating current power source 17, it will have the voltage-current characteristics illustrated in Figure 2. As the voltage increases, the current likewise increases in a substantially linear manner to point *a* where the current jumps abruptly to the value at point *b*. Thereafter the current again increases substantially linearly as the voltage increases. If the voltage is decreased with the circuit in the high current state, the current will decrease through point *b* to point *c* where the current abruptly decreases to the value at *d*.

This ferroresonant effect depends upon non-linear changes in the effective inductance of the saturable core inductor 15 with changes in current. At low values of current, the inductive reactance of the inductor 15 is greater than the reactance of capacitor 16. An increase in the applied voltage from the alternating current source 17 increases the current which decreases the effective inductance and brings the circuit closer to resonance. At the critical voltage corresponding to point *a* in Figure 2, any further increase in voltage produces a cumulative increase in current and decrease in inductive reactance to cause the current to abruptly increase. In approximately three cycles of the supply frequency, the current will increase from point *a* to point *b*.

In employing ferroresonant circuits for control purposes, the usual practice heretofore has been to connect the energizing winding of an ordinary relay in series with the inductor 15 and the capacitor 16, or to connect the relay energizing winding in parallel with the capacitor 16. The problems of weight, size, power requirements, and cost resulting from the use of ordinary relays have prevented widespread use of ferroresonant circuits although they are otherwise well-suited for many control applications.

To overcome the disadvantages of the prior art ferroresonant circuits, the control device in accordance with the present invention is arranged to serve the dual purpose of providing a saturable core inductor for the ferroresonant circuit and a switch for performing any desired switching operation. The control device, in effect, comprises an inductor and a relay using a common coil.

Referring now to the drawings, the numeral 20 indicates a ferroresonant relay constructed in accordance with this invention. The relay 20 has a magnetic core 21 comprising a stack of identical laminations 22 secured together between clamping plates 23 and 24 by rivets 25. Clamping plate 23 has extensions 26 and 27 which are provided with holes 28 and 29 for securing relay 20 to a suitable base. The clamping plates 23 and 24 may be stamped from brass or other non-magnetic material.

The laminations 22 are made of highly permeable metal such as silicon electrical steel. As illustrated in Figure 6, each lamination is substantially U-shaped and comprises a base portion 30 from which extend substantially parallel side portions 31 and 32. The width of side portion 31 is about two-thirds that of the side portion 32 and about one-half that of the base portion 30. The core 21 is formed to have a narrow side leg 33, a wide side leg 34, and the connecting legs 35 and 36 by stacking the laminations 22 with the narrow side portions 31 of all laminations on one side but with alternate laminations 22 reversed to dispose the base portions 30 of alternate laminations on opposite ends of the core 21. Core 21 thus has a wholly closed continuous magnetic path which no air gap fully interrupts. Because of the air spaces 37 between the lamination base portions 30, the effective cross-sectional area of the end legs 35 and 36 is equal to that of the narrow side leg 33. The cross-

sectional area of the wide side leg 34 is one and one-half times that of the other core legs 33, 35, and 36.

The wide core leg 34 passes through the rectangular bore 38 of bobbin 39 which is preferably molded from a suitable insulating material such as nylon. The bobbin 39 is provided with end flanges 40 and 41 which engage the inner faces of the core end legs 35 and 36 to prevent lateral movement of the bobbin 39. Coil 42 is wound on the bobbin 39 and has lead wires 43 and 44 through which the coil 42 is energized. For certain control applications the coil 42 may be provided with more than one winding.

Assembled adjacent to the core 22 is a U-shaped frame 45 formed of suitable magnetic material such as soft relay steel and provided with a body portion 46 terminating in two parallel arms 47 and 48. Arm 47 extends adjacent to the outer edge of the wide core leg 34 through the bobbin bore 38. Bobbin 39, wide core leg 34, and the frame arm 47 are bonded together with an epoxy resin or other suitable adhesive material. Arm 47 has slots 47a to receive a shading coil 49 which is securely attached to arm 47 as by crimping. Shading coil 49 is preferably formed from tubing of non-magnetic material such as copper. Bracket 50 is provided to prevent vibration of the free end of arm 48 and the resulting hum and buzzing noise when coil 42 is energized. As best shown in Figure 5, bracket 50 which is made of non-magnetic material such as brass has a slot 51 to snugly receive the free end of frame arm 47. Flange 52 of bracket 50 extends along the frame arm 48 and is secured thereto as by welding.

The contact and terminal assembly 53 is secured to frame arm 48 at one end by screws 54. This assembly comprises a substantially L-shaped supporting member 55 stamped from a suitable insulating material such as a phenol formaldehyde canvas base laminate. Contact springs 56 and 57 are secured against opposite sides of the supporting member 55 by retaining plates 58 and rivets 59. Contact spring 56 carries movable contact 60 arranged to coact with fixed contact 61 carried by contact spring 57. The ends of the contact springs 56 and 57 opposite contacts 60 and 61 terminate in soldering terminals 62. Other contact arrangements may be used where desired. The free end of the supporting member 55 is positioned relative to frame arm 48 by rotation of adjusting screw 63.

An armature 64 of suitable magnetic iron is pivotably mounted upon laterally spaced extensions 65 of the frame arm 48 for co-operation with the pole face 66 at the extreme end of frame arm 47. The armature 64 is provided with a longitudinally extending arm 67 which carries an insulator 68 for operating movable contact 60 to engage with and disengage from fixed contact 61. Interposed between the supporting member 55 and the frame arm 48 are an armature retaining plate 69 and an armature stop member 70. The retaining plate 69 has a rectangular opening 71 into which armature extension 72 projects and which together with the armature hooks 73 hold the armature 64 in bearing engagement with the frame arm extensions 65. The armature stop member 70 has a bendably adjustable arm 74 extending substantially parallel with the armature arm 67 to limit the extent to which the armature 64 may pivot away from the pole face 66.

The end of the armature 64 disposed opposite the pole face 66 is coined such that it presents a convex surface to the pole face 66. As the armature 64 touches the frame 45 elsewhere at only the two frame extensions 65, it is supported in a stable manner such that it cannot rock or vibrate in an undesirable manner when coil 42 is energized. To obtain further armature stability, a projection 75 is provided on the armature intermediate the armature extension 72 and each armature hook 73 such that the armature 64 actually bears against only two spaced parts of the armature retaining plate 69.

The adjustment of the contact and terminal assembly 53 and the armature 64 is accomplished in a conventional manner by first adjusting the contact spring 56 to require a specified contact closing force. Then with the armature 64 properly aligned in respect to the armature retaining plate 69 and the frame arm 48, the armature 64 is held against the pole face 66 and the armature arm 67 is bent until the insulator 68 not quite touches the contact spring 56. The adjusting screw 63 is then threaded into the supporting member 55 to engage the frame arm 48 and establish the desired contact follow or distance that contacts 60 and 61 travel together after just touching. The adjustment of the contact separation or distance between contacts 60 and 61 when they are in the open position is made by bending the arm 74 of the armature stop member 70 relative to the frame arm 48 to change the maximum separation between the armature 64 and the pole face 66.

In Figure 7, coil 42 of relay 20 is shown connected in series with capacitor 16 to an alternating voltage power source 17 of constant frequency. The closed magnetic circuit of core 21 provides a low reluctance path for the flux produced when the current through coil 42 is low and the inductance value of relay 20 is accordingly high. As the current through coil 42 is further increased, the inductance value of relay 20 will decrease at a non-linear rate since the saturation characteristics of the closed core 21 are non-linear. At some definite value of current, the inductive reactance of the relay 20 will be equal to the reactance of capacitor 16 and the circuit is resonant.

If the voltage of the power source 17 is varied, the ferroresonant effect previously described will occur. As the applied voltage is increased above a critical value, the current through coil 42 will change abruptly from a low value to a relatively high value. The voltage at which this abrupt current change occurs is dependent upon the value of current at which the inductive reactance of relay 42 is equal to the reactance of capacitor 16. To provide ferroresonant circuits in which the abrupt change from the low current state to the high current occurs within specified narrow limits, it is necessary that the inductance of relay 20 and the capacitance of capacitor 16 be accurately matched. Because of manufacturing limitations, it is not practical to produce inductors and capacitors without substantial variations in their electrical characteristics. This is one of the reasons why the use of ferroresonant circuits had not become widespread although their advantages had been recognized for many years.

According to the present invention, the electrical characteristics of the relay 20 are economically and accurately adjusted to match those of the capacitor 16 with which it is to be employed. The cross-sectional area of the narrow core leg 33 is such that the inductance value of the relay 20 is initially greater than that required to match any capacitor with which it might be employed. The characteristics of the relay 20 are adjusted to match the capacitor 16 by drilling a hole 78 in the narrow core leg 33 to reduce the cross-sectional area thereof. The inductance value of the relay 20 is reduced in proportion to the depth of the hole 78 drilled in the narrow core leg 33 over a wide range. Automatic calibration of relay 20 with a particular capacitor to have a specified critical voltage at which the current jumps from the low current state to the high current state is accomplished by connecting a relay and a capacitor in series to a voltage equal to the desired critical voltage. Hole 78 is then drilled to the required depth by drilling apparatus employing a control circuit which provides for termination of the drilling at the instant the current jumps to the high current state.

As long as the circuit in which relay 20 is connected remains in the low current state substantially all the flux produced will flow in core 21 since this is the path of least resistance for the flux. Very little flux flows in the magnetic path comprising the high reluctance frame

5

48 and armature 64 and which is interrupted by the air gap between the pole face 66 and the armature 64. When the applied voltage is raised above a critical voltage, the current flow through coil 42 jumps to the high current state and sufficient flux is generated by it to produce a high degree of saturation in the narrow core leg 33 and the core end legs 35 and 36. The wide core leg 34 does not become appreciably saturated because its cross-section is substantially greater than that of the other legs 33, 35, and 36. A certain amount of flux will by-pass the highly saturated core legs 33, 35, and 36, and will follow leakage paths external to core 21 and extending between the ends of the wide core leg 34. Since frame 45 and armature 64 offer less resistance for the flux than do flux paths through the air, sufficient leakage flux is forced through the air gap between the armature 64 and the frame pole face 66 to cause attraction of the armature 64 to the pole face 66. When the armature 64 is attracted, insulator 68 carried by armature arm 67 displaces contact spring 56 and movable contact 60 engages fixed contact 61.

Even though coil 42 encircles frame arm 47, only a negligible amount of flux flows through the major portion of frame arm 47 because its reluctance is high compared to that of the wide core leg 34. Furthermore, the magnetic path through the armature 64 and the portions of the frame 45 not shunted by core 21 also has a high reluctance compared to that of the wide core leg 34. The attraction of the armature 64 is thus entirely dependent upon the leakage flux which flows from the ends of the wide core leg 34 when the remainder of core 21 is saturated. As a result, movement of the armature 64 will not affect the flow of flux through the core 21 or the corresponding inductance valve of the relay 20.

It is important that the attraction of the armature 64 depends only upon leakage flux to avoid changes in the inductance values of relay 20. Changes in the inductance value of relay 20 occurring from movement of armature 64 could cause the current through coil 42 to oscillate and the relay armature to chatter and vibrate. If attraction of the armature 64 increases the inductance value of relay 20 sufficiently to throw the circuit out of resonance, the current through coil 42 decreases to a low value and armature 64 returns to its normal biased position where the inductance value of relay 20 is at its minimum value. The circuit again becomes resonant and this cycle of operation would repeat continuously causing the current to repeatedly rise and fall in an oscillating manner and causing the armature to chatter and vibrate.

Conventional alternating current relays have the disadvantage that their reactance is low when operated much above their pull-in voltage or at just below the pull-in or armature closing voltage. Under such conditions, the current through their coils is high and the coils will overheat. Instead, according to the present invention, the magnetic circuit of relay 20 always presents a high reluctance to coil 42. Therefore, the relay 20 can be operated either at below the pull in voltage or at voltages much higher than the pull-in voltage without damaging the coil 42. Until the armature 64 closes, the current through coil 42 is much lower than current with the armature 64 close. If the applied voltage be increased substantially above the pull-in voltage, the increase in the current of coil 42 reduces the inductance value of relay 20 and this will have the effect of detuning the resonant circuit to limit the current increase to a low value. Because the reluctance of relay 20 decreases, most of the increase in voltage appears across the capacitor 16.

The voltage at which the current returns from the high current state to the low current state is always less than the voltage at which the current changes from the low current state to the high current state. The contact opening voltage of relay 20 is thus always less than the contact closing voltage but may be increased to within 93 percent of the contact closing voltage by adding a

6

series resistor 79 as illustrated in the circuit of Figure 8. The contact-opening voltage can be adjusted to a desired value with negligible effect on the contact closing voltage by varying the resistance of resistor 79.

In addition to the ease and economy of adjusting the operating points of this relay 20, the small size and low power requirements of relay 20 make it particularly adaptable for many control applications. In one version of the preferred embodiment of the invention illustrated herein, the space required was only $2\frac{1}{2} \times 1\frac{1}{2} \times 1$ inches and the ferrosont circuit, including the relay, required only slightly more than one volt-ampere to operate the relay in the high-current state. The core consisted of 18 laminations .019 inch thick and having overall dimensions of $\frac{7}{8}$ by $1\frac{1}{4}$ inches. The armature and frame had thicknesses respectively of .050 inch and .062. The coil consisted of 7250 turns of #41 A.W.G. copper wire and had a D.C. resistance of 1730 ohms.

Relays constructed according to the present invention may be employed for a wide variety of purposes. The relay is voltage responsive when connected in circuits such as those of Figures 7 and 8. The operating points of the relay in such circuits can be adjusted by varying the capacitance of capacitor 16 and the resistance of resistor 79. Because the operation of the relay depends upon a resonant effect, it will also be sensitive to changes in frequency.

From the foregoing description taken in connection with the accompanying drawings, it can be readily seen that this invention provides an electromagnetic switch of novel design and construction suitable for a wide variety of applications. The construction thus attained is not only inexpensive, light in weight and compact, but is also sensitive, extremely accurate, and capable of easy adjustment. The contact closing and opening points of relays according to this construction are unaffected by coil resistance, armature and contact wear, and other such factors. This means that the accuracy of the operating points is unaffected and the operating points will not change even after several million operating cycles.

While the invention has been illustrated and described in its preferred embodiments and has included certain details, it should be understood that the invention is not to be limited to the precise details herein illustrated and described since the same may be carried out in other ways falling within the scope of the invention as claimed.

What is claimed is:

An electromagnetic relay apparatus including, in combination, a generally rectangular, saturable magnetic core having two side legs and two connecting legs defining a closed magnetic path; the effective cross-sectional areas of said end legs and a first leg of said side legs being substantially equal and smaller than the cross-sectional area of the second leg of said side legs whereby said second leg is capable of being relatively unsaturated when said other three legs are saturated; said core being constructed of identical U-shaped laminations having two leg members of equal length joined by a base member; said leg members being unequal in width; said laminations being stacked with the alternate laminations reversed end-for-end with leg members of the same width arranged together whereby said first side leg consists of the narrow leg members, said second side leg of the core consists of the wide side legs and said end legs consist of said base members; said base members having a width substantially equal to twice the width of the narrow leg members; a magnetic actuator including a U-shaped magnetic frame having a pair of arms; the broad face of one of said arms of the frame being positioned against said second side leg of the core; an alternating current winding encircling said second side leg of the core and said one arm of frame; said first side leg of the core being provided with a hole therein for causing said second side leg to attain a predetermined degree of saturation with a predetermined current flow through said winding; said magnetic

frame including a magnetic armature extending across the open end of said U-shaped frame for movement to a magnetically attracted position from an unattracted position by leakage flux upon saturation of said end legs of the core and said first side leg of the core; and the magnetic circuit of said magnetic actuator having a reluctance substantially greater than the reluctance of said second side leg of the core such that the impedance of said winding is substantially independent of the position of said armature.

5

10

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