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**ELECTRICAL SWITCHING APPARATUS INCLUDING A COIL AND A
NUMBER OF AUXILIARY SWITCHES, AND METHOD OF
CONTROLLING AND CONTROL SYSTEM FOR THE SAME**

5 CROSS REFERENCE TO RELATED APPLICATION

 This application claims the benefit of U.S. Provisional Patent
Application Serial No. 61/160,421, filed March 16, 2009, which is incorporated by
reference herein.

BACKGROUND

10 Field

 The disclosed concept pertains generally to electrical switching
apparatus and, more particularly, to electrical switching apparatus, such as, for
example, relays, contactors or solenoid-actuated switches, including a coil and a
number of auxiliary switches. The disclosed concept also pertains to methods of
15 controlling such electrical switching apparatus. The disclosed concept further
pertains to control systems for such electrical switching apparatus.

Background Information

 Figure 1 shows a conventional three-phase contactor 2 including three
main contacts 4,6,8 controlled by a coil 10. A number of sets of electromechanical
20 auxiliary contacts 12 are responsive to the closed position or the open position of the
three main contacts 4,6,8. The contactor 2 employs two conductors, such as 14,16,
for each set of the electromechanical auxiliary contacts 12. The contactor 2 has a
relatively large size and weight, includes individual mechanical adjustments (e.g.,
without limitation, an adjustment to provide “wear allowance” to ensure proper
25 function as various parts wear). For example, each set of the electromechanical
auxiliary contacts 12 requires adjustment to ensure that it is actuated when the main
contacts 4,6,8 are actuated. Each set of the electromechanical auxiliary contacts 12
includes an electromechanical auxiliary switch that provides the corresponding
auxiliary contact function (e.g., normally closed (NC); normally open (NO)). While
30 no power is required for NC auxiliary switches, the electromechanical auxiliary
switches are susceptible to foreign object debris (FOD) and contaminants.

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There is room for improvement in electrical switching apparatus, such as relays, contactors or solenoid-actuated switches, including a coil and a number of auxiliary switches.

There is also room for improvement in methods of controlling such
5 electrical switching apparatus.

There is further room for improvement in control systems for such electrical switching apparatus.

SUMMARY

These needs and others are met by embodiments of the disclosed
10 concept, which monitor a magnetic field of a magnetic frame cooperating with a coil, detect a predetermined characteristic of a current flowing through the coil, and change a state of a number of auxiliary switches if the magnetic field is greater than a predetermined value and if the predetermined characteristic is detected.

In accordance with one aspect of the disclosed concept, a method
15 controls an electrical switching apparatus including a coil, a magnetic frame cooperating with the coil, and a number of auxiliary switches. The method comprises: monitoring a magnetic field of the magnetic frame; detecting a predetermined characteristic of a current flowing through the coil; and changing a state of the number of auxiliary switches if the magnetic field is greater than a
20 predetermined value and if the predetermined characteristic is detected.

The method may further comprise reducing the current flowing through the coil; employing the predetermined value as a first predetermined value; employing a second predetermined value, which is smaller than the first predetermined value; and determining if the magnetic field decreases to less than the
25 smaller second predetermined value and responsively changing the state of the number of auxiliary switches.

The method may further comprise employing a ferrous plunger with the coil; and detecting the predetermined characteristic of the current flowing through the coil when the ferrous plunger moves both far enough and fast enough responsive
30 to the magnetic field.

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The method may further comprise determining a magnitude of the current flowing through the coil; and adjusting the predetermined value as a function of the magnitude of the current.

As another aspect of the disclosed concept, a control system is for an electrical switching apparatus including a coil, a magnetic frame cooperating with the coil, and a number of auxiliary switches. The control system comprises: a current sensor structured to sense a current flowing through the coil; a magnetic sensor structured to sense a magnetic field of the magnetic frame; and a circuit structured to detect a predetermined characteristic of the sensed current flowing through the coil and output a control signal responsive to the magnetic field being greater than a predetermined value and the predetermined characteristic being detected.

As another aspect of the disclosed concept, an electrical switching apparatus comprises: a coil; a magnetic frame cooperating with the coil; a number of separable contacts controlled by the coil; a number of auxiliary switches; a current sensor structured to sense a current flowing through the coil; a magnetic sensor structured to sense a magnetic field of the magnetic frame; and a circuit structured to detect a predetermined characteristic of the sensed current flowing through the coil and output a control signal responsive to the magnetic field being greater than a predetermined value and the predetermined characteristic being detected, wherein the control signal is structured to cause a change in state of the number of auxiliary switches.

The coil may include a ferrous plunger; the separable contacts may include a number of fixed contacts and a number of movable contacts movable by the ferrous plunger; and the current flowing through the coil may cooperate with the magnetic frame to cause the magnetic field to move the ferrous plunger from a first position wherein the separable contacts are open to a different second position wherein the number of movable contacts electrically engage the number of fixed contacts.

The circuit may be further structured to determine a magnitude of the current flowing through the coil and adjust the predetermined value as a function of the magnitude of the current.

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The control signal may be structured to cause a change in state of the number of auxiliary switches to a first state when the magnetic field is greater than the predetermined value and the predetermined characteristic is detected; the predetermined value may be a first predetermined value; a second predetermined value may be smaller than the first predetermined value; and the circuit may be further structured to determine if the magnetic field is subsequently less than the smaller second predetermined value and to cause a further change in state of the number of auxiliary switches to a different second state.

BRIEF DESCRIPTION OF THE DRAWINGS

A full understanding of the disclosed concept can be gained from the following description of the preferred embodiments when read in conjunction with the accompanying drawings in which:

Figure 1 is a block diagram of a contactor.

Figure 2 is a block diagram of a contactor including electronic auxiliary switches and actuation logic therefor in accordance with embodiments of the disclosed concept.

Figure 3 is a block diagram of a contactor including electronic auxiliary switches and actuation logic therefor in accordance with another embodiment of the disclosed concept.

Figure 4 includes plots of magnetic frame magnetic field, coil current and the state of the main contacts of a contactor or relay switch being switched to a first state in accordance with another embodiment of the disclosed concept.

Figure 5 includes plots of magnetic frame magnetic field, coil current and the state of the main contacts of a contactor or relay switch being switched to a second state with an abnormal result in accordance with another embodiment of the disclosed concept.

Figure 6 includes plots of magnetic frame magnetic field, coil current and the state of the main contacts of a contactor or relay switch being switched to a second state with a normal result in accordance with another embodiment of the disclosed concept.

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Figure 7 is a block diagram in schematic form of the auxiliary switch actuation logic of Figure 2 and corresponding current and magnetic sensors in accordance with another embodiment of the disclosed concept.

Figure 8 is a cross section of a vertical elevation view of a relay in accordance with another embodiment of the disclosed concept.

Figure 9 is a block diagram in schematic form of the economizer and coil of Figure 2.

Figure 10 is a flowchart of a routine executed by the logic circuit of Figure 7.

10 DESCRIPTION OF THE PREFERRED EMBODIMENTS

As employed herein, the term “number” shall mean one or an integer greater than one (*i.e.*, a plurality).

As employed herein, the term “processor” means a programmable analog and/or digital device that can store, retrieve, and process data; a computer; a workstation; a personal computer; a microprocessor; a microcontroller; a microcomputer; a central processing unit; a mainframe computer; a mini-computer; a server; a networked processor; or any suitable processing device or apparatus.

As employed herein, the term “glitch” means a momentary decrease in a current flowing through a coil before it subsequently reaches a larger current value.

As employed herein, the term “auxiliary switch” means auxiliary contacts, an electromechanical auxiliary switch or an electronic auxiliary switch.

As employed herein, the term “coil” means a relay coil, a contactor coil or a solenoid coil.

The disclosed concept is described in association with three-phase relays and three-phase contactors having a plurality of electronic auxiliary switches, although the disclosed concept is applicable to a wide range of electrical switching apparatus including a coil, any number of phases, and any number of auxiliary switches, such as auxiliary contacts, electromechanical auxiliary switches or electronic auxiliary switches.

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Example 1

Figure 2 shows a contactor 20 including a plurality of bi-directional electronic auxiliary switches 22 and actuation logic 24 therefor. The example bi-directional electronic auxiliary switches 22 mimic electromechanical auxiliary switches, such as 12 of Figure 1. A power input 26 provides power to activate any normally closed (NC) electronic auxiliary switches 22. A control input 28 is provided to an economizer 30, which is discussed, below, in connection with Figure 9. The economizer 30, in turn, controls a coil 54, which controls the main contacts 4,6,8 with a plunger 52. The actuation logic 24 is discussed, below, in connection with Figures 7 and 10.

Example 2

Figure 3 shows another contactor 40 including a plurality of electronic auxiliary switches 42 and actuation logic 44 therefor. The example electronic auxiliary switches 42 mimic electromechanical auxiliary switches, such as 12 of Figure 1, except that a common and independent auxiliary switch ground 45 of power input 46 is employed to provide single-ended auxiliary outputs 43, in order to reduce external conductor count. The independent auxiliary switch ground 45 preferably reduces EMI issues. The electronic auxiliary switches 42 can employ any suitable relatively high or relatively low voltage logic, and corresponding power connections. For example, MOSFET or bipolar transistors (not shown) can be employed depending on individual auxiliary switch needs. High-side or low-side transistor circuits (not shown) can be employed. The example contactor 40 employs switch-to-ground low side auxiliary switches 42 as shown in Figure 3.

It will be appreciated that although example contactors 20 and 40 of Figures 2 and 3 are shown, the disclosed concept is applicable to a wide range of different contactors, relays or solenoid-actuated electrical switch configurations in order to address a wide range of electrical switching applications.

In addition, the example electronic auxiliary switches 22,42 of Figures 2 and 3 can be logic level switches and/or can control other relays within a system. As non-limiting examples, the electronic auxiliary switches 22,42 can drive up to about 1 A for logic level applications, while relay-type auxiliary switches can typically be rated up to about 10 A.

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Example 3

Referring to Figures 4-6, when a relay or contactor coil, such as 54, is energized, the magnetic field strength inside a corresponding magnetic frame (not shown, but see magnetic frame 50 of Figures 7 and 8) generally does not reach full strength until the moving plunger (not shown, but see plunger 52 of Figures 7 and 8) of the coil (see coil 54 of Figures 7 and 8) is moved completely to the energized position where it comes to rest in such a way as to reduce the reluctance of the magnetic frame magnetic circuit. The decrease in reluctance, which occurs when the plunger completes the magnetic circuit path, allows the magnetic field strength inside the plunger to reach its fullest strength.

Figure 4 includes plots 60, 62 and 64 of magnetic frame magnetic field 66, coil current 68 and the state 70 (e.g., off or open is high; on or closed is low) of the main contacts (see 4,6,8 of Figure 2) of an electrical switching apparatus, such as a contactor or relay switch, being switched to a first state (e.g., off), respectively. When turning-off the example relay or contactor, in response to a removal or sufficient drop in the coil current 68 (e.g., at 72), the magnetic field 66 of the magnetic frame 50 (Figures 7 and 8) drops to a magnetic strength (e.g., at 74) where the auxiliary switches 22,42 (Figures 2 and 3) change state (and function) and the main contacts open (e.g., at 76).

Figure 5 includes plots 80, 82 and 84 of magnetic frame magnetic field 86, coil current 88 and the state 90 of the main contacts (see 4,6,8 of Figure 2) being attempted to be switched to a second state (e.g., on), respectively, but with an abnormal result since the state 90 does not change. When power is applied to the contactor or relay coil 54 (Figures 7 and 8), the coil current 88 increases to a final value 92 that is a function of the coil resistance; however, the wave shape of the increasing coil current 88 is influenced by several factors. Current waveforms observed during the period following the initial application of power normally display a “glitch” 94 (Figure 6) resulting from the magnetic “back-EMF” effect of the moving plunger (not shown, but see plunger 52 of Figures 7 and 8), which momentarily results in coil current decreasing before achieving the final value 92. If the plunger does not move, or if it moves slowly or partially (e.g., not far enough; not fast enough), then the glitch 94 (Figure 6) will not be present as shown in area 94' of

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Figure 5. This is because the moving plunger, in this instance, does not create “back-EMF” sufficient to cause the dip in the coil current 88. Although the coil current 88 still reaches the full inrush value 92 (e.g., based on the coil resistance) (e.g., without limitation, about 3.1 A at 25°C), because the plunger did not seat, there is an air gap
5 that limits the final value 96 of the magnetic field 86. As a result, the state 90 remains high corresponding to the open or off state of the main contacts.

As will be discussed, below, in connection with Figure 10, a control method to change the state of the auxiliary switches 22,42 (Figures 2 and 3) includes:
(1) determining if the glitch 94 (Figure 6) is present; and (2) determining if the
10 magnetic field strength 96,96' is sufficient; and (3) creating a control signal 27,47 (Figures 2 and 3) from the actuation logic 24,44 (Figures 2 and 3), which changes the state of the corresponding auxiliary switches 22,42 (i.e., to a state corresponding to the main contacts 4,6,8 being closed).

Figure 6 includes plots 100,102,104 of magnetic frame magnetic field
15 106, coil current 108 and the state 110 of the main contacts (see 4,6,8 of Figure 2) being switched to a second state (e.g., on), respectively, with a normal result. Here, the “glitch” 94 is detected. This detection is ANDed with the detection of the magnetic field strength signal 96' being over the threshold 112. As is shown in Figure 5, the “glitch” 94 is not present in area 94' when, for example, the plunger (not shown, but
20 see plunger 52 of Figures 7 and 8) is stalled. A coil current value 113 is detected with a suitable sensor (e.g., without limitation, a Hall sensor 114 (Figure 7)). This current value 113 can be used, as will be explained, to set or adjust the threshold 112 for the magnetic field strength 86,106. The threshold 112 of the magnetic field strength 86,106 can be determined using the coil current value 113, as is discussed in
25 Examples 4, 9 and 10, below.

Example 4

One of the variables controlling the final magnetic field strength 96,96' in the magnetic frame (not shown, but see magnetic frame 50 of Figures 7 and 8) is the final magnitude 92,113 of the current 88,108. The magnitude of the current
30 88,108 varies with temperature inversely. To set the threshold 112 for determining whether the magnetic field strength 96,96' is sufficient, the magnitude 92,113 of the

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coil current 88,108 can be employed to set this threshold for such magnetic field strength.

Example 5

When it is desired to return the state of the auxiliary switches 22,42 (i.e., to a state corresponding to the main contacts 4,6,8 being open with the coil 54 being de-energized with no or sufficiently reduced current flowing therethrough), suitable control logic (e.g., an algorithm) can be employed. This control logic includes: (1) determining if the magnetic field 66,106 in the magnetic frame 50 decreases below a different predefined threshold (e.g., without limitation, smaller than the threshold 112; determined empirically; adjusted for ambient temperature, coil current and/or coil voltage) (see, for example, 74 of Figure 4) known to be less than that needed to maintain contact closure; and (2) providing the control signal 27,47 to command the auxiliary switches 22,42 to revert to their original state.

Example 6

Figure 7 shows the auxiliary switch actuation logic 24 of Figure 2, the corresponding current sensor 114 structured to sense current flowing through the coil 54, and the corresponding magnetic field sensor 120 structured to sense the magnetic field 106 (Figure 6) of the magnetic frame 50. It will be appreciated that the actuation logic 44 of Figure 3 can be the same as or similar to the actuation logic 24. Both of the actuation logics 24,44 can be implemented with a suitable processor, such as for example and without limitation, a microcontroller or microcomputer including a suitable analog to digital converter 122. The actuation logic 24 and sensors 114,120 provide a control system (control circuit) to control the auxiliary switches 22,42 for an electrical switching apparatus based on the sensed magnetic field 124 of the magnetic frame 50 and the sensed current 126 flowing through the coil 54. This control system monitors and detects the strength of the magnetic field in the magnetic frame 50 and detects the “glitch” characteristic 94 of the coil current waveform.

A relay 130 (portions of which are shown in Figure 8) includes a positive electrical terminal 132 and a negative electrical terminal 134, which input a single actuation signal (e.g., without limitation, 28 VDC; any suitable DC voltage). The actuation logic 24 outputs the electronic auxiliary switch control signal 27, which is structured to change the state of the auxiliary switches 22,42 (Figures 2 and 3). The

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magnetic field sensor 120 is preferably sensitive to the full range of the magnetic strength present during the operation of the coil 54. The actuation logic 24 is structured to detect a predetermined characteristic, such as the glitch 94 of the sensed current 126 flowing through the coil 54, and output the control signal 27 responsive to the sensed magnetic field 124 being greater than the threshold 112 (Figure 6) and the
5 the predetermined characteristic being detected.

Example 7

Referring to Figure 8, an electrical switching apparatus (e.g., without limitation, such as the example relay 130; a contactor; a solenoid-actuated electrical
10 switch) includes the coil 54 (also shown in Figure 9), the magnetic frame 50 cooperating with the coil 54, a number of separable contacts 137 (not fully shown, but see the main contacts 4,6,8 of Figure 2) controlled by the coil 54, a number of auxiliary switches 136 (e.g., auxiliary switches 22,42 of Figures 2 or 3), the current sensor 114 (Figure 7) structured to sense the current flowing through the coil 54, the
15 magnetic sensor 120 structured to sense the magnetic field of the magnetic frame 50, a circuit, such as 24, and the economizer 30.

The relay 130 functions as a coil-actuated (e.g., solenoid-actuated) electrical switch in which the magnetic field generated by an electromagnet formed by the coil 54 and the magnetic frame 50 causes the axial ferrous plunger 52 to move
20 from a rest position (e.g., up with respect to Figures 7 and 8) to an energized position (e.g., down with respect to Figures 7 and 8) when the coil 54 is suitably energized. The predetermined characteristic (e.g., glitch 94) of the sensed current 126 flowing through the coil 54 is responsive to a magnetic “back-EMF” effect of the ferrous plunger 52 when moved by the magnetic field of the electromagnet. The actuation
25 logic 24 detects this predetermined characteristic when the ferrous plunger 52 moves both far enough and fast enough responsive to the magnetic field.

The separable contacts 137 (not fully shown, but see the main contacts 4,6,8 of Figure 2), which are coupled to the plunger 52, can be moved from a rest position to an energized position. As shown in Figure 2, the separable contacts 137
30 can include a number of fixed contacts 138 and a number of movable contacts 140 (also shown in Figure 8) movable by the ferrous plunger 52. The current flowing through the coil 54 cooperates with the magnetic frame 50 to cause the magnetic field

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to move the ferrous plunger 52 from a first position (e.g., up with respect to Figures 7 and 8) wherein the separable contacts 137 are open to a different second position (e.g., down with respect to Figures 7 and 8) wherein the number of movable contacts 140 electrically engage the number of fixed contacts 138. The separable contacts 137
5 can switch any suitable voltage (e.g., AC; DC). Although three sets of separable contacts 137 are shown, any suitable number can be employed. In the example of Figure 2, the three sets of movable contacts 140 are driven by the plunger 52 of the coil 54.

The example relay 130 also includes a cover (not shown), a printed
10 circuit board (PCB) 142 including the electronic auxiliary contacts 136, a PCB 144 including the actuating logic 24 and the economizer 30, a base 146, and a plurality of terminals 148 in electrical communication with the fixed contacts 138 of Figure 2 (only three of six terminals 148 are shown). A terminal 150 provides the power input 26 (Figure 2) to activate any NC electronic auxiliary switches 22. The terminals
15 132,134 provide power to the economizer 30 and the PCB 144 as shown in Figure 7. The terminals 132,134,150 can be employed as part of a common connector. Power terminals, such as 148, typically include bus bars (not shown) or threaded stud terminals (not shown) for external electrical connections.

Example 8

20 Figure 9 shows the economizer 30 and coil 54 of Figure 2. The economizer 30 is a conventional coil relay/contactors control circuit that allows for a relatively much greater magnetic field in an electrical switching apparatus during, for instance, the initial (e.g., without limitation, 50 mS) time following application of power to ensure that the plunger 52 completes its travel and overcomes its own inertia,
25 friction and spring forces. This is achieved by using a dual coil arrangement in which there is a suitable relatively low resistance circuit or coil 160 and a suitable relatively high resistance circuit or coil 162 in series with the coil 160. Initially, the economizer 30 allows current to flow through the low resistance circuit 160, but after a suitable time period, the economizer 30 turns off the low resistance path. This approach
30 reduces the amount of power consumed during static states (e.g., relatively long periods of being energized).

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The dual bifilar coil 54 is employed inside the magnetic frame 50. The RC timing components 164 control the inrush time period. The coil 160 is, for example and without limitation, 9 ohms and the coil 162 is, for example and without limitation, 90 ohms. When the coil 162 is shunted by FET 166 during the initial time
5 after the application of power, the current is relatively high (e.g., without limitation, $28 \text{ VDC} / 9 \text{ ohms} = 3.1 \text{ A}$). The FET 166 provides a coil current shunt path to dramatically increase current through the coil 160 during the initial period after the application of power. Based on the coil design, the coil 160 creates a relatively very strong magnetic field even though no appreciable current flows through the other coil
10 162 during this time. Magnetic field strength is a function of the product of the coil current and the number of turns of the corresponding coil(s) 160,162.

When the capacitor 168 charges to a predefined threshold voltage, the control logic 170 turns FET 166 off, the shunt path is no longer present, and the coil current now flows through both of the coils 160,162. The coil design is such that the
15 coil current creates enough magnetic force to hold the electrical switching apparatus in the energized state. In this case, the current would be reduced to (e.g., without limitation, $28 \text{ VDC} / (9 + 90 \text{ ohms})$ or about 0.28 A), which is fewer amps, but with many more turns of the coils 160,162.

Because the power is a function of the current squared times the
20 resistance, a reduction of the coil current by a factor of about 11 causes the power needed to hold the corresponding electrical switching apparatus closed to be significantly reduced. The relatively high power at the time of the application of power ensures that the electrical switching apparatus closes properly and completely.

Example 9

25 Figure 10 shows a routine 180 executed by the actuation logic 24 of Figure 7. Initially, at 182, the control input 28 (control voltage) (Figure 2) is applied between the electrical terminals 132,134. Next, at 184, the coil economizer 30 and actuation logic circuit 24 are activated, and the actuation logic circuit 24 begins to monitor the coil current for the glitch 94 (Figure 6). Then, at 186, it is determined if
30 the inrush current glitch 94 is present. If not, then at 188, the state of the auxiliary switches 22 (Figure 2) is not changed (e.g., maintain the normally open auxiliary switches and the normally closed auxiliary switches in their prior states). Otherwise,

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at 190, if the magnetic field strength is within acceptable limits (e.g., above a suitable predetermined value (threshold 112 of Figure 6); above a suitable empirically determined value; above a value from a look-up table as a function of a suitable predetermined value, ambient temperature, voltage and/or current), then, at 192, the
 5 normally open auxiliary switches are activated and the normally closed auxiliary switches are de-activated by changing the state of the control signal 27 (Figure 2). Otherwise, at 194, the state of the auxiliary switches 22 (Figure 2) is not changed (the state of the control signal 27 is not changed). The routine 180 monitors the magnetic field of the magnetic frame 50, detects the predetermined characteristic of the current
 10 flowing through the coil 54, and changes the state of the number of auxiliary switches 22,42 if the sensed magnetic field 124 is greater than the predetermined value (threshold 112) and if the predetermined characteristic 94 is detected.

Example 10

The magnetic field of the magnetic frame 50 is preferably
 15 characterized throughout the voltage/temperature range of the corresponding electrical switching apparatus. For example, as a typical contactor or relay is energized, the magnetic field is changing. The magnetic field in the magnetic frame 50 is influenced by the amount of coil current flowing and the effect of position and movement of the plunger 52. Copper resistance (R) varies dramatically with temperature (T), therefore,
 20 the current that flows through the coil 54 varies as a function of temperature as shown in Equation 1.

$$R = R_0[1 + \alpha(T-T_0)]$$

(Eq. 1)

wherein:

25 R₀ is the initial resistance (ohms);
 T₀ is the initial temperature (°C); and
 α is the temperature coefficient of the material (e.g., α for copper is 3.9 x 10⁻¹⁰/°C).

If the coil current varies as a function of temperature, then the force on
 30 the plunger 52 when it is energized is changed resulting in more or less acceleration of the plunger 52 from its de-energized position to its energized position. The energized state is defined by the completion of transfer of position of the plunger 52

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and the separable contacts 137 coming to rest in the transferred (e.g., closed) position. After the electrical switching apparatus coil 54 is energized, the coil current 108 (Figure 6) continues to increase for a brief period of time as a result of the inductance of the coil 54. The magnetic field in the magnetic frame 50 is in a dynamic state until
5 this time and it is different from apparatus to apparatus depending on temperature and variations in spring and friction forces. Hence, by determining the magnitude of the current flowing through the coil 54, a suitable adjustment of the predetermined value (threshold 112) can be made as a function of the magnitude of the coil current.

By monitoring the magnetic field with suitable instrumentation, it can
10 be possible to identify characteristics in the magnetic field to determine the state of the plunger 52. By incorporating a suitable sensing and control circuit in the apparatus that identifies the state of the plunger 52, the actuation logic circuit 24 can control auxiliary switches 22,42 to change their proper state according to the determined position of the plunger 52.

15

The disclosed concept employs a single control input 28 (single actuation signal) (Figure 2). This can employ electronic auxiliary switches 22,42 (Figures 2 and 3) and, thus, avoid the need for multiple mechanical adjustments. This provides reduced size and weight, is not susceptible to FOD or contaminants, and
20 improves reliability and life expectancy of the electrical switching apparatus.

The example electronic auxiliary switches 42 potentially reduce aircraft conductor count.

While specific embodiments of the disclosed concept have been described in detail, it will be appreciated by those skilled in the art that various
25 modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the disclosed concept which is to be given the full breadth of the claims appended and any and all equivalents thereof.

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What is Claimed is:

1. A method of controlling an electrical switching apparatus (130) including a coil (54), a magnetic frame (50) cooperating with the coil, and a number of auxiliary switches (22), said method comprising:

monitoring (120) a magnetic field (66,106) of the magnetic frame;

detecting (186) a predetermined characteristic (94) of a current (108) flowing through the coil; and

changing (192) a state of the number of auxiliary switches if (190) the magnetic field is greater than a predetermined value and if (186) the predetermined characteristic is detected.

2. The method of claim 1 further comprising employing the predetermined characteristic as a glitch (94).

3. The method of claim 1 further comprising:
reducing the current flowing through the coil;
employing the predetermined value as a first predetermined value;

employing a second predetermined value (74), which is smaller than the first predetermined value; and

determining if the magnetic field decreases to less than the smaller second predetermined value and responsively changing the state of the number of auxiliary switches.

4. The method of claim 1 further comprising employing the predetermined characteristic as a momentary decrease (94) in the current flowing through the coil before subsequently reaching a larger current value (113).

5. The method of claim 1 further comprising:
employing a ferrous plunger (52) with the coil; and
detecting (186) the predetermined characteristic of the current flowing through the coil when the ferrous plunger moves both far enough and fast enough responsive to the magnetic field.

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6. The method of claim 1 further comprising:
determining a magnitude (113) of the current flowing through the coil; and

adjusting the predetermined value (112) as a function of the magnitude of the current.

7. A control system (144) for an electrical switching apparatus (130) including a coil (54), a magnetic frame (50) cooperating with the coil, and a number of auxiliary switches (22), said control system comprising:

a current sensor (114) structured to sense a current (108,126) flowing through the coil;

a magnetic sensor (120) structured to sense a magnetic field (66,106) of the magnetic frame; and

a circuit (24) structured (180) to detect a predetermined characteristic (94) of the sensed current (126) flowing through the coil and output a control signal (27) responsive to the magnetic field being greater than a predetermined value and the predetermined characteristic being detected.

8. The control system (144) of Claim 7 wherein the control signal is structured to change a state of the number of auxiliary switches (22).

9. The control system (144) of Claim 7 wherein the predetermined characteristic is a glitch (94).

10. The control system (144) of Claim 7 wherein the current sensor is a Hall sensor (114).

11. The control system (144) of Claim 7 wherein said number of auxiliary switches are a number of electronic auxiliary switches (22); and wherein said control signal is structured to change the state of said number of electronic auxiliary switches.

12. The control system (144) of Claim 7 wherein said number of auxiliary switches are a number of electronic auxiliary switches (22); and wherein said control signal is an electronic signal (27) structured to open or close said number of electronic auxiliary switches.

13. The control system (144) of Claim 7 wherein said coil includes a ferrous plunger (52); and wherein the predetermined characteristic of the sensed

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current flowing through the coil is responsive to a magnetic “back-EMF” effect of the ferrous plunger when moved by the magnetic field of the magnetic frame.

14. An electrical switching apparatus (130) comprising:
 - a coil (54);
 - a magnetic frame (50) cooperating with said coil;
 - a number of separable contacts (127) controlled by said coil;
 - a number of auxiliary switches (22);
 - a current sensor (114) structured to sense a current (108,126) flowing through the coil;
 - a magnetic sensor (120) structured to sense a magnetic field (66,106) of the magnetic frame; and
 - a circuit (24) structured (180) to detect a predetermined characteristic (94) of the sensed current (126) flowing through the coil and output a control signal (27) responsive to the magnetic field being greater than a predetermined value (112) and the predetermined characteristic being detected,
 - wherein the control signal is structured to cause a change in state of said number of auxiliary switches.
15. The electrical switching apparatus (130) of Claim 14 wherein said electrical switching apparatus is a relay (130).
16. The electrical switching apparatus (130) of Claim 14 wherein said electrical switching apparatus is a contactor (130).
17. The electrical switching apparatus (130) of Claim 14 wherein said electrical switching apparatus is a solenoid-actuated electrical switch (130).
18. The electrical switching apparatus (130) of Claim 14 wherein said coil includes a ferrous plunger (52); wherein said separable contacts include a number of fixed contacts (138) and a number of movable contacts (140) movable by said ferrous plunger; and wherein the current flowing through the coil cooperates with the magnetic frame to cause the magnetic field to move the ferrous plunger from a first position wherein said separable contacts are open to a different second position wherein said number of movable contacts electrically engage said number of fixed contacts.

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19. The electrical switching apparatus (130) of Claim 14 wherein said circuit is further structured to determine a magnitude (113) of the current flowing through the coil and adjust the predetermined value as a function of the magnitude of the current.

20. The electrical switching apparatus (130) of Claim 14 wherein the control signal is structured to cause a change in state of said number of auxiliary switches to a first state when the magnetic field is greater than said predetermined value and the predetermined characteristic is detected; wherein said predetermined value is a first predetermined value; wherein a second predetermined value (74) is smaller than the first predetermined value; and wherein said circuit is further structured to determine if the magnetic field is subsequently less than the smaller second predetermined value and to cause a further change in state of said number of auxiliary switches to a different second state.

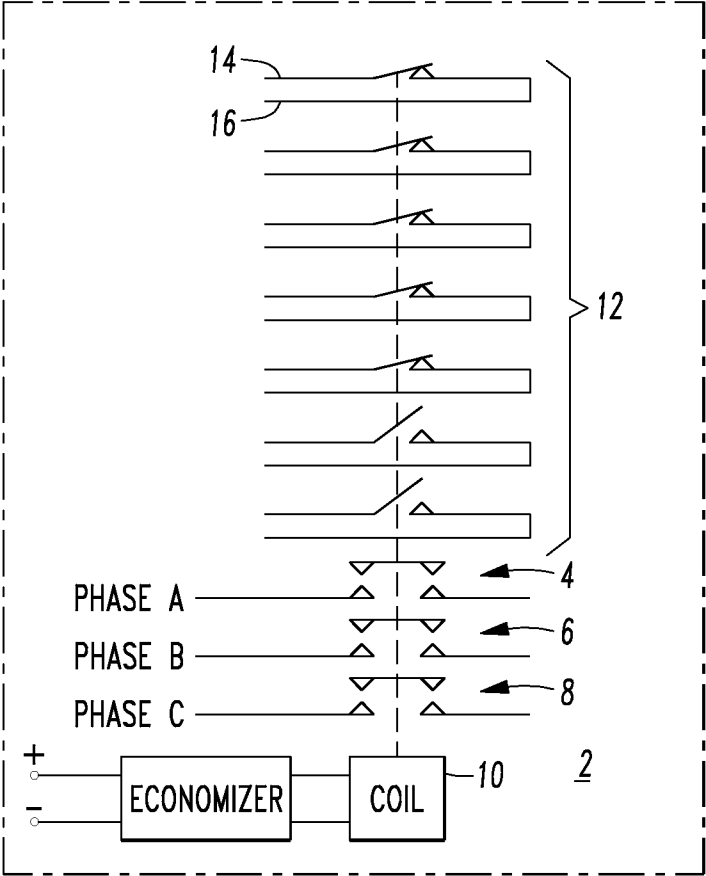


FIG. 1
PRIOR ART

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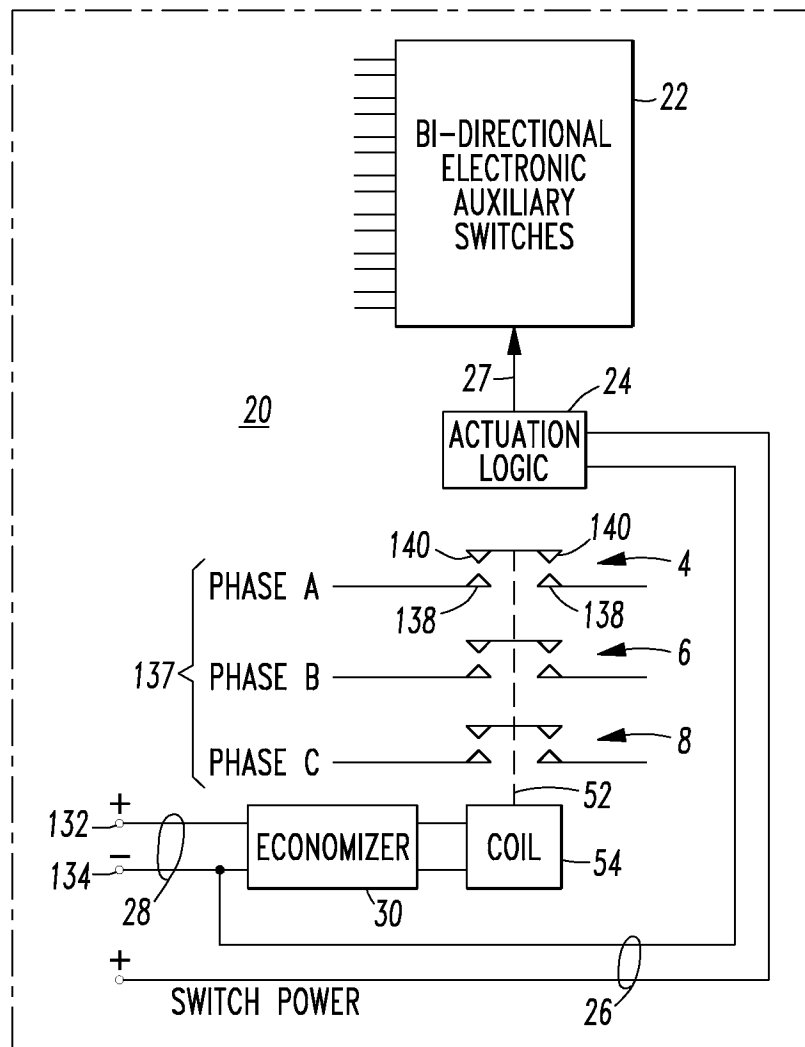
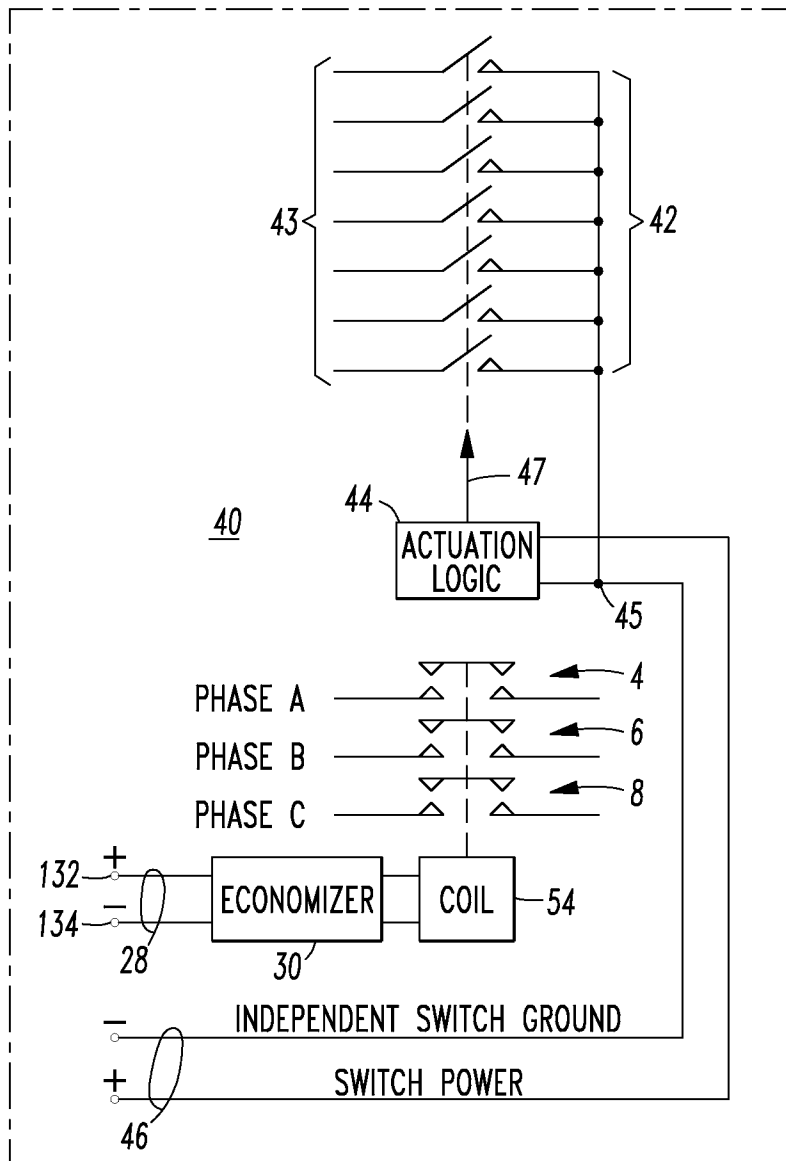


FIG.2

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*FIG. 3*

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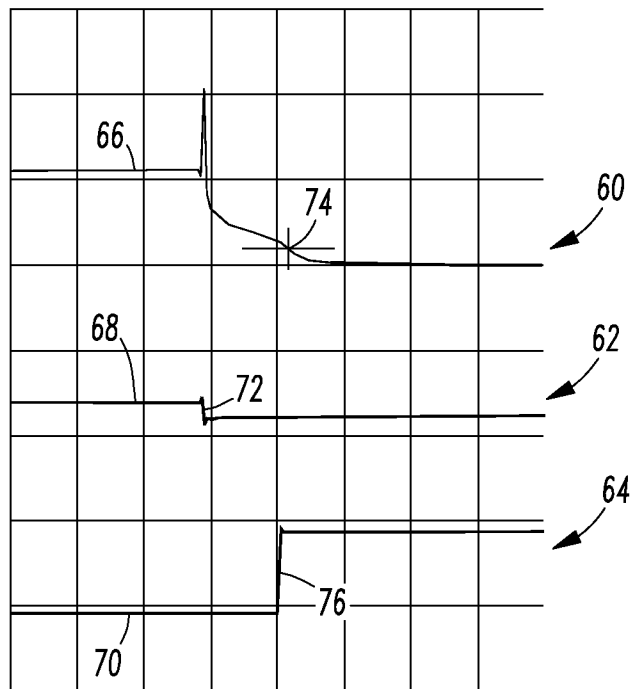


FIG. 4

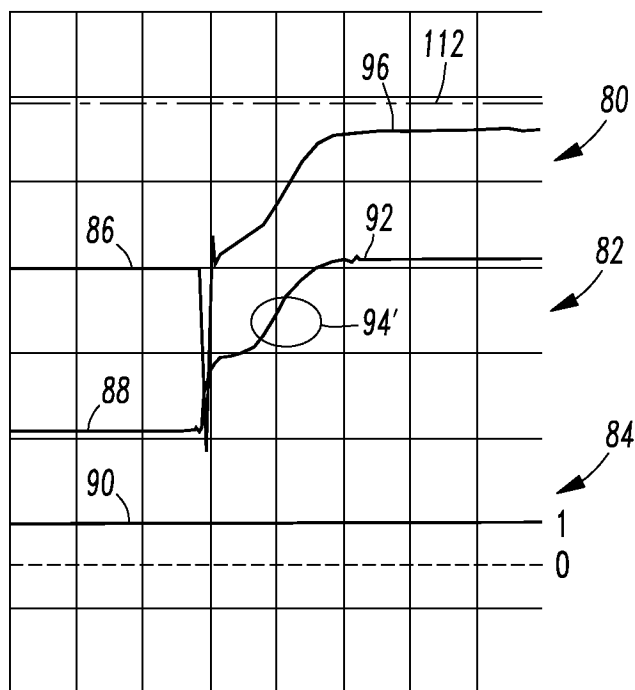


FIG. 5

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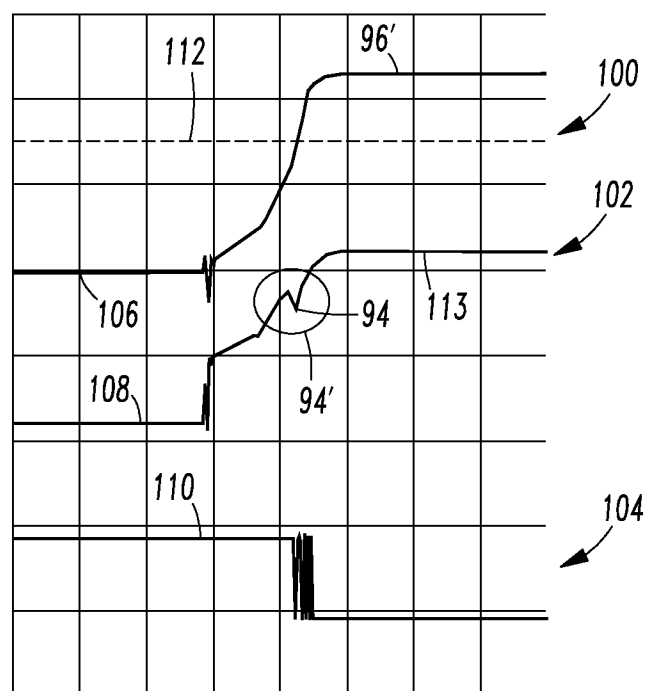


FIG. 6

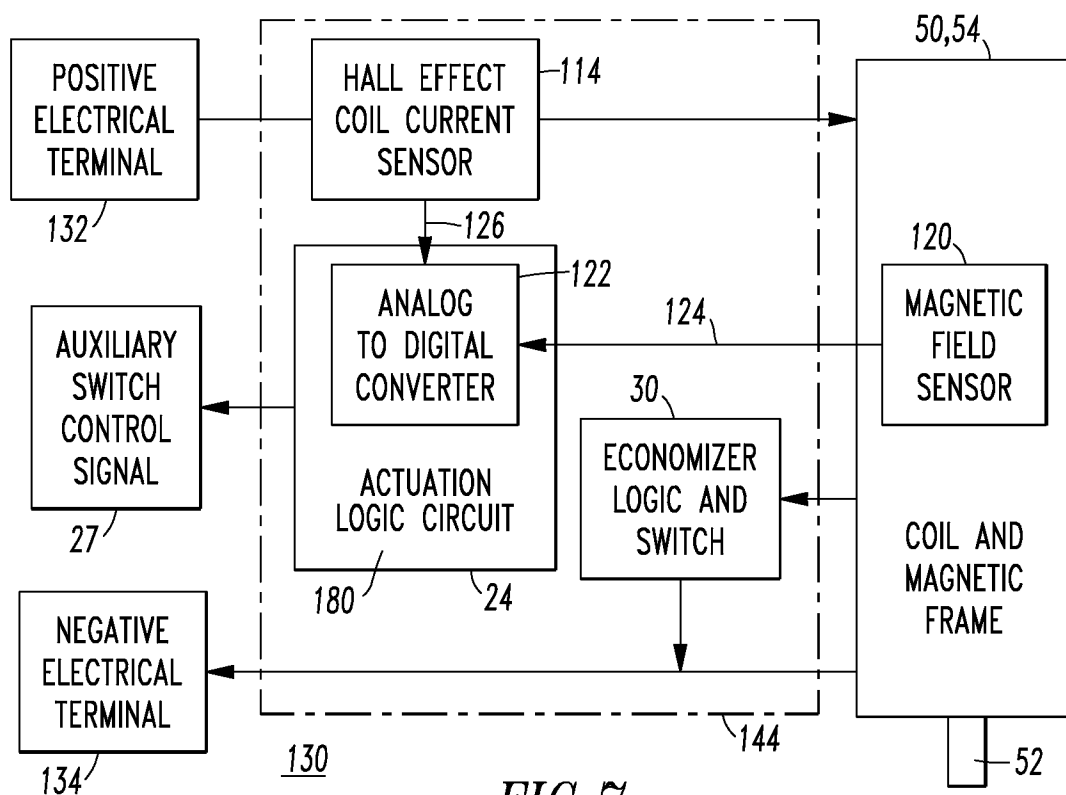
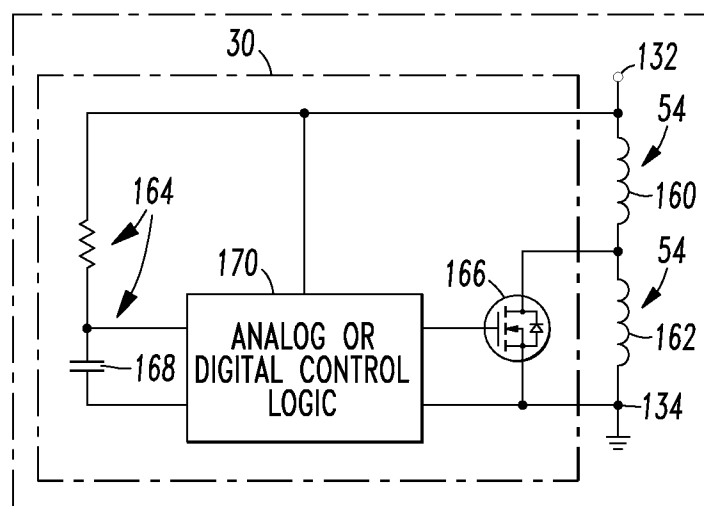
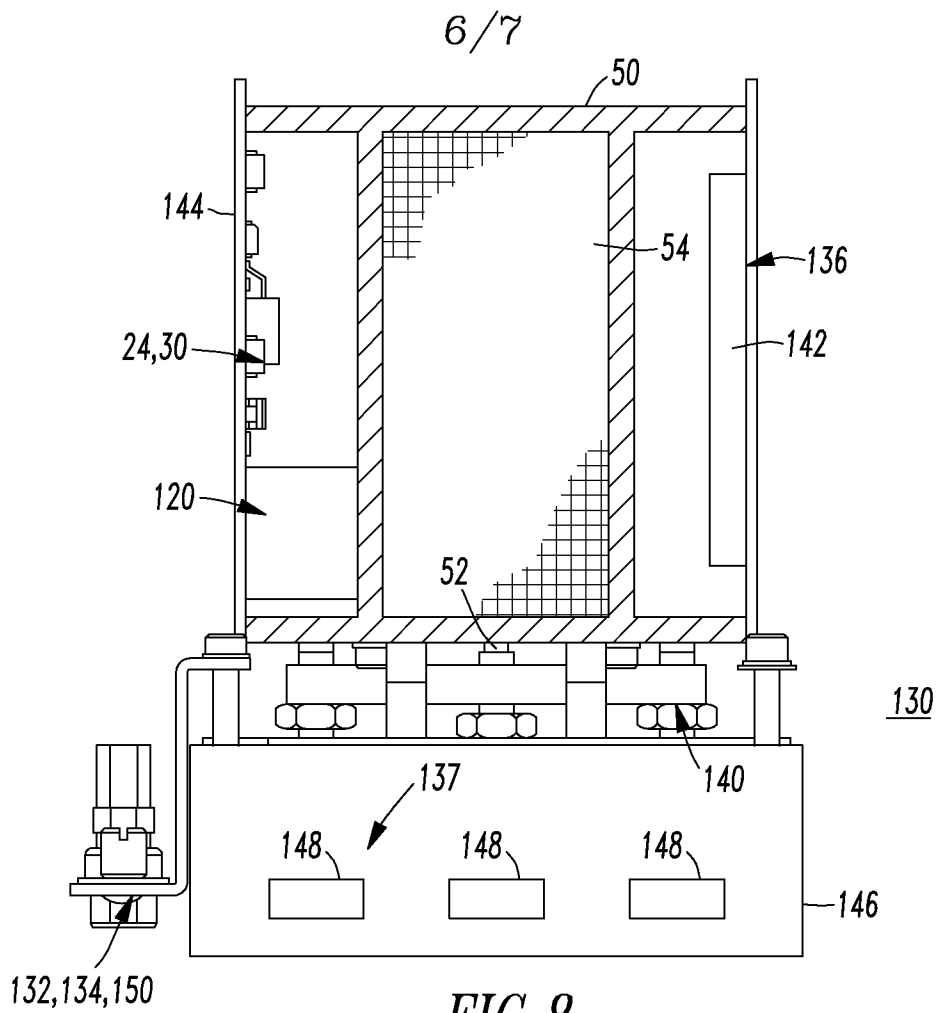


FIG. 7



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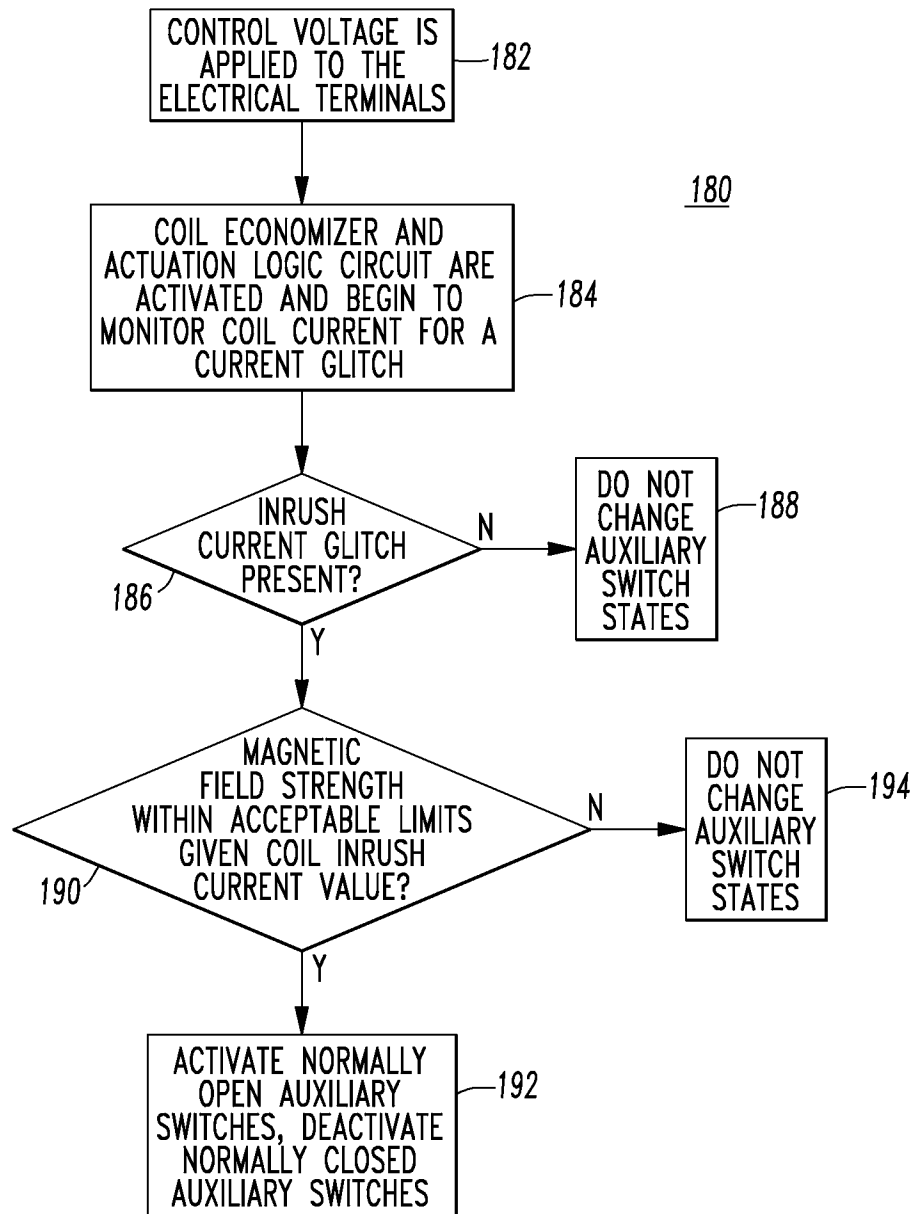


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 10/26992

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G05B 11/01 (2010.01)

USPC - 700/13

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

USPC: 700/13

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 700/11; 335/2; 335/147 (keyword limited - see search terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PubWEST (PGPB, USPT, USOC, EPAB, JPAB); GOOGLE; Google Scholar

Terms: contractor, switching, system, apparatus, coil, magnetic, field, sensed, circuit, auxiliary, switch, current, plunger.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2004/0252421 A1 (Knox et al.) 16 December 2004 (16.12.2004), entire document, especially abstract, para [0023], [0101], [0102], [0123], [0129].	1-20
Y	US 6,061,217 A (Grunert et al.) 09 May 2000 (09.05.2000), entire document, especially abstract, col. 1, ln 23 to col. 2, ln 16, col. 3, ln 66 to col. 4, ln 13, col. 4, ln 23 to col. 5, ln 8, col. 5, ln 19-29, col. 5, ln 45-56, col. 5, ln 66 to col. 6, ln 22, col. 7, ln 34-62.	1-20
A	US 2007/0247091 A1 (Maiocchi) 25 October 2007 (25.10.2007), entire document, especially abstract, para [0011], [0051], [0052], [0053].	1-20

☐ Further documents are listed in the continuation of Box C.

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

19 April 2010 (19.04.2010)

Date of mailing of the international search report

04 MAY 2010

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