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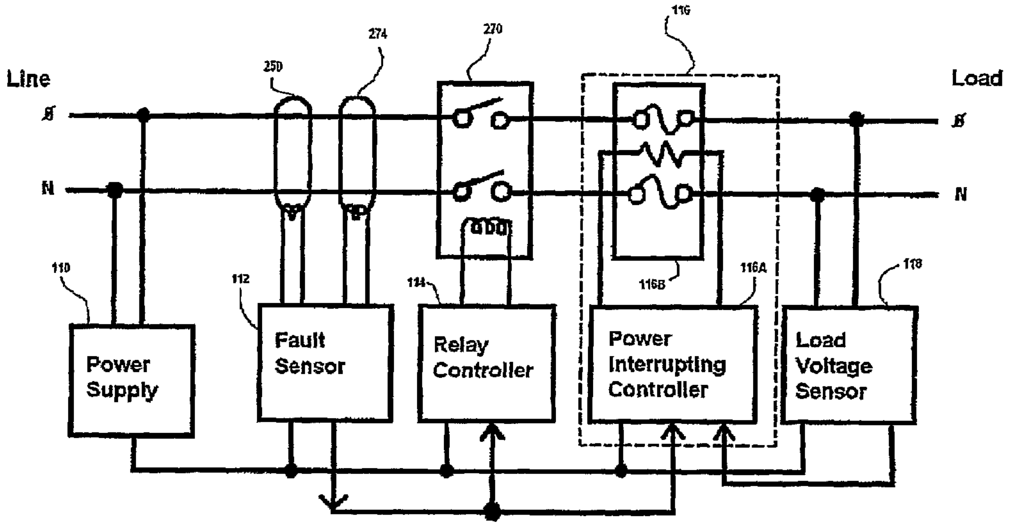

(57) Abstract: Resettable circuit interrupting devices having self-test and non-resettable or limited resettable power interrupting systems are provided. The permanent power interrupting system activates when a circuit interrupting device is no longer capable of operating in accordance with applicable standards governing such devices or the device is no longer capable of operating in accordance with its design characteristics.

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CIRCUIT INTERRUPTING DEVICE WITH AUTOMATIC TEST

BACKGROUND

1. Field

The present application is directed to resettable circuit interrupting devices including without limitation ground fault circuit interrupters (GFCI's), arc fault circuit interrupters (AFCI's), immersion detection circuit interrupters (IDCI's), appliance leakage circuit interrupters (ALCI's), equipment leakage circuit interrupters (ELCI's), circuit breakers, contactors, latching relays and solenoid mechanisms.

2. Description of the Related Art

Many electrical wiring devices have a line side, which is connectable to an electrical power supply, and a load side, which is connectable to one or more loads and at least one conductive path between the line and load sides. Electrical connections to wires supplying electrical power or wires conducting electricity to the one or more loads are at line side and load side connections respectively. The electrical wiring device industry has witnessed an increasing call for circuit breaking devices or systems which are designed to interrupt power to various loads, such as household appliances, consumer electrical products and circuits or systems branching from the device. In particular, electrical codes require electrical circuits in home bathrooms and kitchens to be equipped with ground fault circuit interrupters (GFCI), for example. Presently available GFCI devices, such as the device described in commonly owned U.S. Pat. No. 4,595,894, which is incorporated herein in its entirety by reference, use an electrically activated trip mechanism to mechanically break an electrical connection between the line side and the load side. Such devices are resettable after they are tripped by, for example, the detection of a ground fault. In the device discussed in the '894 patent, the trip mechanism used to cause the mechanical breaking of the circuit (i.e., the conductive path between the line and load sides) includes a solenoid (or trip coil). A test button is used to test the trip mechanism and circuitry used to sense faults, and a reset button is used to reset the electrical connection between line and load sides.

Over the years circuit interrupting devices have evolved to include circuit interrupting devices with a reset lock-out function intended to prohibit devices with, for example, an inoperable circuit interrupting portion (i.e., fault sensing circuit and trip mechanism), an open neutral condition, or a reverse wiring condition, from being reset. Commonly owned U.S. Pat. No. 6,040,967, (hereinafter " the "967 patent) which is incorporated herein in its entirety by reference, describes a family of resettable circuit interrupting devices capable of locking out the reset portion of the device if the circuit interrupting portion (referred to as the "circuit interrupter in the '967 patent) is non-operational or if an open neutral condition exists. Commonly owned U.S. Pat. No. 6,246,558, which is incorporated herein in its entirety by reference, describes a family of resettable circuit interrupting devices capable of locking out the reset portion of the device if a reverse wiring condition exists.

While most, if not all, existing circuit interrupting devices meet existing standards governing electrical fault protection devices, there are indications that next generation standards may require circuit interrupting devices capable of permanently interrupting the power supplied to the load side of the device in the event the device is no longer capable of operating according to applicable standards. Further, next generation standards may require automatic testing of the trip mechanism of the device and permanently interrupting the power supplied to the load side of the device in the event the device is no longer capable of operating according to applicable standards.

SUMMARY

The present disclosure relates to resettable circuit interrupting devices having self-test and permanent power interrupting systems. The permanent power interrupting system is activated when a circuit interrupting device experiences a device malfunction. The device malfunction refers to circumstances and/or conditions where the circuit interrupting device of the present invention is unable to operate in accordance with applicable standards governing the device and/or is unable to operate in accordance with its design characteristics.

In one embodiment the circuit interrupting devices includes a phase conductive path and a neutral conductive path each conductive path having a line side and a load side. A fault sensor is provided to monitor the phase and neutral conductive paths for a fault condition and said fault sensor outputs a condition signal in the event a fault condition is detected. Thus, the condition signal indicates that a fault condition has been detected. The fault condition can be a ground fault, an arc fault, an appliance leakage fault, an immersion fault or the results of a test of some or all of the circuit interrupting portion. A relay controller coupled to a relay is provided and said relay controller is configured to receive the condition signal. In this configuration, when the relay controller receives the condition signal the relay controller energizes the relay causing electrical discontinuity in the phase and neutral conductive paths between the line side and load side. A sensor is provided for monitoring the load side of the circuit interrupting device. For example, a load voltage sensor can be provided to measure the voltage between the phase and neutral conductive paths at the load side and to output a voltage signal in response to the measured voltage; this measured voltage signal is generally referred to as a monitoring signal. The power interrupting system is provided to cause permanent or non-resettable electrical discontinuity in the conductive paths in response to the detection of a device malfunction. In general, the device malfunction is detected based upon the condition signal and the monitoring signal. Examples of device malfunctions include the improper operation of all or a part of the fault sensing circuitry, improper operation of all or a part of the mechanical components of the circuit interrupting device, e.g, a faulty solenoid or fused contacts, or the improper operation of all or a part of the support circuitry for the circuit interrupting device, e.g., the self-test system or controllers.

The power interrupting system includes a power interrupting controller and a power interrupter capable of causing the permanent electrical discontinuity in the phase and neutral conductive paths between the line side and load side. Preferably, the power interrupter includes a fuse assembly (e.g., at least one fusible link) thermally coupled to a heater assembly (e.g., at least one heating element). The power interrupting controller may be a switching network, or a combination of a switching network and condition test logic circuitry (or a microcontroller or microprocessor) capable of receiving inputs from a plurality of sensors, processing said inputs and activating the switching network in response to the inputs from the plurality of sensors.

The circuit interrupting device may further include a self-test system capable of automatically inducing a fault condition into the fault sensor or inducing conditions that typically result when a fault occurs (e.g., a current imbalance between phase and neutral conductors when a ground fault occurs).

In an alternative embodiment, the circuit interrupting device includes a housing, and a phase conductive path and a neutral conductive path each disposed at least partially within the housing between a line side and a load side. Preferably, the phase conductive path terminates at a first connection capable of being electrically connected to a source of electricity, a second connection capable of conducting electricity to at least one load and a third connection capable of conducting electricity to at least one user accessible load. Similarly, the neutral conductive path terminates at a first connection capable of being electrically connected to a source of electricity, a second connection capable of providing a neutral connection to the at least one load and a third connection capable of providing a neutral connection to the at least one user accessible load. The device also includes a circuit interrupting portion disposed within the housing and configured to cause electrical discontinuity in the phase and neutral conductive paths between the line side and the load side upon the occurrence of a fault condition. The fault condition can be a ground fault, an arc fault, an appliance leakage fault, an immersion fault or the result of a test of a part of or all of the circuit interrupting portion. A power interrupting system is also disposed within the housing and configured to cause permanent or non-resettable electrical discontinuity in the phase and neutral conductive paths between the line side and the load side upon the occurrence of a device malfunction.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present application are described herein with reference to the drawings in which similar elements are given similar reference characters, wherein:

FIG. 1 is a perspective view of a circuit interrupting device (implemented as a GFCI) constructed in accordance with the present invention;

FIG. 2 is a schematic representation of one embodiment of the circuit interrupting device of the present invention having a power interrupting system and an optional automatic self-test system;

FIG. 3 is a schematic representation of one embodiment of a fault sensor and relay controller for detecting ground faults and resetting the device of Fig. 2;

FIG. 3A is a schematic representation of FIG. 3 with a self test system;

FIG. 4 is a schematic representation of one embodiment of a power interrupting system for disconnecting power to the load side of the GFCI device of Fig. 2;

FIG. 4A is a schematic representation of an alternative embodiment of a power interrupting system for disconnecting power to the load side of the GFCI device of Fig. 2;

FIG. 5 is a schematic representation of yet another alternative embodiment of a power interrupting system for disconnecting power to the load side of the device of Fig. 2;

FIG. 5A is a schematic representation of a further alternative embodiment of a power interrupting system for disconnecting power to the load side of the device of Fig. 2;

FIG. 6 is a schematic representation of a further alternative embodiment of a power interrupting system for disconnecting power to the load side of the device of Fig. 2;

FIG. 7 is a schematic representation of a further alternative embodiment of a power interrupting system for disconnecting power to the load side of the device of Fig. 2;

FIG. 8 is a schematic representation of an embodiment of a circuit interrupting device with a power interrupting system and an optional automatic self-test feature;

FIG. 9 is a schematic representation of yet another embodiment of a circuit interrupting device with a power interrupting system and an optional automatic self-test system;

FIG. 10 is an exemplary flow diagram for the operation of the different exemplary embodiments of the power interrupting system controllers.

DETAILED DESCRIPTION OF EMBODIMENTS

The present disclosure contemplates various types of circuit interrupting devices that are capable of breaking at least one conductive path at both a line side and a load side of the device. The conductive path typically has at least a first end (i.e., the line side) that connects to a source of electrical power and at least a second end (i.e., the load side) that connects to one or more loads. As noted, the various devices in the family of resettable circuit interrupting devices include: ground fault circuit interrupters (GFCI's), arc fault circuit interrupters (AFCI's), immersion detection circuit interrupters (IDCI's), appliance leakage circuit interrupters (ALCI's) and equipment leakage circuit interrupters (ELCI's).

For the purpose of the present disclosure, the structure, mechanisms or systems used in the circuit interrupting devices, shown in the drawings and described hereinbelow, are incorporated into a GFCI receptacle suitable for installation in a single-gang junction box used in, for example, a residential electrical wiring system. However, the mechanisms and systems according to the present disclosure can be included in any of the various devices in the family of resettable circuit interrupting devices.

The GFCI receptacles described herein have line, load and user accessible phase connections, line, load and user accessible neutral connections. The load and user accessible connections permit external conductors or appliances to be connected to the device and the line connections permit electrical connection to a source of electricity; these connections may be implemented, for example, with electrical fastening devices that secure or connect external conductors to the circuit interrupting device, as well as conduct electricity. Examples of such connections include binding screws, lugs, terminals and external plug connections.

The circuit interrupting and reset portions described herein preferably use electro-mechanical components to break (open) and make (close) one or more conductive paths between the line and load sides of the device. However, electrical components, such as solid state switches, semiconductor components, integrated circuits and other supporting circuitry, may be used to open and close the conductive paths.

Generally, the circuit interrupting portion is used to automatically break electrical continuity in one or more conductive paths (i.e., open the conductive path) between the line and load sides upon the detection of a fault, which in the particular embodiments described is a ground fault. The reset portion is used to close the open conductive paths. In the embodiments including a reset lockout, the reset portion is used to close the open conductive paths when allowed by the reset lockout. In this configuration, the operation of the reset and reset lockout portions is in conjunction with the operation of all or part of the circuit interrupting portion, so that electrical continuity in open conductive paths cannot be reset if all or part of the circuit interrupting portion is non-operational, if an open neutral condition exists and/or if the device is reverse wired. It should be noted that the disclosure is not limited to embodiments where all of the circuit interrupting portion is activated by depressing the reset button for devices with the reset lockout feature. That is, all or a part of the circuit interrupting portion can be activated when the reset button is depressed and the reset lockout will prevent the device from being reset if the activated portion is not operating properly. Therefore, the present disclosure also contemplates embodiments where a portion of the circuit interrupting portion is used in conjunction with the reset or reset lockout portions.

In an alternative embodiment, the circuit interrupting devices may also include a trip portion that operates independently of the circuit interrupting portion so that in the event the circuit interrupting portion becomes non-operational the device can still be tripped. Preferably, the trip portion is manually activated and uses mechanical components to break one or more conductive paths. However, the trip portion may use electrical circuitry and/or electro-mechanical components to break either the phase or neutral conductive path or both paths.

The above-described features can be incorporated in any resettable circuit interrupting device, but for simplicity the descriptions herein are directed to GFCI receptacles. A more detailed description of a GFCI receptacle is provided in U.S. Pat. Nos. 4,595,894; 6,437,700; 6,040967 and 6,246,558 which are incorporated herein in their entirety by reference.

It should also be noted that binding screws are exemplary of the types of wiring terminals that can be used to provide the electrical connections. Examples of other types of wiring terminals include set screws, pressure clamps, pressure plates, push-in type connections, pigtails and quick-connect tabs.

Turning now to FIG. 1, the exemplary GFCI device 10 shown is a GFCI receptacle having a housing 12 consisting of a relatively central body 14 to which a face or cover portion 16 and a rear portion 18 are removably secured. The face portion 16 has entry ports 20 for receiving normal or polarized prongs of a male plug of the type normally found at the end of a cord for an appliance (e.g., a lamp), as well as ground-prong-receiving openings 22 to accommodate a three-prong plug. The receptacle also includes a mounting strap 24 used to fasten the receptacle to a junction box.

A reset button 30 forming a part of a reset mechanism extends through opening 32 in the face portion 16 of the housing 12. The reset button is used to reestablish electrical continuity between the input and output conductive paths or conductors. A test button 26 extends through opening 28 in the face portion 16 of the housing 12. The test button is used to manually activate a test cycle, which test the operation of all or part of a circuit interrupting portion of the device.

Electrical connections to existing household electrical wiring are made via binding screws 34 and 36, where screw 34 is an input (or line) connection point and screw 36 is an output (or load) connection point. It should be noted that two additional binding screws (not shown) are located on the opposite side of the receptacle 10. Similar to binding screws 34 and 36, these additional binding screws provide input and output connection points. Further, the input connections are for line side phase (hot) and neutral conductors of the household wiring, and the output connections are for load side phase (hot) and neutral conductors of the household wiring. The plug connections are also considered output conductors. The circuit interrupting portion, to be described in more detail below, is used to break electrical continuity between input (line) and output (load) conductive paths (or conductors).

Referring to FIG. 2, a block diagram of the electrical components of a GFCI device with a circuit interrupting system and optional automatic self-test system is shown. In this embodiment, the device includes a power supply 110 connected to the line side phase and neutral conductors, that utilizes known techniques to convert AC line voltage to DC power suitable for supplying power to the fault sensor 112, relay controller 114, power interrupting controller 116A and load voltage sensor 118. It should be noted that the fault sensor 112, relay controller 114 and relay 270 are associated with the circuit interrupting portion of the device.

In one embodiment, the fault sensor 112 utilizes a pair of differential transformers 250 and 274 that monitors the AC phase and neutral conductors for ground fault conditions and generates control signals to relay controller 114 and to power interrupting controller 116 in the event a ground fault condition is detected or a self-test cycle is performed. For example, if a ground fault condition is detected by fault sensor 112, a signal is sent to relay controller 114 causing the controller 114 to energize relay 270 thus opening the conduction path (causing electrical discontinuity) between the line side and load side phase and neutral conductors.

One implementation of the fault sensor 112, relay controller 114 and relay 270 is shown in FIG. 3. However, other implementations of the fault sensor, relay controller and relay are also contemplated. Referring to FIG. 3, a schematic representation of conventional circuitry for the fault sensor 112 used to detect fault conditions, here ground faults, and relay controller 114 and relay 270 are used to open the phase and neutral conductive paths in the event a ground fault is detected. Typically, the fault sensor uses a differential transformer and neutral transformer to sense ground faults and energize a relay that disconnects power to the load side in the event a ground fault is detected. The circuit of FIG. 3 is for single phase applications with 120 volts line to ground, is exemplary of a fault sensor 112 and relay controller 114, and operates in the following manner:

For phase to neutral fault detection, differential transformer 250 monitors the flow of current in the line side phase and neutral conductors, 252 and 254, respectively, and produces in its secondary winding a fault or condition signal when the current flowing in the phase conductor (or conductors) 252 does not equal the current flowing in the neutral conductor 254. The output from the secondary of differential transformer 250 (i.e., the condition signal) is conveyed to integrated circuit 256 through diode 258, capacitors 260, 262 and 264, and resistor 266. Integrated circuit 256 may be a type LM 1851 Ground Fault Interrupter manufactured by National Semiconductor Corporation. Diode 258 and resistor 266 are arranged so as to promote quick discharge of capacitor 260. This discharge of capacitor 260 allows integrated circuit 256 to be kept continuously energized and thus considerably reduces the time required for detection of a fault. Continuous energization of integrated circuit 256 from the line side is made possible by capacitor 268 which is attached to output pin 7 of integrated circuit 256, which basically controls the trip circuit while minimizing burnout of the trip coil 270.

For neutral to ground fault detection (otherwise referred to as a ground neutral condition), the fault sensor 112 functions similarly to the phase to neutral fault detection described above. Transformer 274 (together with differential transformer 250) form part of an induction coil that has a signal induced on its secondary windings that is carried through capacitors 276 and 278 to input pin 4 of integrated circuit 256. This induced signal is another type of a condition signal indicating to integrated circuit 256 that a ground neutral condition has been detected and that the device should be tripped. Thus, at least two types of ground faults can be detected by the circuit diagram shown in FIG. 3: phase to neutral fault and a neutral to ground fault.

The trip circuit for both types of faults is identical in that if a fault (ground fault or ground neutral condition) is detected by the input pins 2, 3, and 4 of IC 256, a signal is output from pin 7 of integrated circuit 256 causing capacitor 268 to charge. The signal from pin 7 of integrated circuit 256 is applied to the gate of SCR 272 causing said SCR to conduct causing current to flow through coil 270 thus energizing coil 270. Coil 270 is part of a relay which includes a plunger (not shown) and when coil 270 is energized, the plunger is caused to move to engage movable arms to disconnect the line (phase and neutral) conductors from the load (phase and neutral) conductors. In particular, upon energization of coil 270, contacts 300 and 302 of the ground fault circuit interrupter are opened which in turn disconnects power to the load side phase and neutral conductors 304 and 306.

The fault sensor 112 may include a push-button 308 and resistor 310 as part of a self-test system that induces a ground fault condition (i.e., a current imbalance is caused) onto the line side conductors for detection by the fault sensor 112. Alternatively or in addition to push button 308, a self-test system 309 (seen in FIG. 3A) can be incorporated into the fault sensor 112. The self test system uses TEST button 308 for manual activation of the self test. However, the self-test system 309 is preferably configured to periodically output a test signal through resistor 310 to induce a ground fault condition onto the line side conductors for detection by the fault sensor 112, thus permitting automatic testing of all or part of the circuit interrupting portion. The self-test system may be a clocking circuit configured to output a test signal, for example, once a day, once a week, or once a month. When all or part of the fault sensor circuitry is tested the device is typically set in a tripped state. As a result, the device would need to be reset. The device can then be manually reset using the reset button, or and automatic reset operation could be performed where a reset signal is generated causing the line and load side connections to be reestablished. Since the timing of the self-test may be inconvenient, i.e., when the device is in use, it may be desirable to have the self-test system send a signal to the relay controller 114 to cause the relay 124 to close immediately after it has been opened by the detection of the simulated fault induced by the self-test system. If a self-test is activated when, for example, the device is in use, it is preferable that the self-test cycle and reset time is fast enough so that a human would not notice the brief disruption of power provided to the load. That is, the time between the energizing of the relay 270 to open the conductive paths between line and load phase and neutral conductors and the time the relay closes the conductive paths between line and load phase and neutral conductors is sufficiently small that the disruption in power provided to any load is not significant (i.e., will not adversely affect the operation of the connected load) or detectable by a human.

It should be noted that in the event the circuit interrupting device is a reset lock-out type circuit interrupting device, resetting of the device is prevented if all or any portion of the circuit interrupting portion (i.e., fault sensor 112, differential transformers 250 and 274, relay controller 114 and relay 270) is not functioning properly, or if all or any portion of the relay controller or relay are not functioning properly, or if both the fault sensor and relay controller and relay are not functioning properly. Examples of reset lockout type circuit interrupting devices are described in commonly owned US Patent Nos. 6,040,967; 6,381,112; 6,657,834 and 6,671,145 each of which is incorporated herein in its entirety by reference.

Referring again to FIG. 2, the circuit interrupting device according to the present disclosure may include a power interrupting system 116 capable of causing permanent electrical discontinuity in the conductive paths (i.e., opening the conductive paths) between the line side phase and neutral conductors and the load side phase and neutral conductors in the event one or more device malfunctions exist. The power interrupting system 116 includes a controller 116A and a power interrupter 116B. In the embodiment of FIG. 2, the controller 116A receives signals from the fault sensor 112 and load voltage sensor 118 and uses logic circuitry to determine whether or not one or more device malfunctions exist. In the event one or more device malfunctions is detected the power interrupter 116B is activated by controller 116A to cause all or a part of the power interrupting system to become disabled and thus cause non-resettable electrical discontinuity in the phase and neutral conductive paths preventing power distribution to the load side of the circuit interrupting device 10.

The power interrupting system 116 will be described with reference to the various exemplary embodiments depicted in FIGS. 4-7. In the embodiment of FIG. 4 , the power interrupting controller 116A includes condition testing logic circuit 400 capable of receiving inputs from either the fault sensor 112, the load voltage sensor 118 (seen in FIG. 2) or both. For example, the gate input of SCR 272 (seen in FIG. 3 and shown as originating from pin 7 of IC 256) on which the trip signal is received and is used to energize relay 270 could be inputted to the condition test logic circuit 400. The output of the condition testing logic is transferred to switching assembly 401 including transistor 402, biasing resistors 404 and 406 and rectifying diode 408. Here the output of the condition testing logic is transferred to the base of transistor 402. If the gate input of SCR 272 is used as the input to the condition test logic circuit 400, and the SCR is activated beyond its design time period, which may be indicative of a device malfunction, the power interrupter 116B may be sufficiently activated to cause all or a part of the power interrupter to become disabled, thus causing non-resettable electrical discontinuity in the phase and neutral conductive paths and preventing power distribution to the load side of the circuit interrupting device 10. It should be noted that an SCR or Triac could be used for the switching assembly 401 as shown in FIG. 5.

Continuing with FIG. 4, the power interrupter 116B includes a fuse assembly, e.g., thermal fusible links 410 and 412, connected in series with the phase and neutral conductive paths as shown, and heater assembly 414 thermally coupled to the fuse assembly. In this configuration, when energy is supplied to the heater assembly heat is transferred to the fuse assembly, here the fusible links. When sufficient heat energy is transferred to the fuse assembly to cause the fuse assembly to open, non-resettable or limited resettable electrical discontinuity in the phase and neutral conductive paths occurs. As a result, power to the load side of the circuit interrupting device is removed.

The fusible links could be, for example, lengths solder or other material that when heated to a certain temperature open or otherwise break the respective conductive path. The fusible links may also include thermal fuses, thermally activated switches, a muscle wire formed of, for example, a material described in Appendix A (attached to this application and which is incorporated herein by reference) and other thermally responsive devices and/or materials capable of changing their shape, length or overall structure when subjected to a certain amount of heat. It should be noted that in instances where a thermally responsive material is used as the fusible link having characteristics of breaking the conductive paths when heated and reestablishing the conductive paths when cooled, the electrical discontinuity in the conductive path is a limited resettable electrical discontinuity. It should also be noted that non-thermal fusible links are also contemplated by the present disclosure.

Further, thermally responsive materials can be incorporated in a circuit interrupting device and more particularly interfaced with the circuit interrupting portion of a circuit interrupting device (activated with a TEST button) or interfaced with the reset mechanism of the circuit interrupting device (activated with a RESET button) —for circuit interrupting devices having the reset lockout feature or for devices that do not have the reset lockout feature. As shown in Appendix B attached to this application and which is incorporated herein by reference, a material such as Flexinol (shape memory alloy) can be coupled to the reset mechanism (including a reset button) of a circuit interrupting device shown in FIG. 1 (such a device is disclosed in an application titled Circuit Interrupting Device and System Utilizing Bridge Contact having serial no. 10/690,776, which is incorporated herein by reference) so that the expansion or contraction of these materials when subjected to a threshold amount of heat will change their shape accordingly to interact with the TRIP button causing the circuit interrupting device to trip or interact with the reset button causing the circuit interrupting device to reset which automatically tests all or part of the circuit interrupting portion when the circuit interrupting device has the reset lockout feature.

The heater assembly 414 could include the solenoid (e.g., trip coil 270) provided with conventional circuit interrupting devices and used to open and close the conductive paths that perform the circuit interrupting operation of the device. If the solenoid is used as the heater assembly 414, sufficient heat is generated when the solenoid is activated for a period of time that exceeds the normal time needed to trip the circuit interrupting device. Alternatively, the heater assembly 414 may be a heating element, e.g. a resistor.

On embodiment is to connect a heating element such as a resistor in parallel with the solenoid. This heater would act on an expanding or contracting material in such a manner that the time required to cause a reaction is greater than the maximum allowable trip time of the circuit interrupting device. The expansion and/or contraction would be able to permanently disable the device when such expanding material is engaged or coupled to at least a portion of the circuit interrupting portion.

Thermal coupling of the heater assembly to the fuse assembly could be achieved by, for example, wrapping solder lengths (the fuse assembly) around one or more resistors acting as the heater assembly 414.

In operation, when the output signal from the condition testing logic 400 is sufficient to turn on transistor 402 current will flow through the heater assembly heating the fusible links until they open the respective conductive path. If the fusible links are solder lengths, the solder would melt when heated thus permanently opening the respective conductive path. As noted above, if a thermal responsive material is used as the fusible link having characteristics where when heated a break in a conductive path occurs and when cooled the conductive path is again made, the electrical discontinuity in the conductive path is a limited resettable electrical discontinuity.

In the embodiment of FIG. 5, the power interrupting controller 116A includes condition testing logic 400 capable of receiving inputs from either the fault sensor 112, or load voltage sensor 118 (seen in FIG. 2) or both. The output of the condition testing logic is transferred to switch assembly 401 that includes triacs 420 and 422. The power interrupter 116B includes a fuse assembly, e.g., thermal fusible links 410 and 412, connected in series with the phase and neutral conductive paths as shown, and heater assembly 414 thermally coupled to the fuse assembly. In this configuration, when sufficient energy is supplied to the heater assembly the fuse assembly, here the fusible links, opens thus causing permanent electrical discontinuity in the phase and neutral conductive paths. As a result, power to the load side of the circuit interrupting device is removed. The fusible links can be similar to those described above. In this embodiment, the heater assembly includes two heating elements 416 and 418, e.g. resistors, where one heating element heats fusible link 410 and the other heats fusible link 412.

FIGS. 4A and 5A are similar to FIGS. 4 and 5 respectively, except that the signal supplied to the switch assembly, i.e., power interrupter and/or power interrupting controller comes from an external source, e.g., a controller or supervisory circuit instead of a logic circuit.

The embodiment of FIG. 6 is similar to the embodiment of FIG. 4, except that microcontroller 430 provides the signal to the power interrupting controller 116A to cause the power interrupter 116B to open the conductive paths as described above. In this embodiment, the microcontroller 430 can be used to initiate a self-test of the circuit interrupting device operation and in the event a device malfunction is detected by the microcontroller 430 switch assembly is activated causing the heater assembly to activate the fuse assembly to open the conductive paths. FIG. 7 is similar to FIG. 5 except that the switching assembly includes brownout protection. In this embodiment of controller 116A, microcontroller 430 provides an output signal to transistor Q1 via capacitor C1 and resistor R1. Transistor Q1, which controls when transistor Q4 can turn on, is provided to hold the voltage across capacitor C2 to about zero volts and is briefly turned on by the output signal from microcontroller 430. If the output of the microcontroller 430 is left floating, or a short time after the output of the microcontroller is driven high or low, resistor R1 quickly bleeds capacitor C1 thereby turning off transistor Q1. When transistor Q1 is off, transistor Q4 can turn on when the voltage on the phase conductive path overcomes the zener voltage of zener diode Z2, the diode drop across diode D2, and voltage across resistor divider R4/(R2+R3+R4). With transistor Q1 off, voltage on the phase conductive path is free to charge capacitor C2 to the point where transistor Q4 turns on and energize heater assembly 414. Energizing the heater assembly takes place by current flowing from the phase conductive path through the heater assembly 414, through diode D4 and transistor Q4 to the neutral conductive path. Such current flow occurs on positive half-cycles due to diode D4 and when transistor Q4 is turned on. Heater assembly 414 then begins to transfer heat energy to the fusible links 410 and 412, and in the event the heat energy transferred to the fusible links reaches the melting point of the fusible link, then fusible links will break causing electrical discontinuity in the conductive paths.

Referring now to FIG 8 an alternative embodiment of the circuit interrupting device is shown. In this embodiment, microcontroller 440 is connected to fault sensor 112, relay controller 114 and power interrupting system 116 and is provided to perform a self-test of the fault sensor, relay controller and power interrupting system and determine if one or more device malfunctions exist and then activate the power interrupting system 116 to open the conductive paths as described above.

Referring to FIG. 9, another alternative embodiment of the circuit interrupting device is shown. In this embodiment, microcontroller 450 is connected to fault sensor 112, fault inducer 452, relay controller 114, power interrupting system 116 and load voltage sensor 118, and is provided to cause the fault inducer 452 to initiate a self-test of the fault sensor, relay controller, relay and power interrupting system and determine if one or more device malfunctions exist and then activate the power interrupting system to open the conductive paths as described above.

FIG. 10 provides an exemplary flow diagram for the operation of the microcontroller 440 or 450.

As noted, although the components used during circuit interrupting and some device reset operations are electro-mechanical in nature, the present application also contemplates using electrical components, such as solid state switches and supporting circuitry, as well as other types of components capable or making and breaking electrical continuity in the conductive path.

While there have been shown and described and pointed out the fundamental features of the application, it will be understood that various omissions and substitutions and changes of the form and details of the device described and illustrated and in its operation may be made by those skilled in the art, without departing from the spirit of the application.

Appendix A

THE SHAPE MEMORY EFFECT • Phenomenon, Alloys and Applications

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Introduction

Certain metallic materials will, after an apparent plastic deformation, return to their original shape when heated. The same materials, in a certain temperature range, can be strained up to approx. 10% and still will return to their original shape when unloaded. These unusual effects are called thermal shape memory and superelasticity (elastic shape memory) respectively [1]. Both effects depend on the occurrence of a specific type of phase change known as thermoelastic martensitic transformation. Shape memory and superelastic alloys respond to temperature changes and mechanical stresses in non-conventional and highly amazing ways. They are, therefore, sometimes called "smart materials". The shape memory effect can be used to generate motion and/or force, while superelasticity allows energy storage. Both effects have fascinated scientists and engineers for almost three decades, drawing them to conferences and seminars in great numbers. However, very few developments made it to the market, and can be considered economic successes. Recent successes come mainly from medical applications utilizing the superelasticity and biocompatibility of Ni-Ti alloys.

Shape Memory Effect

"Shape Memory" describes the effect of restoring the original shape of a plastically deformed sample by heating it. This phenomenon results from a crystalline phase change known as "thermoelastic martensitic transformation". At temperatures below the transformation temperature, shape memory alloys are martensitic. In this condition, their microstructure is characterized by "self-accommodating twins". The martensite is soft and can be deformed quite easily by de-twinning. Heating above the transformation temperature recovers the original shape and converts the material to its high strength, austenitic, condition (Fig. 1).

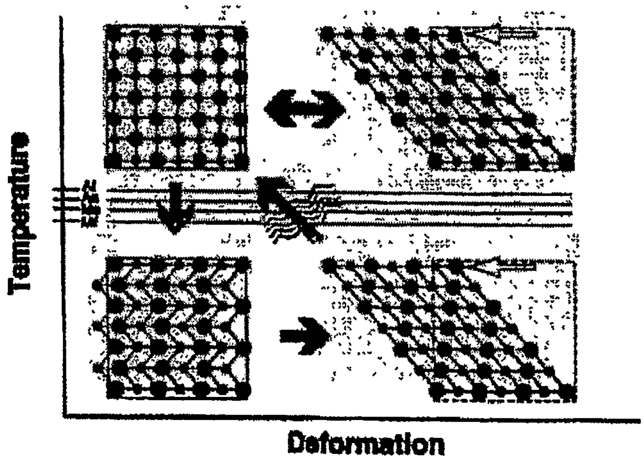

Fig. 1: Schematic representation of the shape memory effect and superelasticity

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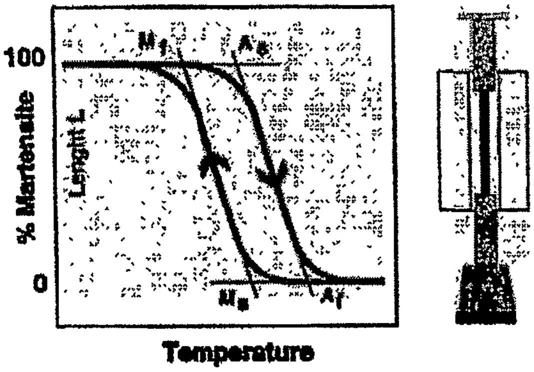
The transformation from austenite to martensite and the reverse transformation from martensite to austenite do not take place at the same temperature. A plot of the volume fraction of martensite, or more practically, the length of a wire loaded with a constant weight, as a function of temperature provides a curve of the type shown schematically in Figure 2. The complete transformation cycle is characterized by the following temperatures: austenite start temperature (As), austenite finish temperature (Af), martensite start temperature (Ms) and martensite finish temperature (Mf).

If a stress is applied to a shape memory alloy in the temperature range between Af and a maximum temperature Md, martensite can be stress-induced. Less energy is needed to stress-induce and deform martensite than to deform the austenite by conventional mechanisms. Up to 10% strain can be accommodated by this process (single crystals of specific alloys can show as much as 25% pseudoelastic strain in certain directions). As austenite is the thermodynamically stable phase at this temperature under no-load conditions, the material springs back into its original shape when the stress is no longer applied. This extraordinary elasticity is also called pseudoelasticity or transformational superelasticity.

It becomes increasingly difficult to stress-induce martensite at increasing temperatures above Af. Eventually, it is easier to deform the material by conventional mechanisms than by inducing and deforming martensite. The temperature at which martensite is no longer stress-induced is called Md. Above Md, the alloys are deformed like ordinary materials. Thus, superelasticity is only observed over a narrow temperature range.



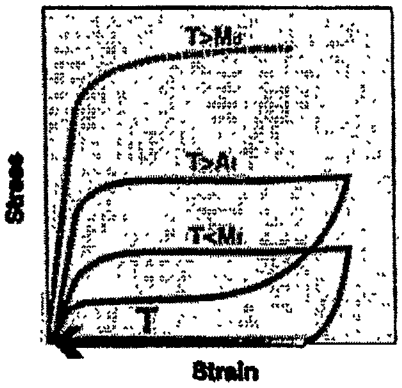


Fig. 2 (left): Schematic representation of the hysteresis loop
Fig. 3 (right): Stress/strain curves at different temperatures

The design of shape memory components, e.g. fasteners or actuators, is based on the distinctly different stress/strain curves of the martensite and austenite, and their temperature dependence. Figure 3 shows tensile curves of a Ni-Ti alloy at various temperatures. While the austenitic curve (T>Md) looks like that of a "normal" material, the martensitic one (T<Mf) is quite unusual. On exceeding a first yield point, several percent strain can be accumulated with only little stress increase. After that, stress increases rapidly with further deformation. The deformation in the "plateau region" can be recovered thermally. Deformation exceeding a second yield point cannot be recovered. The material is then plastically deformed in a conventional way. At temperatures T>Af, again, a plateau is observed upon loading. In this case, it is caused by stress induced martensite. Upon unloading, the material transforms back into austenite at a lower stress (unloading plateau). With increasing temperature, both loading and unloading plateau stress increase linearly [2].

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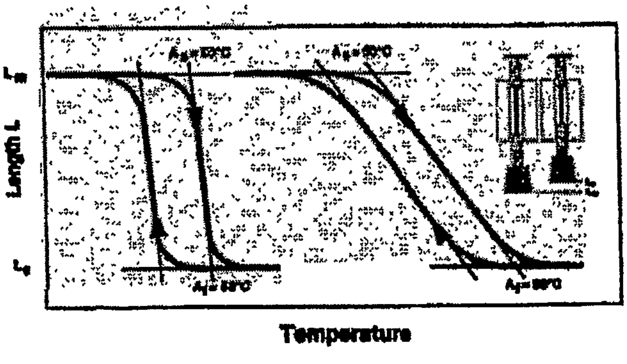
Appendix A

Shape Memory Alloys

The shape memory effect as the result of a martensitic transformation has been known since the mid 1950's, when the effect was discovered in copper base alloys. In the early sixties, researchers at the Naval Ordnance Laboratory found the shape memory effect in Ni-Ti alloys (Nitinol - Ni-Ti Naval Ordnance Lab). Today, these alloys are the most widely used shape memory and superelastic alloys, combining the most pronounced shape memory effect and superelasticity , corrosion resistance and biocompatibility, and superior engineering properties. Copper based alloys like Cu-Zn-Al and Cu-Al-Ni are commercially available, too. These alloys are less stable and more brittle than Ni-Ti, and therefore, although less expensive, have found only limited acceptance. In recent years, iron based shape memory alloys have been widely advertised. However, with their limited shape memory strain, lack of ductility and other essential properties, these alloys will have to prove themselves as viable engineering materials.

The transformation temperatures of shape memory alloys can be adjusted through changes in composition. Ni-Ti as well as Cu-Zn-Al alloys show transformation temperatures between -100°C and +100°C, Cu-Al-Ni alloys up to 200°C. Unfortunately, Cu-Al-Ni alloys are not stable in cyclic applications. Some ternary Ni-Ti-Pd [3], Ni-Ti-Hf and Ni-Ti-Zr [4] alloys also are reported to exhibit transformation temperatures over 200°C. Although not commercially available today, these alloys could eventually expand the applicability of the shape memory effect to much higher temperatures. In the following, only Ni-Ti alloys will be reviewed.

The hysteresis is an important characteristic of the heating and cooling behavior of shape memory alloys and products made from these alloys. Depending on the alloy used and/or its processing, the transformation temperature as well as the shape of the hysteresis loop can be altered in a wide range. Binary Ni-Ti alloys typically have transformation temperatures (Af) between 0°C and 100°C with a width of the hysteresis loop of 25°C to 40°C. Copper containing Ni-Ti alloys show a narrow hysteresis of 7°C to 15°C with transformation temperatures (Af) ranging from 10°C to approx. 80°C. An extremely narrow hysteresis of 0 to 5°C can be found in some binary and ternary Ni-Ti alloys exhibiting a premartensitic transformation (commonly called R-phase). On the other hand, a very wide hysteresis of over 150°C can be realized in Niobium containing Ni-Ti alloys after a particular thermomechanical treatment. Although low transformation temperatures (Af << 0°C) can be reached with binary Ni-Ti alloys, those alloys tend to be brittle and difficult to process. For cryogenic uses, therefore, Fe-containing Ni-Ti alloys are commonly used.



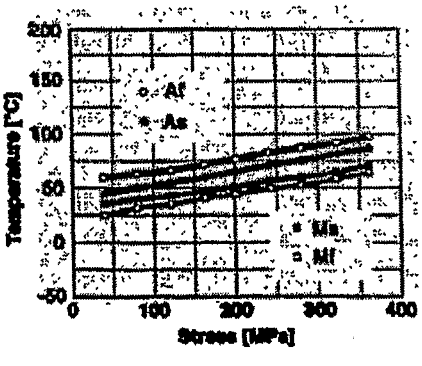


Fig. 4 (left): Influence of processing on the shape of the hysteresis loop (schematic)
Fig. 5 (right): Influence of applied stress on the transformation temperatures

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Appendix A

The standard thermomechanical processing of Ni-Ti alloys generates a steep hysteresis loop (i.e. greater shape change with a lesser change in temperature), which generally is desirable in applications where a certain function has to be performed upon reaching or exceeding a certain temperature. Special processing can yield a hysteresis loop with a more gradual slope, i.e. a small shape change with temperature. This behavior is preferred in applications where proportional control is required [5].

The shape of the hysteresis loop is not only alloy and processing dependent, but is also influenced by the application itself. If a wire (standard processing) works against a constant load, e.g. by lifting a certain weight, the transition from martensite to austenite or vice versa occurs in a very narrow temperature range (typically 5°C). However, if the wire works against a biasing spring, the transition is more gradual and depends on the rate of the spring.

Engineering Aspects

The shape memory effect can be used to generate motion and/or force, while superelasticity can store deformation energy. The function of the different events as shown the stress/strain perspective in Fig. 6 [6] can be explained in simple terms using the example of a straight tensile wire. The wire is fixed at one end. Stretching it at room temperature generates an elongation after unloading. The wire remains in the stretched condition until it is heated above the transformation temperature of this particular alloy. It will then shrink to its original length As no load is applied, this is called *free recovery*. Subsequent cooling below the transformation temperature does not cause a macroscopic shape change.

If, after stretching at room temperature, the wire is prevented from returning to its original length, i.e. if constrained to the extended length upon heating above the transformation temperature, it can generate a considerable force. This so-called *constrained recovery* is the basis of many successful applications [7].

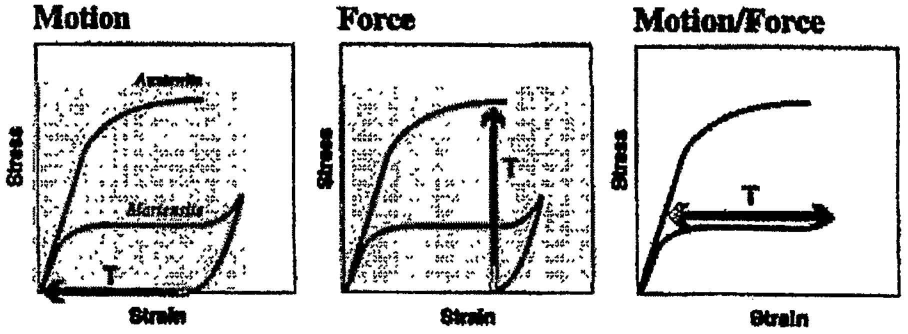

Fig. 6: Shape memory events in the stress/strain perspective [6]

If the opposing force can be overcome by the shape memory wire, it will generate motion against a force, and thus do work. Upon heating, the wire will contract and lift a load, for instance. Upon cooling, the same load will stretch the now martensitic wire and reset the mechanism. This effect is called *two-way-effect with external reset force* [8].

Depending on the kind of biasing mechanism, different force/displacement characteristics can be obtained [9]. In Figure 7, five commonly used scenarios are compared with regard to the force/ displacement response. The level of the force in Fig.7a obviously is given by the weight of the "dead load", while the slope of the force/displacement line in Fig.7b represents the spring rate of the biasing steel spring. In Fig.7c, two shape memory wires are working in opposing directions. When wire 1 is heated (e.g.by electrically heating), it contracts, moves an object, and simultaneously stretches wire 2.

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The object can be moved in the opposite direction by heating wire 2 after cooling of wir [illegible] reverse biasing is shown in Figure 7d and e. The magnet causes the shape memory wire to generate a high static force, that drops sharply when the magnet is separated from its holding plate. A slower drop in force can be achieved by using a cam arrangement with a decreasing lever during actuation of the shape memory wire. Reverse biasing is beneficial when high cyclic stability is important.

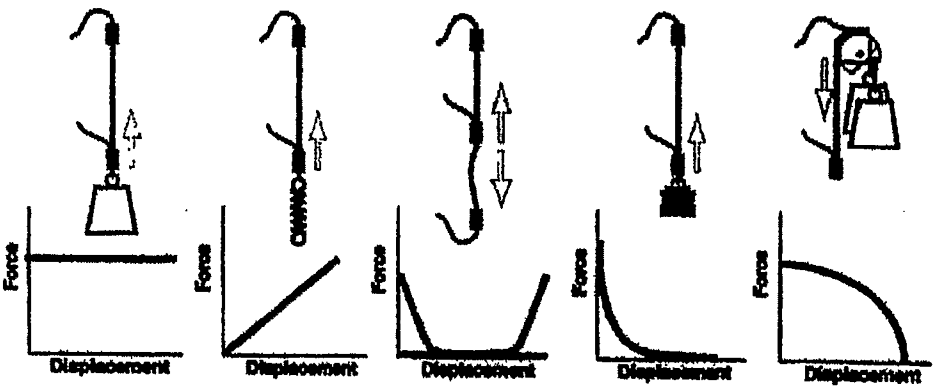
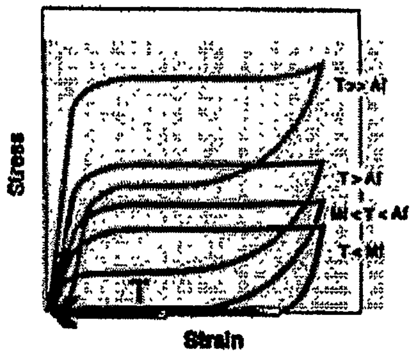


Fig. 7: Biasing Mechanisms and their effect on force/displacement characteristics [9]

Under optimum conditions and no load the shape memory strain can be as high as 8%. However, for cyclic applications the usable strain is much less. The same applies for the stress; for a one-time actuation the austenitic yield strength may be used as maximum stress. Much lower values have to be expected for cyclic applications.

Shape memory alloys can, under certain conditions, show a true two-way-effect, which makes them remember two different shapes, a low and a high temperature shape, even without external force [10]. However, it is smaller and its cyclic behavior is not as well understood as that of the one-way-effect. Because there is no special treatment necessary, the cyclic use of the one-way-effect with external reset force in many cases is the more economic solution.

The forth event is *superelasticity*. A wire is loaded at temperatures above Af, but below Md. After reaching the first yield point, it can be elongated to approx. 8 % strain with no significant stress increase. Upon unloading, the wire recovers its original length elastically, although with a stress hysteresis.



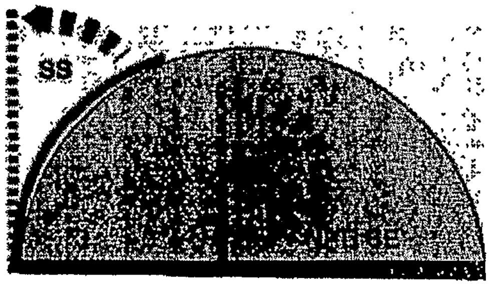


Fig. 8 (left): Tensile behavior of a superelastic wire at different temperatures
Fig. 9 (right): Comparison of the flexibility of a stainless steel and a superelastic wire

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Appendix A

Applications of Shape Memory and Superelastic Alloys

In the following, applications will be categorized according to the function of the shape memory alloy itself, as suggested by Duerig and Melton [6]. The early product development history of Ni-Ti has been full of failures and disappointments [11]. This can be attributed to the lack of understanding of the effects and the unavailability of engineering data, unreliable melting techniques and plain over-expectation. One major disadvantage of shape memory is its spectacular showing. It shows off as if it could solve all the problems in the world (*browsing through the patent literature February 1990 reveals: vacuum cleaner, sleeping device, method of manufacturing shoes, racket gut, shape recoverable fabric, diapers, toy boat, necktie, oilcooler bypass valve, throttle mechanism, concrete processing method* ....). Obviously, it doesn't. In the meantime, after many million $ lost on attempts to build the perpetuum mobile and to compete with thermostatic bimetals and other alternatives, the technology finally has come of age. Engineers understand the benefits, but also the limitations of the material, fabrication methods are reliable, and prices are at an acceptable level. Most new volume applications are based on the superelastic effect, which doesn't require as tight a transformation temperature control as the shape memory effect, as used for actuators, for instance.

The first technical successes clearly were uses of the constrained recovery event for joining and fastening purposes [7]. In the late sixties and early seventies, Raychem Corp. pioneered the development of tube and pipe couplings for aircraft, marine and other applications. The concept is straightforward: a sleeve is machined with an I.D. that is approx. 3% smaller than the diameter of the tubing it is designed to join. It is then cooled to its martensitic state and radially expanded eight percent, making it large enough to slip over two tube ends. When heated, the sleeve shrinks onto the tube ends and, while generating a high force, joins the tubes. Most couplings are made from cryogenic Ni-Ti-Fe alloys and have to be stored in liquid nitrogen after expansion. While this does not seem to pose a problem for aircraft manufacturers, it is a logistics issue for most commercial users. Therefore, wide-hysteresis Ni-Ti-Nb alloys have been developed, which can be stored and shipped at room temperature after expansion at low temperatures, and have to be heated to 150°C for installation [13]. These alloys remain in their high strength, austenitic state even after cooling to below -20°C.

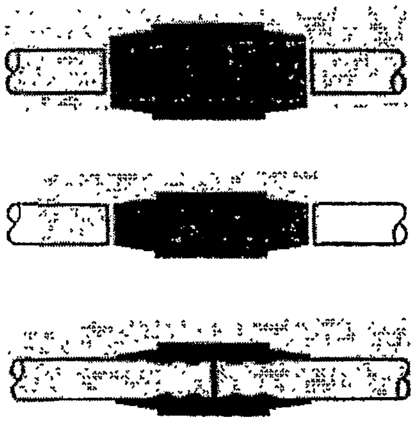

Fig. 10: Coupling, machined and expanded (top), after free recovery (middle) and installed on a tube (bottom) [12]

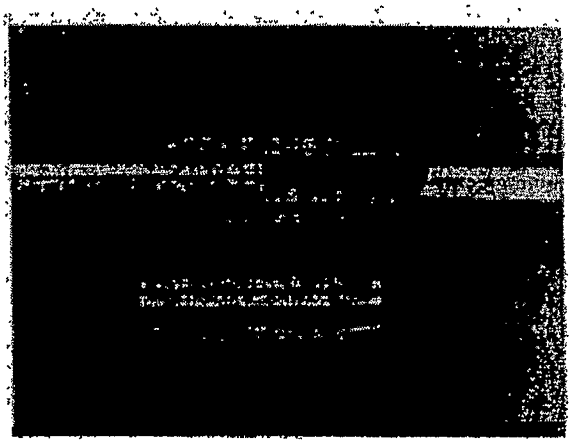

Fig. 11: Cut-away view of a shape memory coupling installed on a stainless steel tube [12]

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To join large diameter pipes, or to create high compressive stresses near weld joints of a fatigue improvement, prestrained Ni-Ti-Nb wire or ribbon can be wound around the pipe and then thermally recovered. This wire wrap technology was recently developed by ABB [14] for nuclear applications. It has to be mentioned, however, that Ni-Ti cannot be used in the high temperature, high pressure lines of a PDR, because of severe hydrogen embrittlement.

Wide hysteresis alloys are also used in a variety of fastening applications. For example, rings may be used to [15]:

- terminate electromagnetic shielding braid to connectors
- terminate heat shielding braid to oxygen sensors
- fix the location of bearings or gears at any point on a shaft, if desired, locking in a controlled axial preload force
- assemble clusters of radially disposed elements by compressing them with controlled uniform radial pressure
- provide very high retention forces and low contact resistance in high amperage connectors.

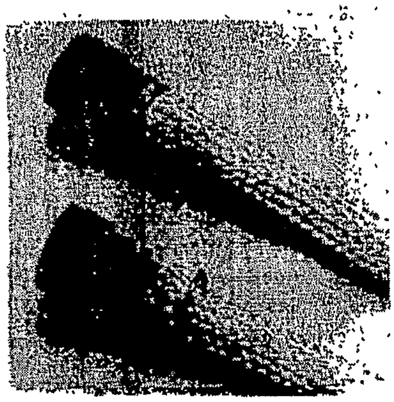

Fig. 12: Electromagnetic shielding braid termination with fastener rings [12]

Fig. 13: Installing braid termination rings with conductive heating [12]

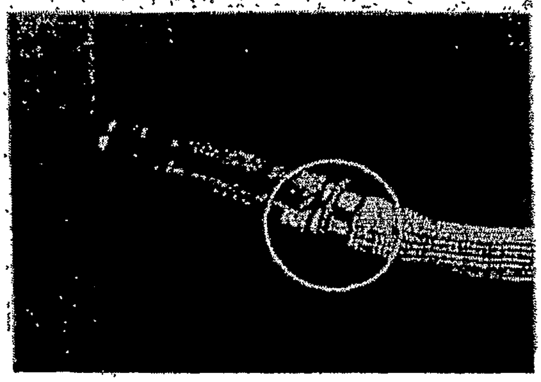

Fig. 14: Heat shielding braid termination on oxygen sensor with fastener ring [15]

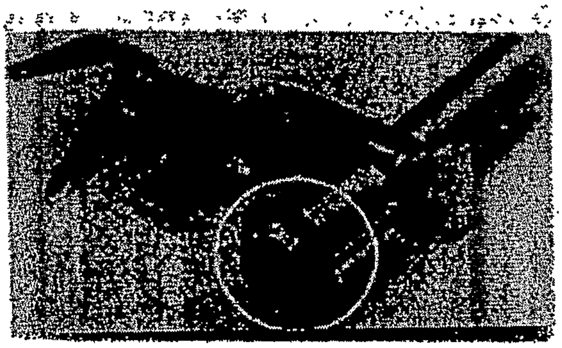

Fig. 15: High amperage pin/socket connector with fastener ring installed [16]

A similar concept is used for ZIF (zero insertion force) connectors. In a technically highly successful pin/socket version of such a connector, a Ni-Ti ring surrounds the outward-bending tangs of a fork contact. When cooled (with liquid nitrogen, for instance), the ring weakens as it transforms to its martensitic phase, enabling the springy tangs to force it open. The mating pin then can be inserted or

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removed freely. Nearly one million contacts have been produced for the Trident program [illegible] connectors incorporate U-shaped actuators that force open a spring clamp when heated with a foil heater attached to the actuator [17].

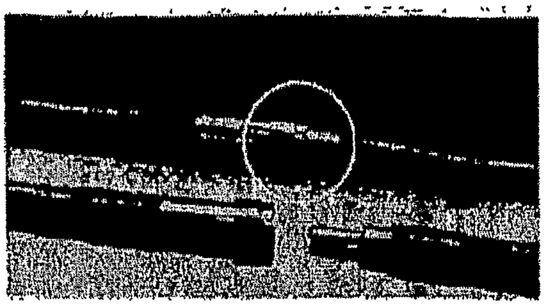

Fig. 16: Cryofit ® pin/socket connector [12]

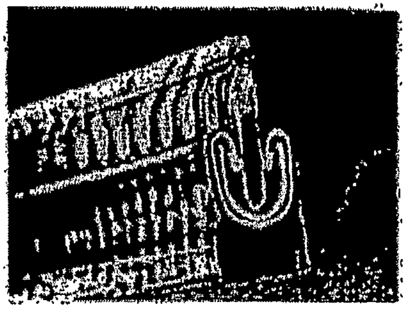

Fig. 17: Printed circuitboard connector [17]

Shape memory actuators respond to a temperature change with a shape change [18]. The change in temperature can be caused by a change of ambient temperature or by electrically heating the shape memory element. In the first case, the shape memory alloy acts as a sensor and an actuator (thermal actuator). In the second case, it is an electrical actuator that performs a specific task on demand. Thermal as well as electrical shape memory actuators combine large motion, rather high forces and small size, thus they provide high work output. They usually consist of only a single piece of metal, e.g. a straight wire or a helical spring, and do not require sophisticated mechanical systems. Although originally considered most important, actuators are the technically and economically least successful applications of the shape memory effect, when measured as outcome vs. development effort. The reasons for the limited success of shape memory actuators are technical insufficiencies as well as cost. Design requirements usually include transformation temperature on heating, reset temperature (hysteresis), force (stress), displacement (strain), cyclic stability (fatigue), response time on heating and cooling, dimensions, over-temperature and over-stress tolerance, etc..

Fig. 18: Thermostatic control valve(cut-away)

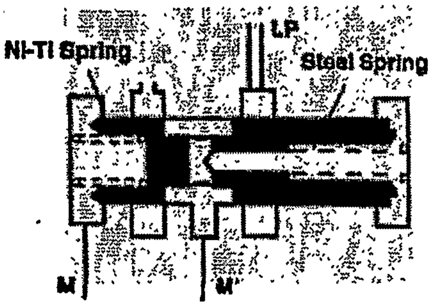

Fig. 19: as 18, function schematic [19]

An example of a technically as well as (at least for the user) economically successful application of a thermal shape memory actuator is the thermally responsive pressure control valve in the Mercedes-Benz automatic transmission. To improve the shifting comfort, the shifting pressure of the transmission is reduced during cold start situations and increased again when the transmission reaches operating temperature [19]. Introduced in model year 1989 Mercedes cars, this system has operated extremely reliably. Why is this application so successful? The required Af temperature is 60°C with a comfortable ±5°C tolerance, the spring is completely immersed in the transmission fluid, thus heating and cooling is

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slow and very uniform, the required force is low (approx. 5 N), very small displacement ambient temperature is 130°C, only 20,000 cycles expected. This fortunate combination of design parameters is seldom found. There has been a wealth of suggested shape memory applications for automotive use, like the "smart idle screw", carburetor ventilation valve, oilcooler bypass valve to name a few [20]. Other applications of thermal shape memory actuators marketed today include viscosity compensating devices, ventilation valves, anti-scald valves, fire detection and prevention devices, air conditioning and ventilation devices, etc..

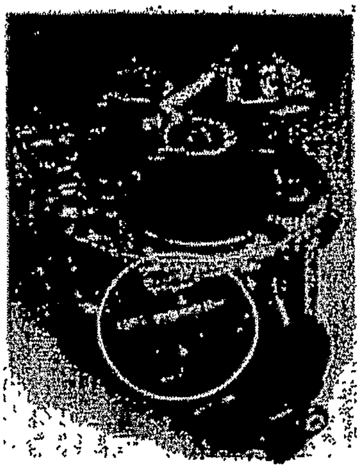

Fig. 20: "Smart idle screw" (prototype) [20]

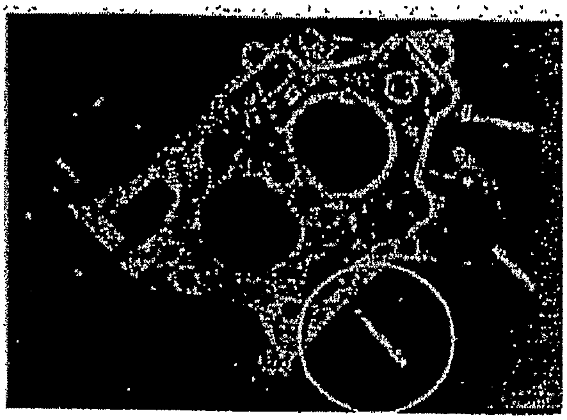

Fig. 21: Carburetor ventilation valve (prototype)

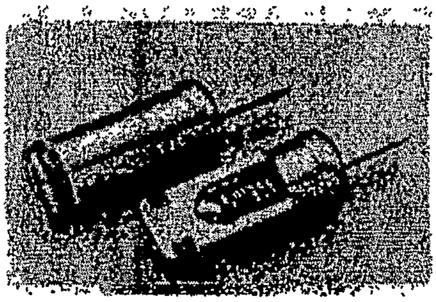

Fig. 22: Oilcooler bypass valve (prototype)

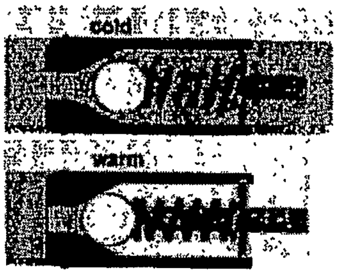

Fig. 23: as 22, schematic function

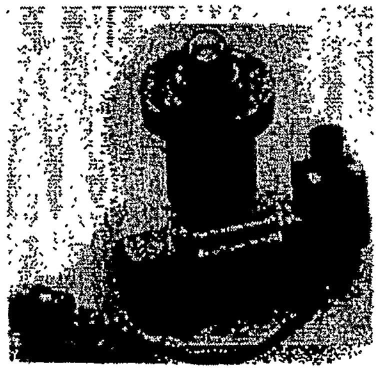

Fig. 24: Clogging indicators for oil coolers [21]

Fig. 25: Automatic gas line shut-off valves [22]

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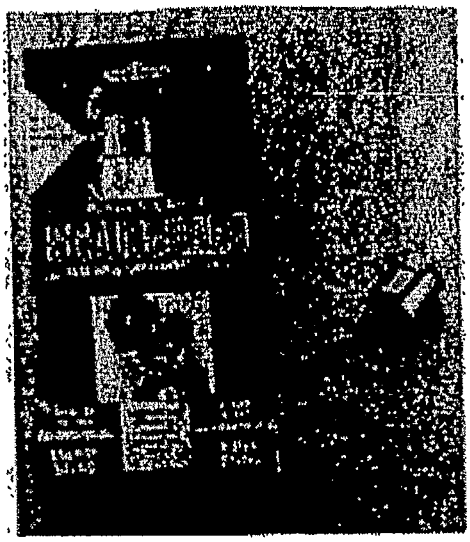


Fig. 26: Anti-Scald valve

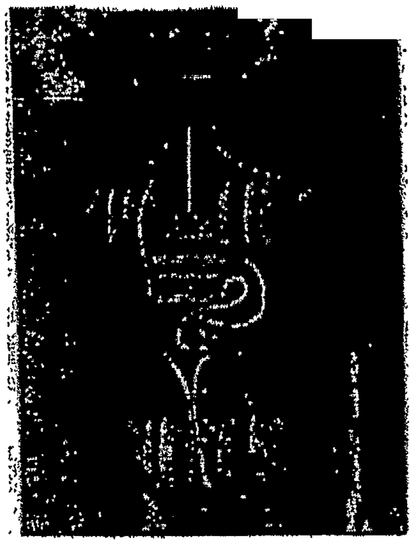


Fig. 27: Motion mechanism in toys

Electrical shape memory actuators have been suggested to replace solenoids, electric motors etc. By controlling the power during electrical actuation, specific levels of force and/or specific positions can be maintained. A variety of valves, triggering devices, animated objects, toys etc. are presently being marketed. The integration of Ni-Ti wires in composite structures has been suggested, to allow the structure to change shape on demand. These "smart composites" can also actively attenuate acoustic noise in structures by having fundamental control over structural stiffness. Strain-compliant shape memory composites can be used as integrated members in truss structures, performing passive and active roles in vibration and shape control. Recently, a system to dampen the low frequency swing of large antennas or reflectors during space shuttle maneuvers has been proposed, using a shape memory controlled hinge system [23].

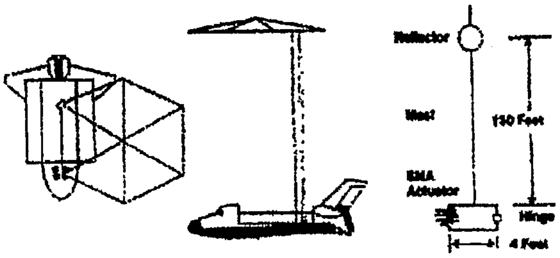


Fig. 28: Active damping system [23]

Fig. 29: Smart composites for shape control [24]

Limiting factors for the use of shape memory alloys in electrical actuators are the transformation temperatures available today and the lack of control over cooling times. In order to work properly, the Mf temperature of the shape memory alloy must be well above the maximum operating temperature of the actuator. Commercially available alloys that are sufficiently stable in cyclic applications, have maximum transformation temperatures (Mf) of around 70°C. Thus, an electrical actuator made from this alloy would fail to reset when ambient temperature reaches 70°C. Correspondingly, the actuator would self-trigger when ambient reaches its As temperature. For applications with high operating temperatures (e.g. automotive), alloys with transformation temperatures well above 150°C are required. above, Ni-Ti-Pd alloys with transformation temperatures up to 200°C might eventually become available.

The use of shape memory actuator for robots has often been proposed, and several prototypes have been presented. However, as the shape memory effect is a thermal phenomenon, response time is dictated by the heating and cooling of the material. While heating can be controlled through the power supplied to the actuator, cooling is less controllable. Depending on the size of the actuator (wire diameter, mass), cooling times can be seconds to minutes.

As mentioned earlier, applications using superelastic Ni-Ti have seen explosive growth during the last two years, with antennae, brassieres and eyeglass frames being the volume leaders, followed by dental archwires and guidewires. The first application of superelastic Nitinol was as orthodontic archwire during the 1970s. The advantages that Nitinol provides over conventional materials, obviously are the increased elastic range and a nearly constant stress during unloading [25].

Superelastic Nitinol guidewires are increasingly used because of their extreme flexibility and kink resistance. They also show enhanced torquability (the ability to translate a twist at one end of the guidewire into a turn of nearly identical degree at the other end)[26], thus significantly improving steerability. The low force required for bending the wire is considered to cause less trauma than stainless steel guidewires. Kink resistance and steerability are also the main reasons for using Nitinol in stone retrieval and fragmentation baskets. The shaft as well as the basketwires can be made from superelastic Nitinol.

More recently, shape memory and superelastic Nitinol alloys have been used very effectively for self-expanding stents. The small profile of the compressed stent facilitates safe, atraumatic placement of the stent. After being released from the delivery system, the stent self-expands either elastically or thermally and exerts a constant, gentle radial force on the vessel wall.

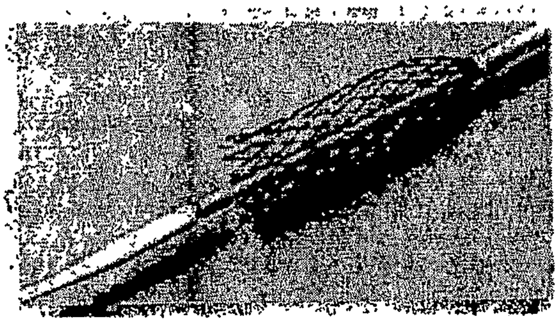


Fig. 30: Self-expanding Nitinol stent [27]

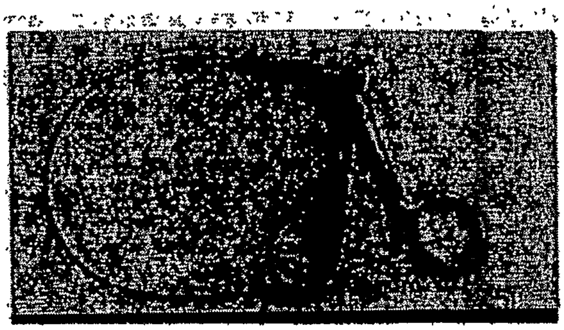


Fig. 31: Non-kinking microsurgical instrument

Medical device manufacturers are increasingly using Nitinol in instruments and devices for minimally invasive procedures [28]. The concept is to enter the body with a minimum profile through small incisions with or without a portal, and then changing shape inside the body cavity. One of the first instruments to use superelastic Nitinol was the Mitek Mammalok® needle wire localizer, used to locate and mark breast tumors so that subsequent surgery can be more exact and less invasive [29]. The concept of constraining a curved superelastic component inside a cannula during insertion into the body is used in a variety of instruments for minimally invasise surgery. Figure 32 shows a dissecting spatula, the curvature of which is increased by progressive extrusion of the superelastic blade. Different blade configurations are used for variable curvature suture and sling passers [30]. Instruments with deflectable

Appendix A

distal ends use curved superelastic components which are constrained in a cannula during the body and deployed once inside the body. Graspers, needle holders and scissors can be inserted through straight trocar cannulae. Once inside the peritoneal cavity, they can change into their curved configuration, thus increasing the degrees of freedom for manipulation [31].

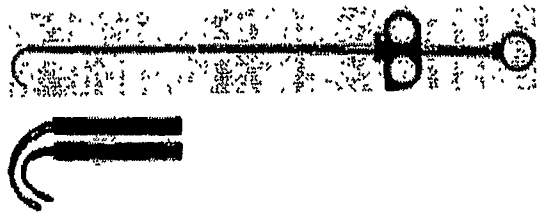


Fig. 32: Retractable spatula [30]

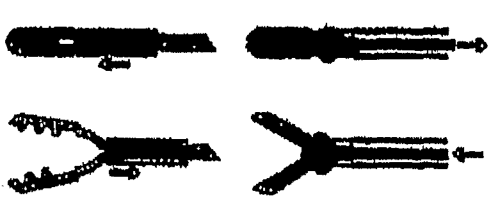


Fig. 33: Hingeless instruments [32]

In a new electrosurgical device for transurethral ablation of prostatic tissue, radiofrequency energy is delivered directly into the prostate via two side-deploying needles. These needles, made from superelastic Nitinol, are deflected from the axis of the catheter around a sharp bend to be deployed radially through the urethral wall into the prostate tissue. After passing the guiding channel, they protrude straight out of the catheter tip [33]

Hingeless instruments use the elasticity of spring materials instead of pivoting joints to open and close the jaws of grasping forceps or the blades of scissors. Because of their simple design without moving parts and hidden crevices, they are easier to clean and sterilize. A new generation of hingeless instruments uses superelastic Nitinol for the actuating component of these instruments, which provides elasticity higher than stainless steel by at least a factor of 10. This results in an increased opening span and/or reduced displacement of the constraining tube for ergonomic handling. In many cases the functional tip can be a monolithic superelastic component, vs. multiple intricate, precision machined components and linkages of conventional instruments. This allows the design of instruments with very small profiles [32].

Long and thin instruments, e.g. like forceps used in urology, tend to be very delicate and can kink easily, destroying an expensive tool. Using superelastic Nitinol for the outer tube and a superelastic actuation rod, makes the instrument very flexible and kink resistant. Superelastic tubes have only recently been made available by different suppliers. They are also used for biopsy needles, e.g. for interventional computer tomography or magnetic resonance imaging. In these techniques Nitinol instruments can be clearly detected without artifacts (glow) [34].

Appendix A

References

[1] T.W. Duerig, K.N. Melton, D. Stoeckel, C.M. Wayman: "Engineering Aspects of Shape Memory Alloys", Butterworth-Heinemann, 1990
[2] T.W. Duerig, R. Zadno, in [1] 369
[3] S.M. Tuominen, R.J. Biermann, J.o.Metals 1988, 32
[4] J.H. Mulder et al., Proc. of SMST (A.R. Pelton et al. eds.) (1994) to be published
[5] D. Stoeckel, Proc. ADPA Conf."Smart Structures" Washington (1990)
[6] T.W. Duerig, K.N. Melton, Proc.SMA 86, Guilin (1986) 397
[7] J.L. Proft, T.W. Duerig, in [1] 115
[8] D. Stoeckel, Advanced Materials & Processes, 138 (1990) Oct., 33
[9] R.G. Gilbertson: "Working With Shape Memory Wires", Mondotronics 1991
[10] J. Perkins, D. Hodgson, in [1] 195
[11] T.W. Duerig, Proc. MRS Conf. Boston (1994) to be published
[12] "Tinel Shape Memory Alloys", RAYCHEM company literature
[13] T.W. Duerig, K.N. Melton, J. Proft, in [1]130
[14] H. Kornfeld, in [4] to be published
[15] D. Stoeckel, T. Borden, Metall 46 (1992) 668
[16] H.P. Kehrer, H. Nußkern, VDI/VDE "Actuator 94" Bremen (1994) 324...............
[17] J.F. Krumme, Connection Technology, April (1987)
[18] D. Stoeckel, T. Waram, SPIE Vol 1543 "Active and Adaptive Optical Components" 1991, 382
[19] D. Stoeckel, J. Tinschert, SAE Technical Paper Series # 910805
[20] D. Stoeckel, Springs Vol. 30, Oct. (1991) 35
[21] J.F. Tertre, D. Stoeckel, Proc. "Actuator 92" VDI/VDE Bremen (1992), 100
[22] "FIRECHECK" MEMRYTECH company literature
[23] T. Stevens, Mat. Eng., Vol. 108, Oct. 1991, 18
[24] Proc. ADPA Conf "Smart Structures" Washington (1990)
[25] R. Sachdeva, S. Miyazaki, in [1] 452
[26] J. Stice, in [4] to be published
[27] ANGIOMED AG, company literature
[28] A. Melzer, D. Stoeckel, in [4] to be published
[29] J.P. O'Leary, J.E. Nicholson, R.F. Gattuma, in [1] 477
[30] STORZ, company literature
[31] P.P. Ponzet, R. Zadno, in [4] to be published
[32] D. Stoeckel, A. Melzer, Proc. 8th CIMTEC Florence (1994) to be published
[33] TUNA, VIDAMED Int'l, company literature
[34] D.H.W. Grönemeyer, R.M.M. Seibel, "Interventionelle Computertomographie", Ueberreuter Wissenschaft, Wien Berlin (1989) 308

APPENDIX A

MUSCLE WIRE

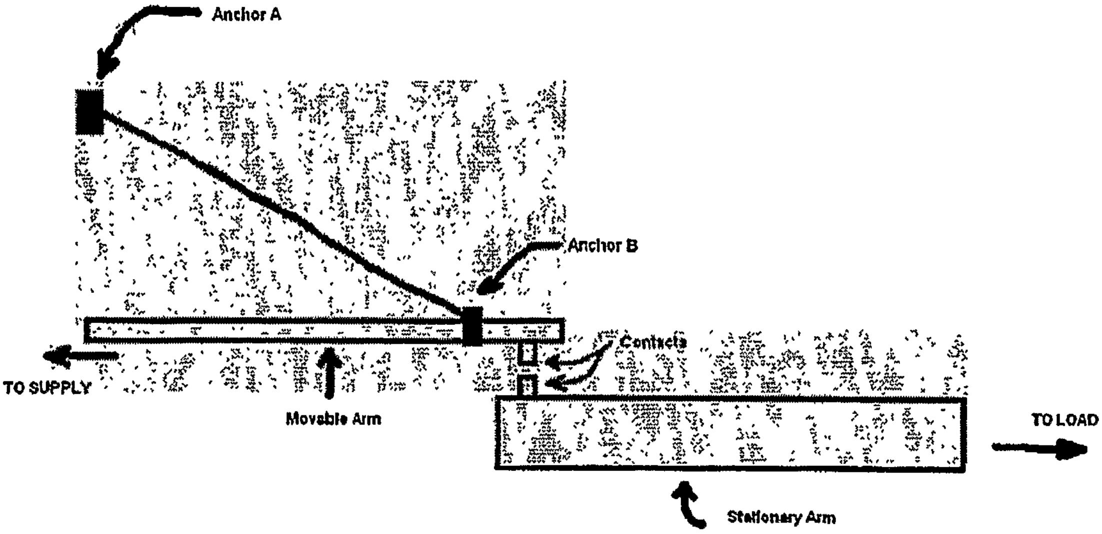
The fusible link can be achieved using a muscle-wire (such as Nitinol described above) mechanism. Heating Nitinol wire, which can be achieved by passing current through it, causes it to contract with great force, by about 10% in length. When Nitinol cools down it does NOT return to its original length. Once cool it can be pulled back to its original length using somewhat less force than was released when it was heated.

There are many ways Nitinol can be employed to disable a device. For example, Nitinol wire can be wrapped around a cam with one end anchored on the cam and the other on a housing, contraction of the Nitinol wire can cause any desired degree of cam rotation to make and break a conductive path. As another example, Nitinol wire can be wrapped around a pulley with one end anchored on a housing and the other end anchored on a target element, such that the Nitinol wire can move the element toward the pulley any desired distance. As another example, and depending upon the movement desired, a straight piece of Nitinol can be employed to achieve the desired breaking and making of the conductive path.

The movement created by the Nitinol can effect self-destruction in many ways. Nitinol can pull movable conductor arms away from their stationary arms, with enough force to break welded contacts, still overcoming spring return force when cool. Nitinol can pull or rotate a contact away or out of position, or can pull or rotate an insulator into position to separate a pair of contacts.

Control of the current through Nitinol wire (to heat it causing a break in the conductive path) can be achieved by any on/off current control.

APPENDIX A



1. Passing current from the phase conductive path (supply) to Anchor A heats the Nitinol wire.

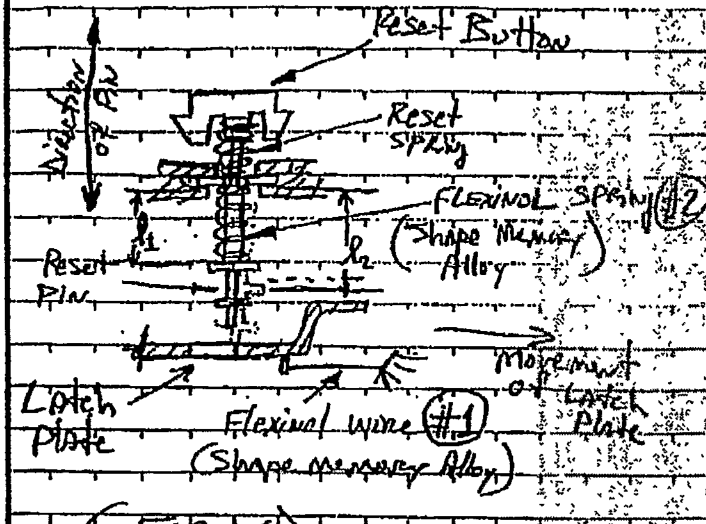
2. As heated the Nitinol wire contracts about 10% causing the contacts to part, thus causing electrical discontinuity in the conductive path.

3. In one embodiment. the movable and stationary arms may be part of the circuit interrupting portion. and part of the power interrupting system.

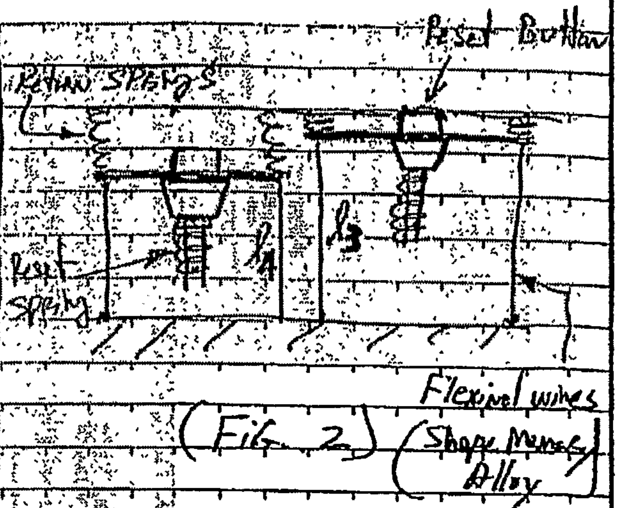
4. In one embodiment. the movable and stationary arms may be part of the power interrupting system.

Appendix B

From Page No. ___



(FIG. 1)



(FIG. 2)

Above Are Two examples of Mechanisms ~~that~~ Which are Controlled by Shape Memory Alloy (wires or Spring).

A) (TRIP)

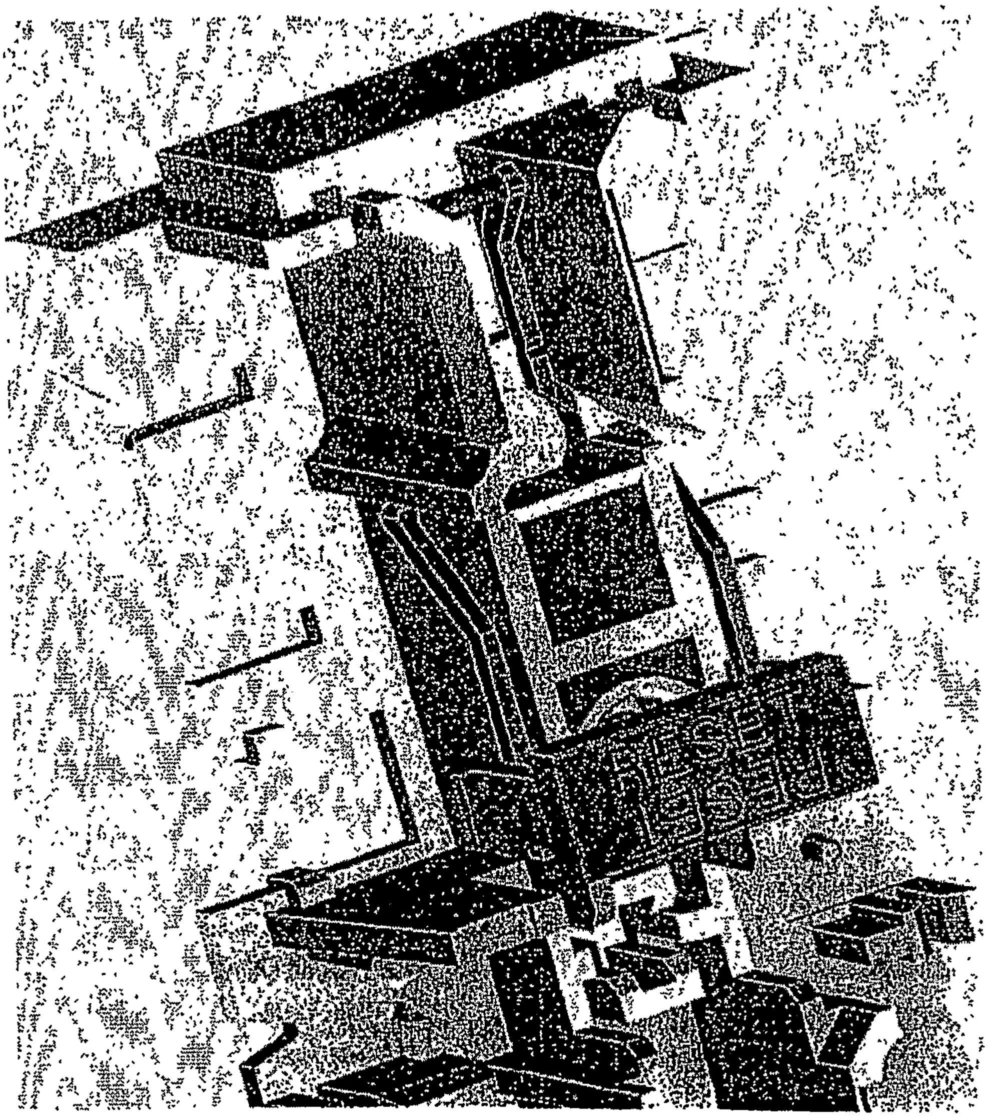
As the Shape memory Alloy is heated (by a rapid discharge Circuit) (wire #1) it Changes its form [Shape (length in This Case)] and Causes the ~~Rele~~ Latch Plate of a "Phase 7" Reset Lock-out" GFCI to move. The movement of the Latch Plate Releases the Reset Pin (TRIPS the GFCI). This Applies for Both Cases (FIG. 1 & FIG. 2)

B) (Reset)

When the Shape memory Alloy (Spring in FIG. 1 & Wire in FIG. 2) is heated, it Changes its Shape and ~~Causes~~ Moves the Reset button so that it Tests The GFCI. (Note, Since This is A Reset-lock-out device, Testing Automatically occurs while resetting). (Note; in Fig. 1, the Shape memory Spring increases its length when heated & over comes the Reset spring, Causing the Reset Button to move down.)

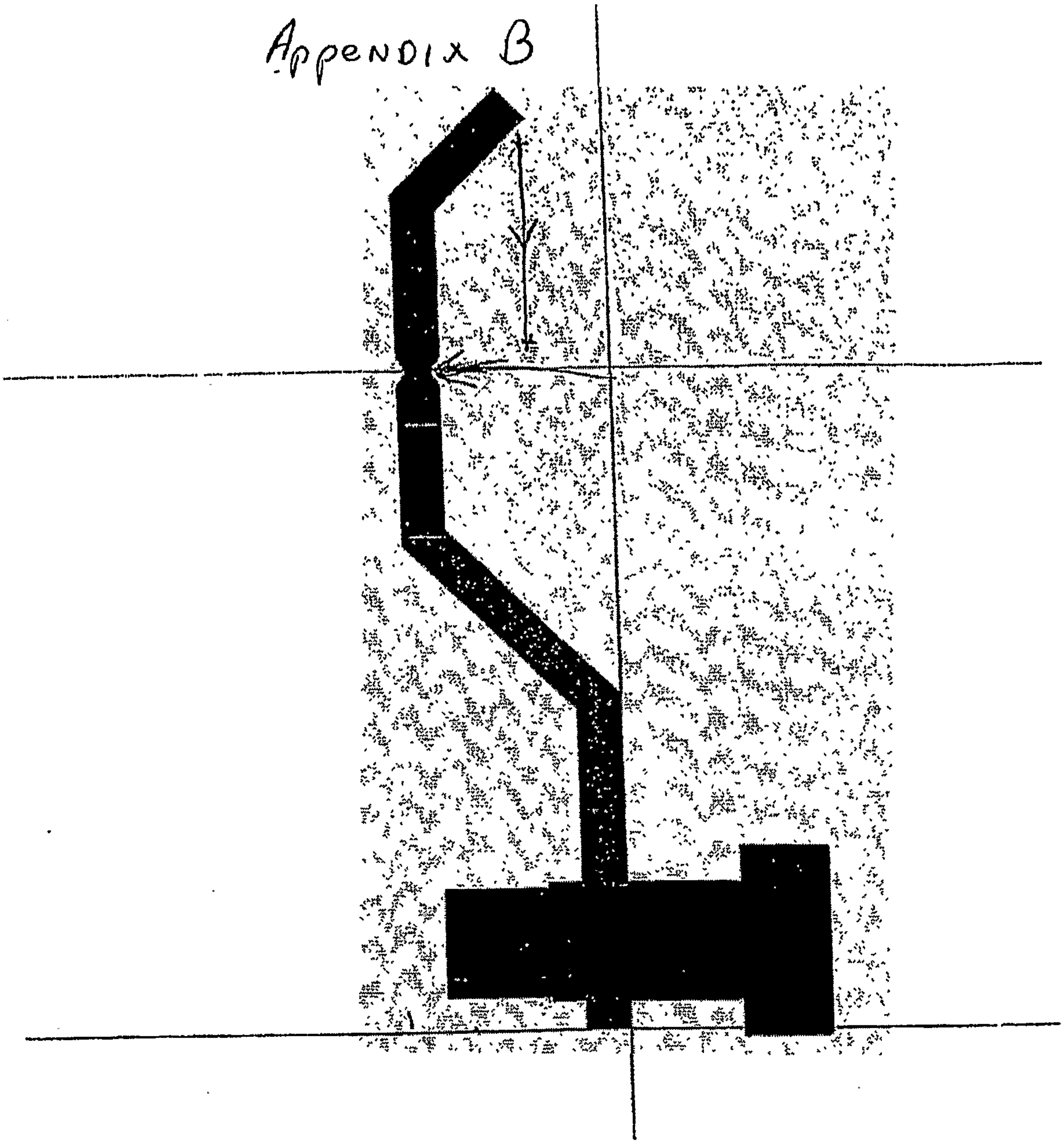
B1

Appendix B



B2

Appendix B



B3

WHAT IS CLAIMED:

1. A circuit interrupting device comprising:

a phase conductive path and a neutral conductive path each having a line side and a load side;

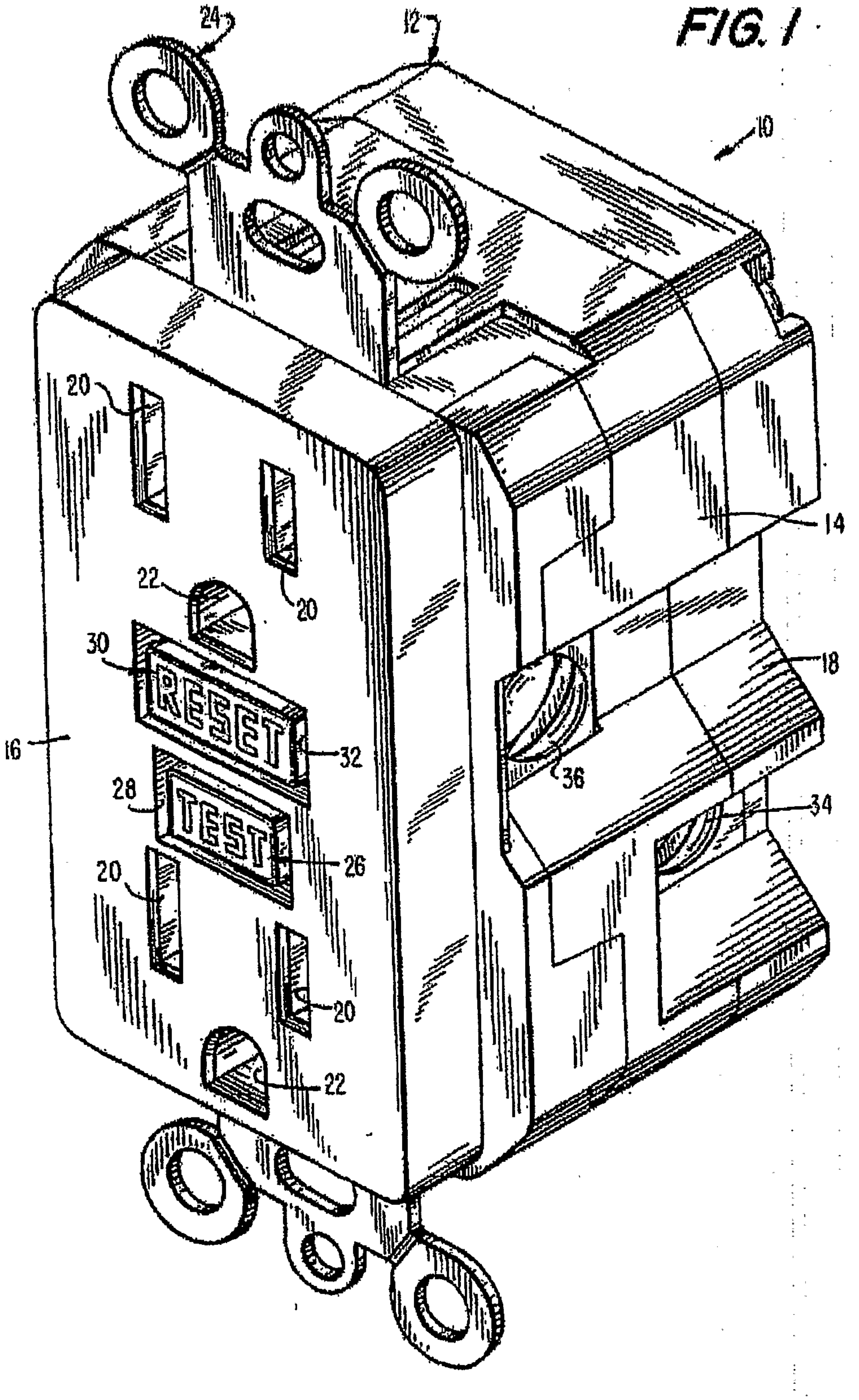
a fault sensor capable of monitoring the phase and neutral conductive paths for a predefined fault condition and outputting a condition signal in the event a predefined fault condition is detected;

a relay controller coupled to a relay and capable of receiving the outputted condition signal, such that when the relay controller receives the outputted condition signal the relay is energized causing electrical discontinuity in the phase and neutral conductive paths between the line side and load side;

a load voltage sensor capable of measuring the voltage between the phase and neutral conductive paths at the load side and outputting a voltage signal in response to the measured voltage; and

a power interrupting system having a power interrupting controller coupled to the fault sensor and the load voltage sensor and capable of outputting a disconnect signal in response to the detection of a predefined operational condition based upon the condition signal and the voltage signal, and a power interrupter capable of causing permanent electrical discontinuity in the phase and neutral conductive paths between the line side and load side in response to the disconnect signal.

FIG. 1



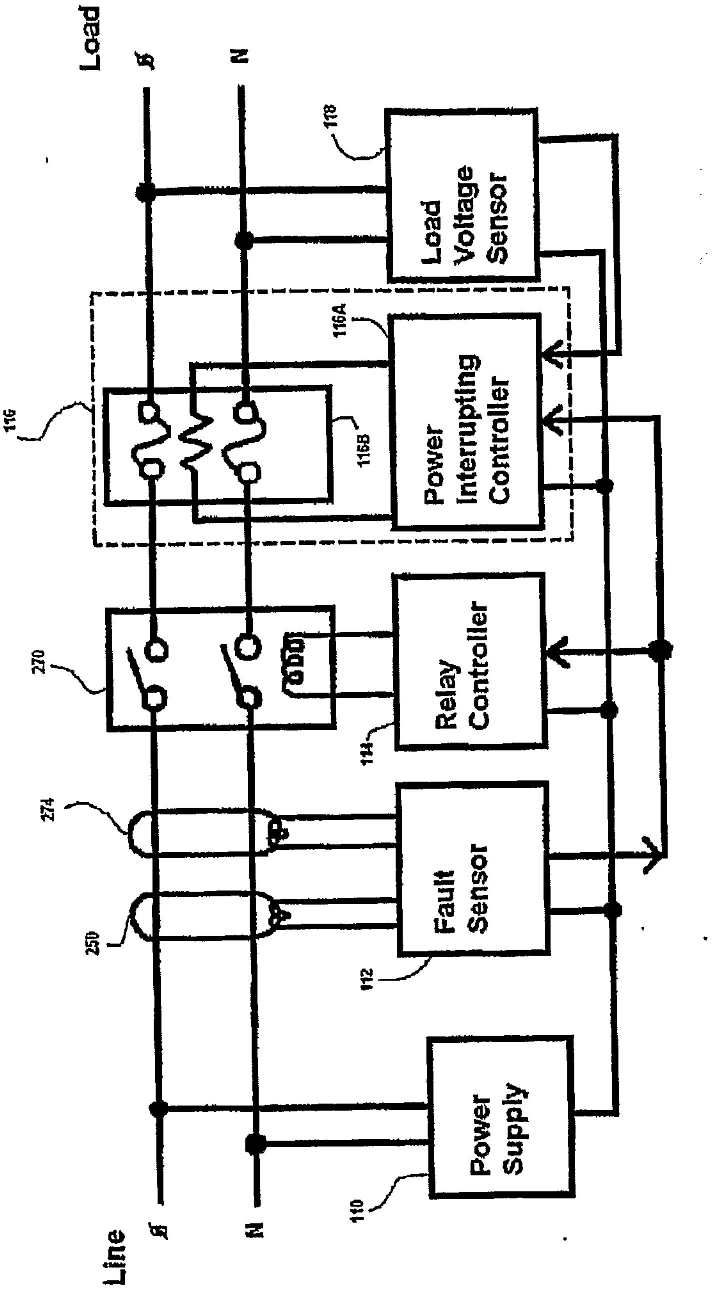

Load
Ø
N
118
Load Voltage Sensor
116A
Power Interrupting Controller
116
116B
270
Relay Controller
114
274
250
Fault Sensor
112
Power Supply
110
Line
Ø
N

FIG. 2

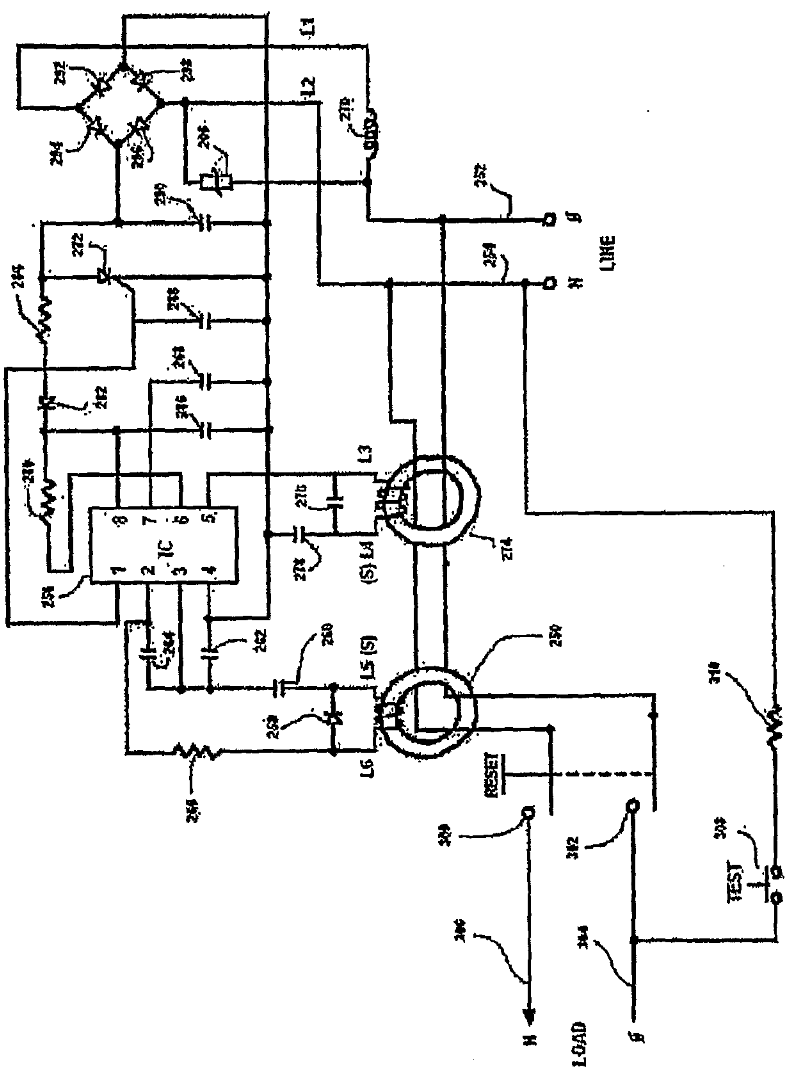
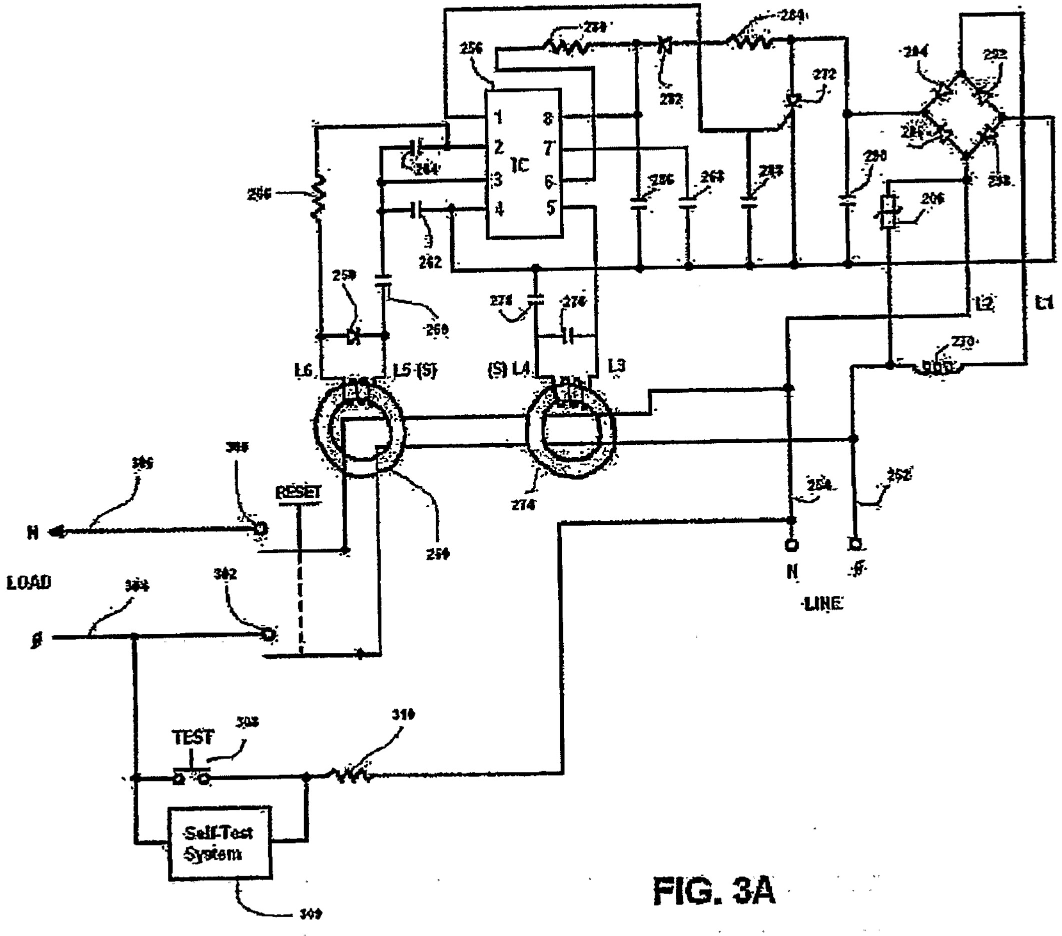


FIG. 3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278
282
284
272
292
294
296
298
1
2
3
4
5
6
7
8
IC
264
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262
286
268
288
290
206
258
260
274
276
L6
L5 (S)
(S) L4
L3
L2
L1
270
306
305
RESET
250
274
254
252
N
LOAD
304
302
ø
N
ø
LINE
TEST
308
310
Self-Test System
309

FIG. 3A

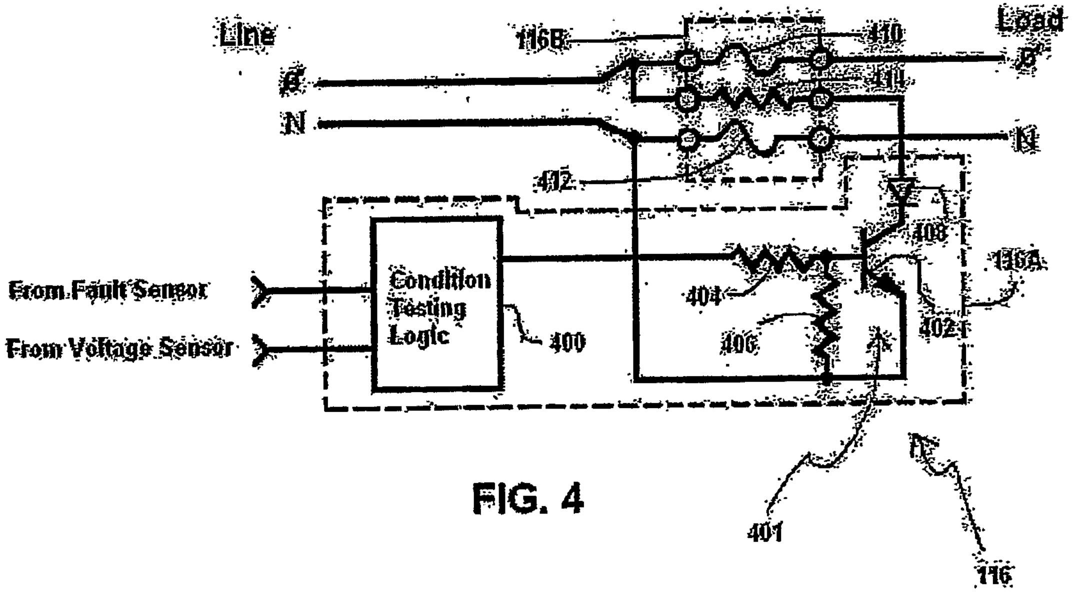

Line
Ø
N
116B
410
414
Load
Ø
N
412
Condition Testing Logic
400
From Fault Sensor
From Voltage Sensor
408
116A
404
406
402
401
116

FIG. 4

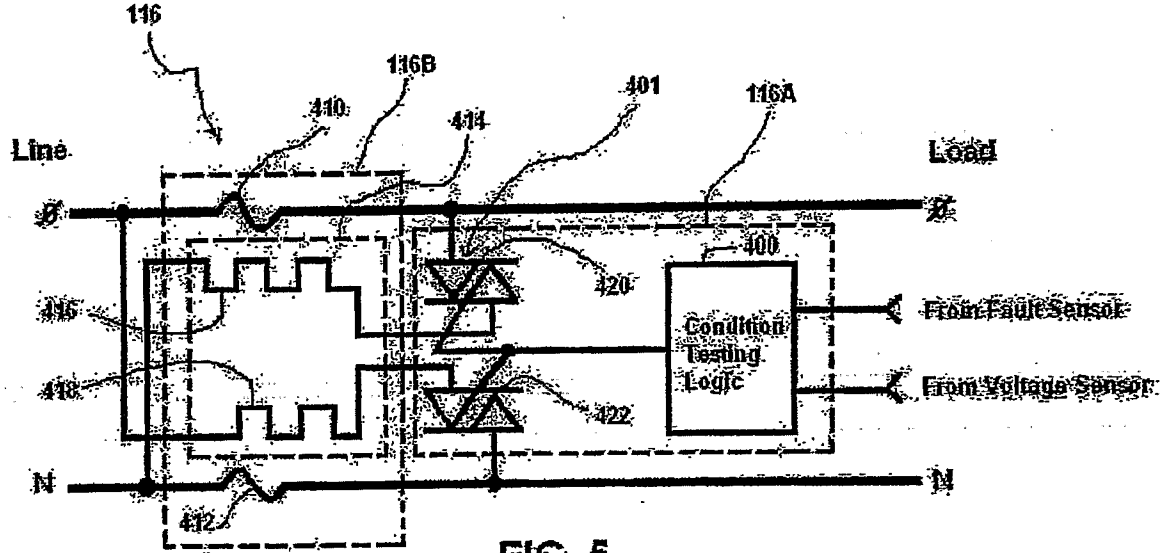
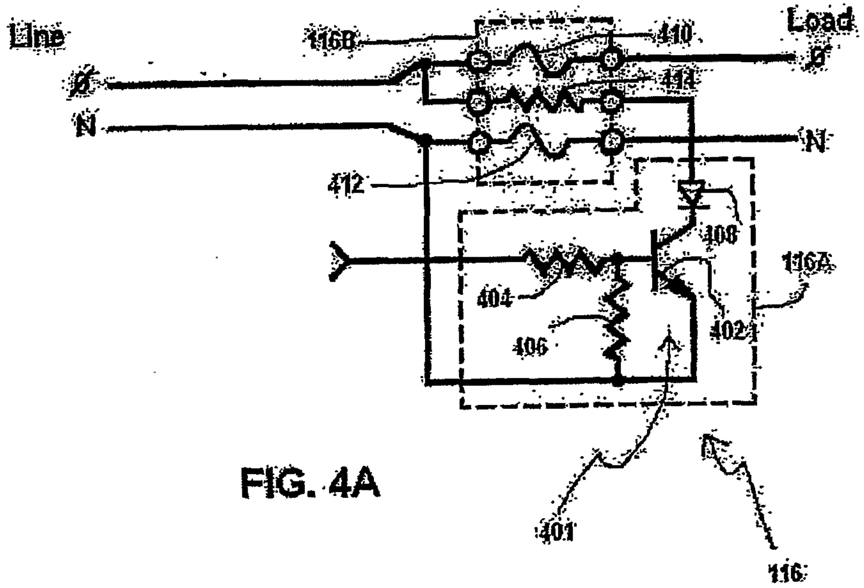

116
116B
410
414
401
116A
Line
Load
Ø
Ø
400
420
Condition Testing Logic
From Fault Sensor
From Voltage Sensor
416
418
422
N
N
412

FIG. 5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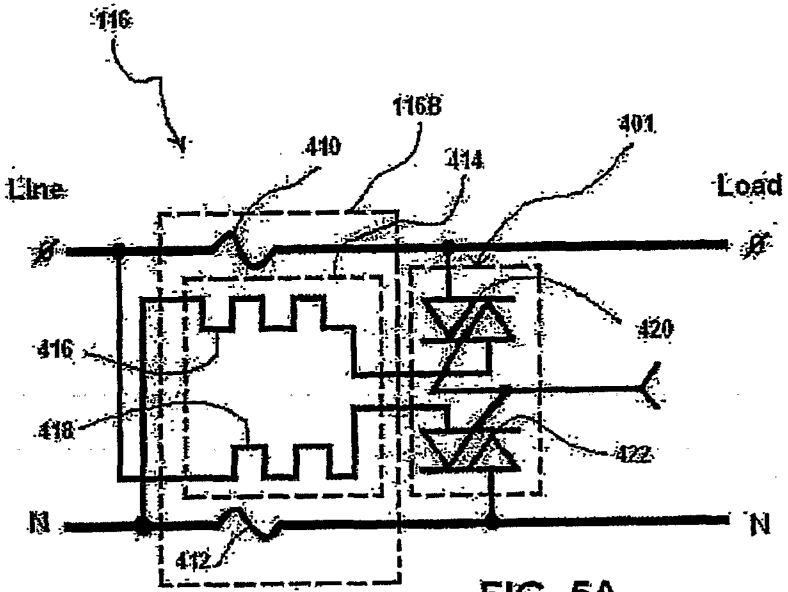
N
116B
410
414
412
Load
Ø
N
408
116A
404
406
402
401
116

FIG. 4A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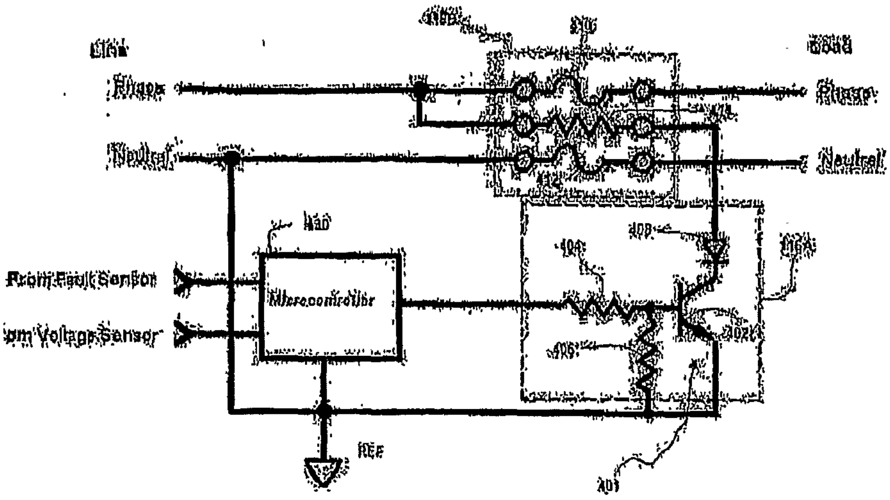
116B
410
414
401
Line
Load
Ø
Ø
416
418
420
422
N
N
412

FIG. 5A


Line
Phase
Neutral
116B
110
Load
Phase
114
Neutral
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450
408
404
116A
From Fault Sensor
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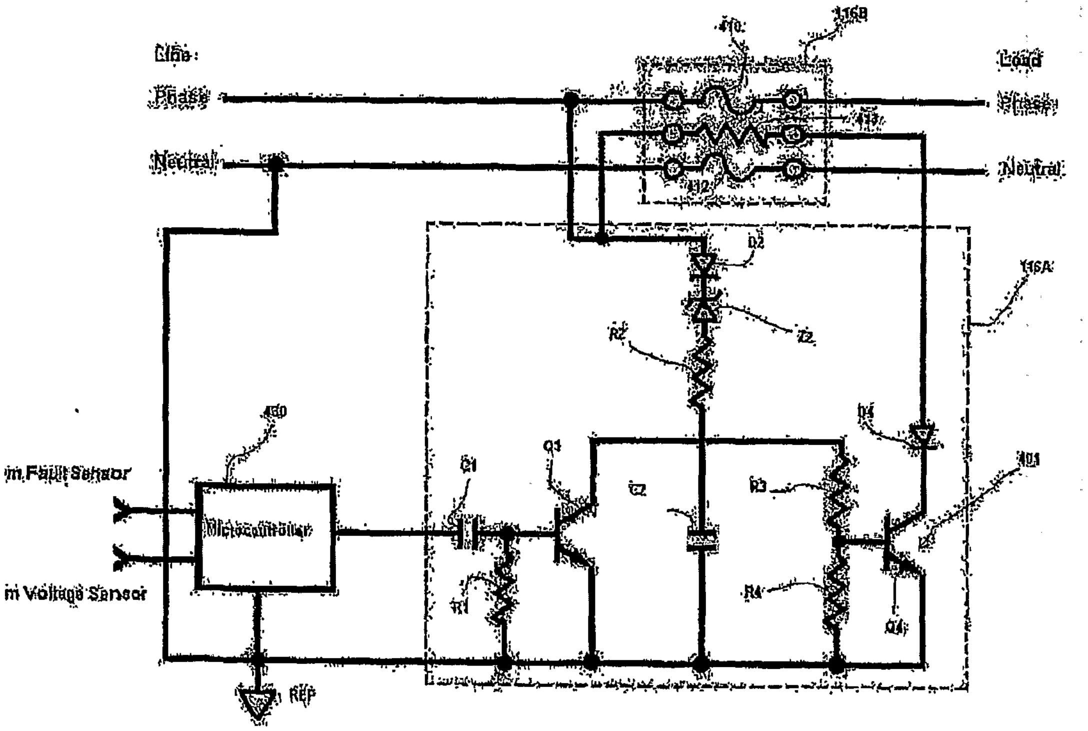
Microcontroller
406
402
REF
401

FIG. 6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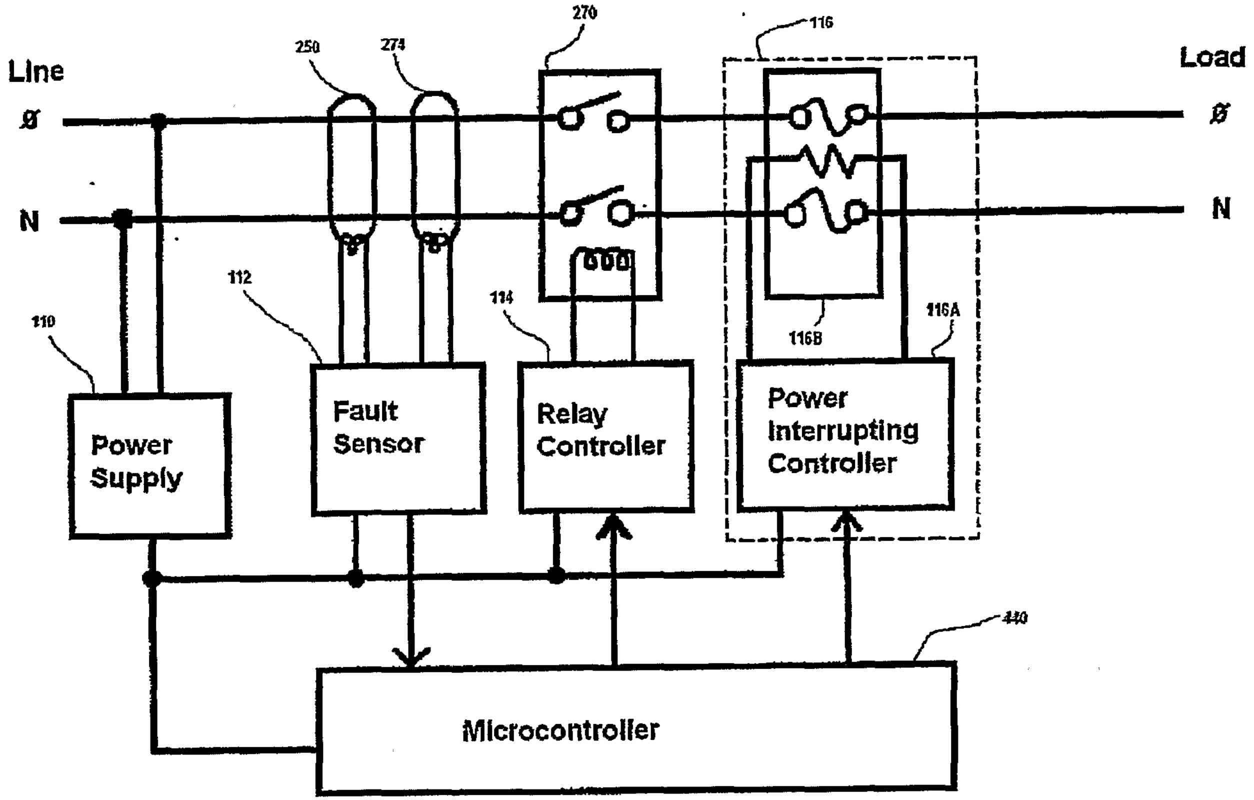
116B
Line
Load
Phase
Phase
114
Neutral
Neutral
112
D2
116A
Z2
R2
450
D4
401
Q1
C1
C2
R3
m Fault Sensor
Microcontroller
m Voltage Sensor
R1
R4
Q4
REF

FIG. 7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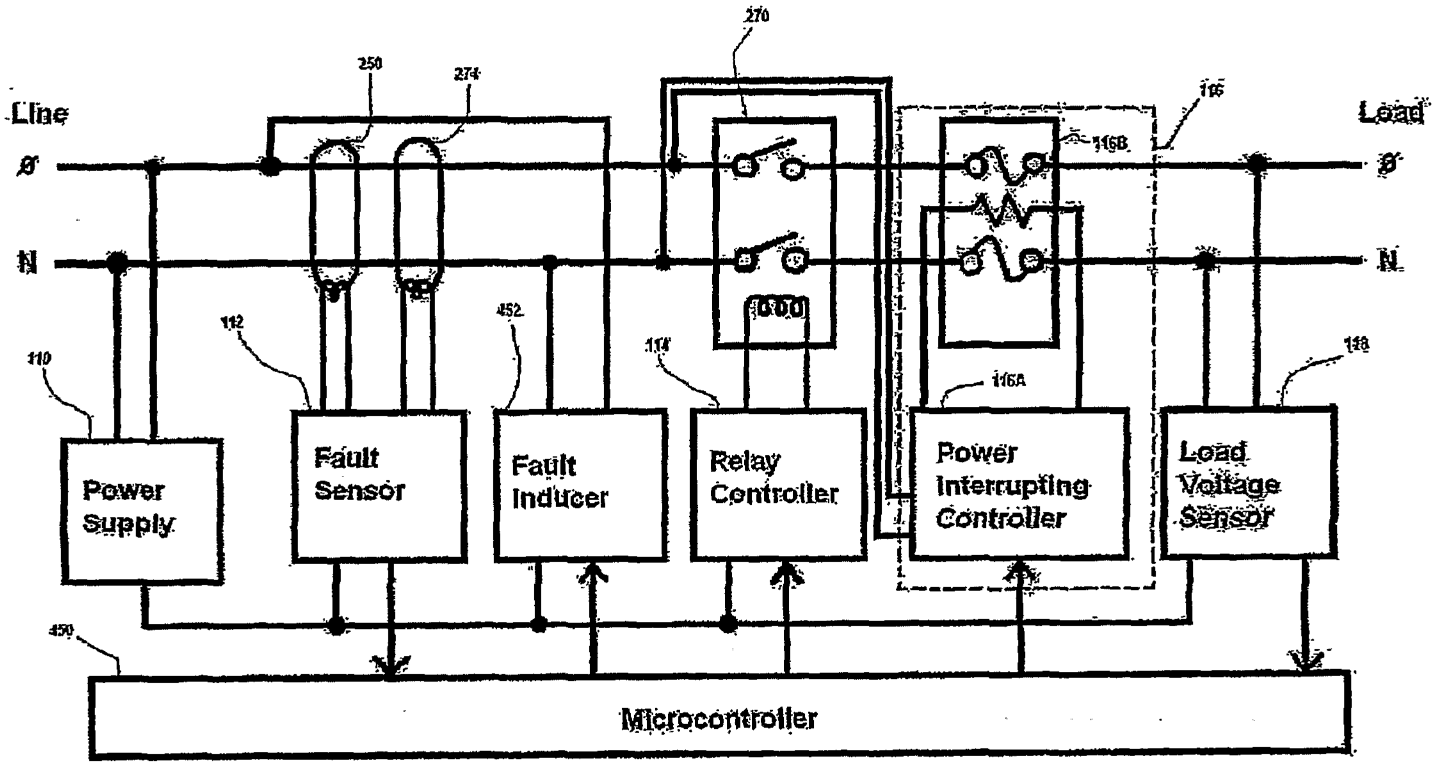
Ø
N
Load
Ø
N
250
274
270
116
116B
116A
110
112
114
440
Power Supply
Fault Sensor
Relay Controller
Power Interrupting Controller
Microcontroller

FIG. 8


Line
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N
Load
Ø
N
250
274
270
116
116B
116A
110
112
452
114
118
450
Power Supply
Fault Sensor
Fault Inducer
Relay Controller
Power Interrupting Controller
Load Voltage Sensor
Microcontroller

FIG. 9

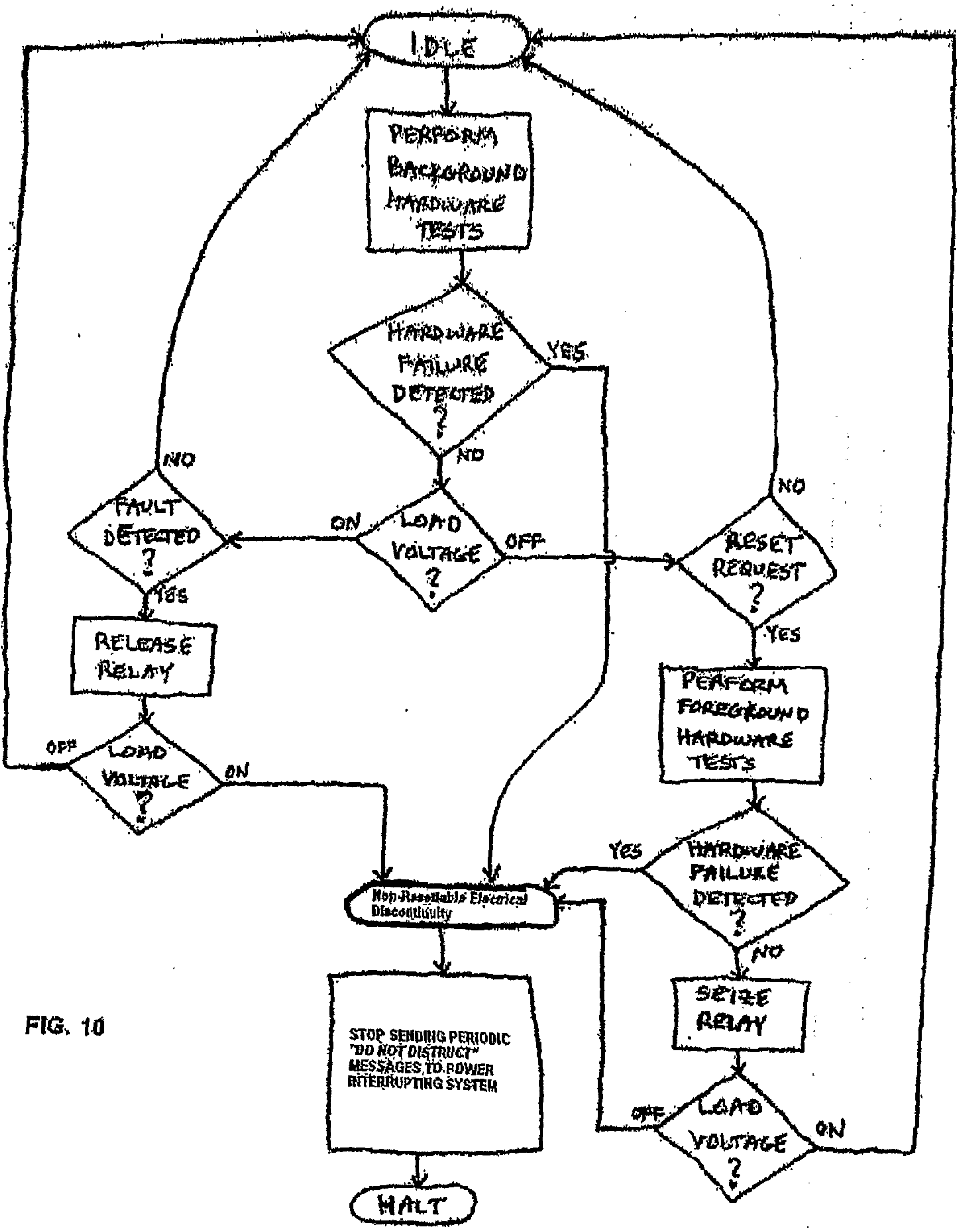
IDLE
PERFORM BACKGROUND HARDWARE TESTS
HARDWARE FAILURE DETECTED ?
YES
NO
LOAD VOLTAGE ?
ON
OFF
NO
FAULT DETECTED ?
YES
RELEASE RELAY
OFF
LOAD VOLTAGE ?
ON
NO
RESET REQUEST ?
YES
PERFORM FOREGROUND HARDWARE TESTS
YES
HARDWARE FAILURE DETECTED ?
NO
SEIZE RELAY
OFF
LOAD VOLTAGE ?
ON
Non-Resettable Electrical Discontinuity
STOP SENDING PERIODIC "DO NOT DISTRUCT" MESSAGES TO POWER INTERRUPTING SYSTEM
HALT

FIG. 10