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(54) **POWER TOOL ANTI-KICKBACK SYSTEM WITH ROTATIONAL RATE SENSOR**

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(73) Assignee: **Black & Decker Inc.**, Newark, DE (US)

(21) Appl. No.: **13/423,736**

(22) Filed: **Mar. 19, 2012**

Related U.S. Patent Documents

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(60) Provisional application No. 60/620,283, filed on Oct. 20, 2004, provisional application No. 60/675,692, filed on Apr. 28, 2005.

(51) **Int. Cl.**
B23Q 15/00 (2006.01)

(52) **U.S. Cl.**
USPC **173/1**; 173/4; 173/5; 173/6; 173/11; 173/176; 173/179

(58) **Field of Classification Search**
USPC 173/4, 5, 6, 11, 176, 178, 179, 161
See application file for complete search history.

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(57) **ABSTRACT**

A control system is provided for use in a power tool. The control system includes: a rotational rate sensor having a resonating mass and a controller electrically connected to the rotational rate sensor. The rotational rate sensor detects lateral displacement of the resonating mass and generates a signal indicative of the detected lateral displacement, such that the lateral displacement is directly proportional to a rotational speed at which the power tool rotates about an axis of the rotary shaft. Based on the generated signal, the controller initiates a protective operation to avoid further undesirable rotation of the power tool. The controller may opt to reduce the torque applied to shaft to a non-zero value that enables the operator to regain control of the tool.

23 Claims, 10 Drawing Sheets

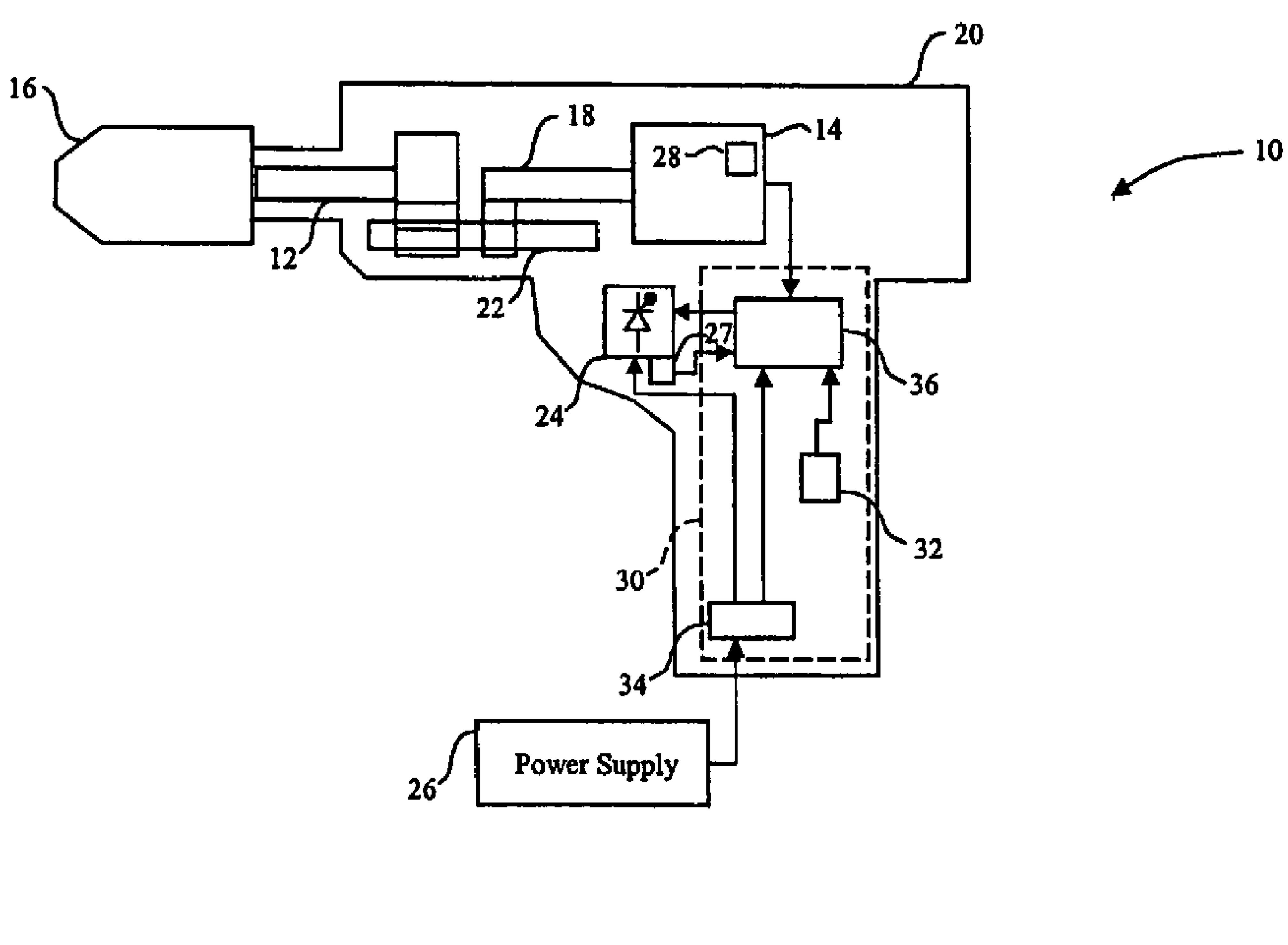

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FIG. 1

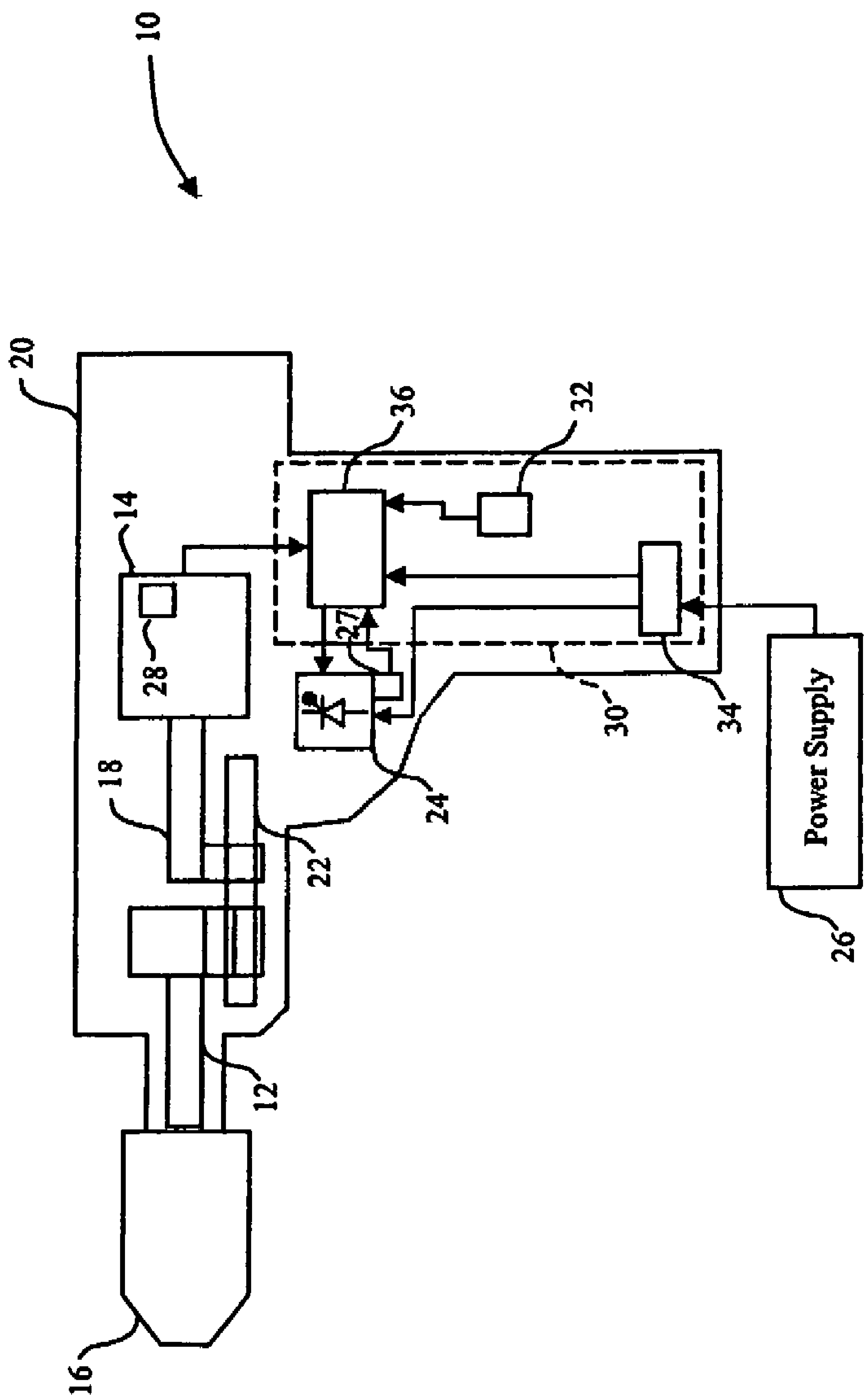


FIG. 2

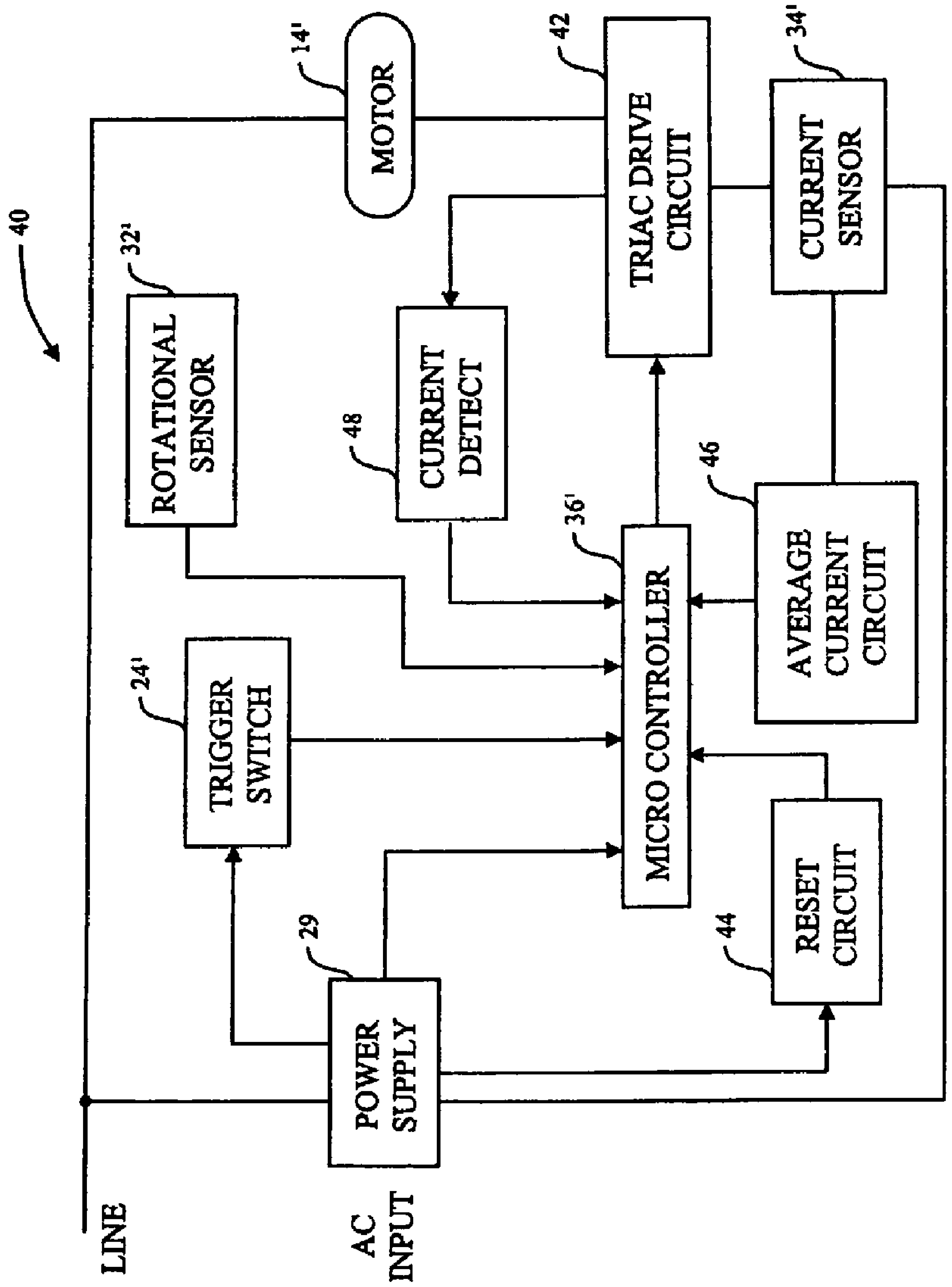

40
MOTOR
14'
TRIAC DRIVE CIRCUIT
42
CURRENT SENSOR
34'
ROTATIONAL SENSOR
32'
CURRENT DETECT
48
MICRO CONTROLLER
36'
AVERAGE CURRENT CIRCUIT
46
TRIGGER SWITCH
24'
RESET CIRCUIT
44
POWER SUPPLY
29
LINE
AC INPUT

FIG. 3

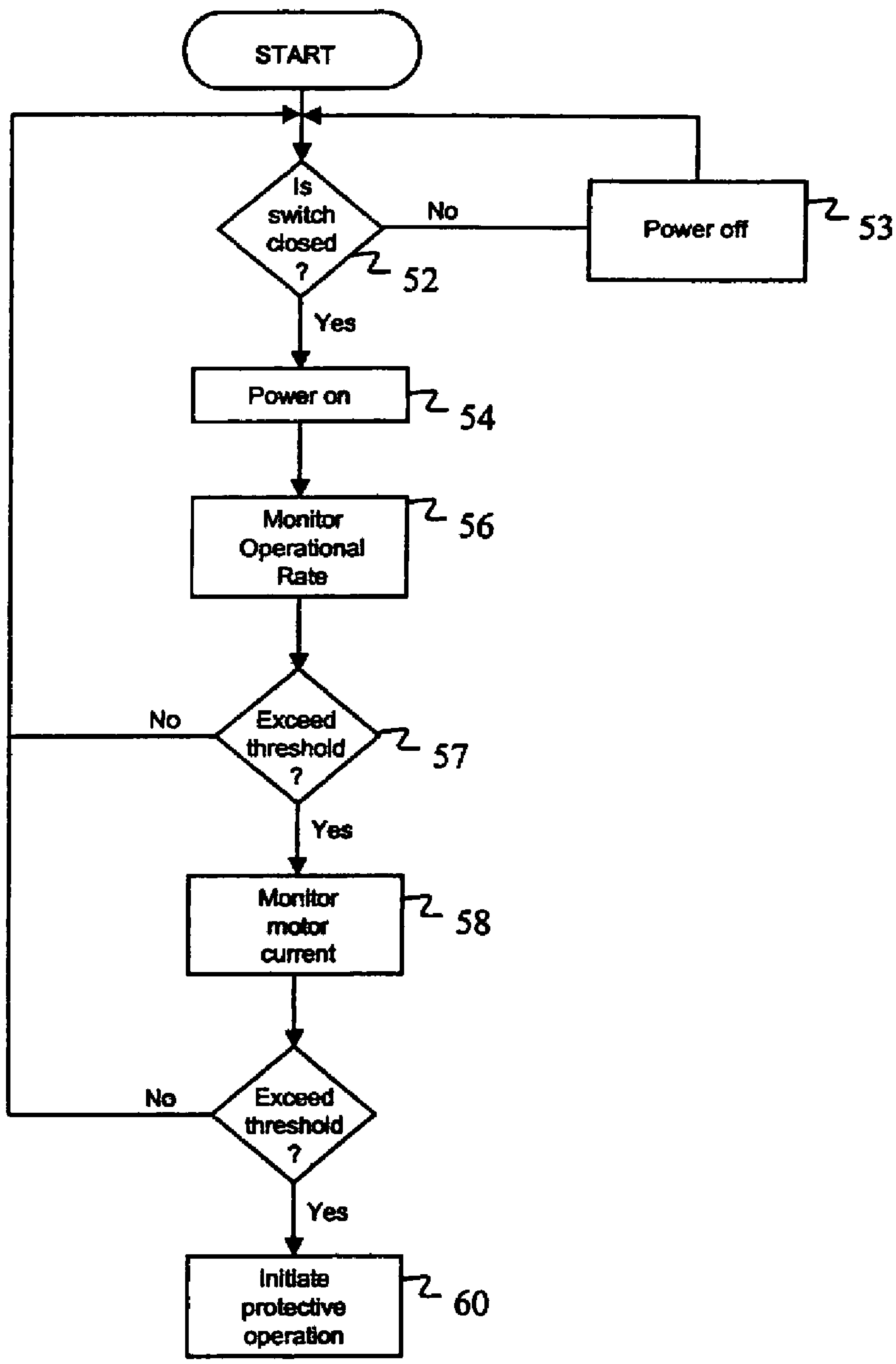

START
Is switch closed ?
No
Power off
53
52
Yes
Power on
54
Monitor Operational Rate
56
Exceed threshold ?
No
57
Yes
Monitor motor current
58
Exceed threshold ?
No
Yes
Initiate protective operation
60

FIG. 4A

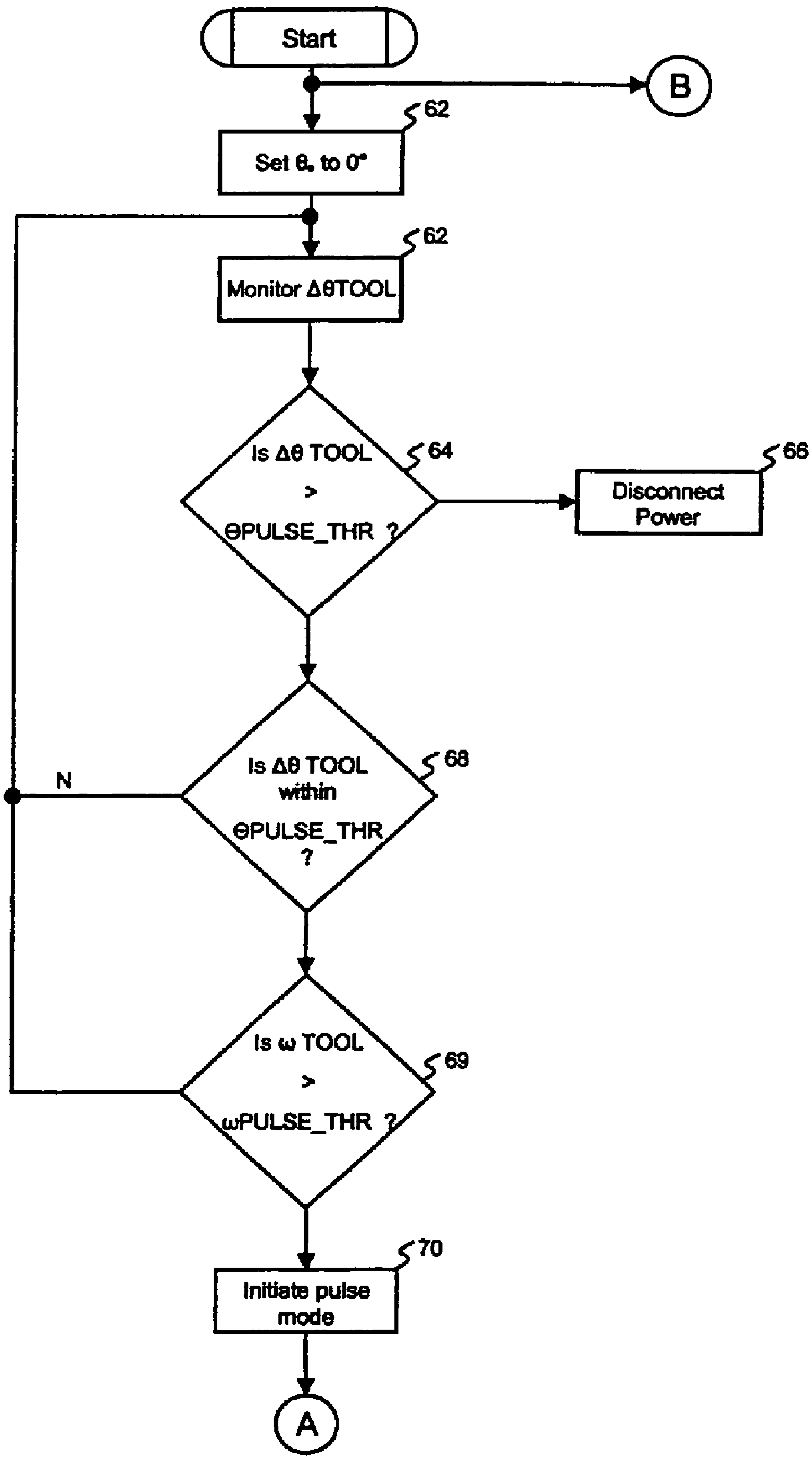

Start
B
62
Set θ₀ to 0°
62
Monitor ΔθTOOL
Is Δθ TOOL > θPULSE_THR ?
64
66
Disconnect Power
N
Is Δθ TOOL within θPULSE_THR ?
68
Is ω TOOL > ωPULSE_THR ?
69
70
Initiate pulse mode
A

FIG. 4B

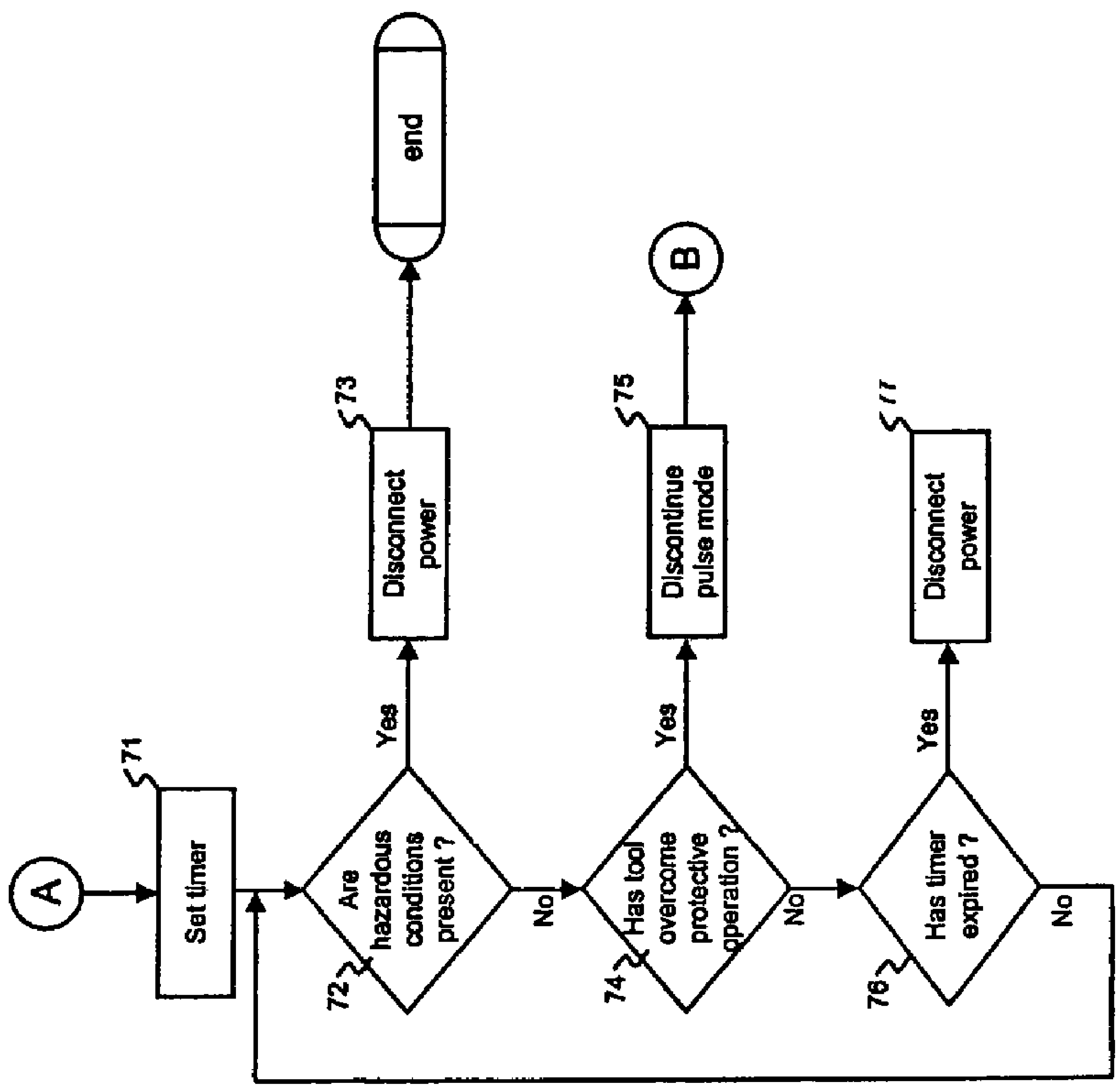

A
Set timer
71
Are hazardous conditions present ?
72
Yes
No
Disconnect power
73
end
Has tool overcome protective operation ?
74
Yes
No
Discontinue pulse mode
75
B
Has timer expired ?
76
Yes
No
Disconnect power
77

FIG. 5

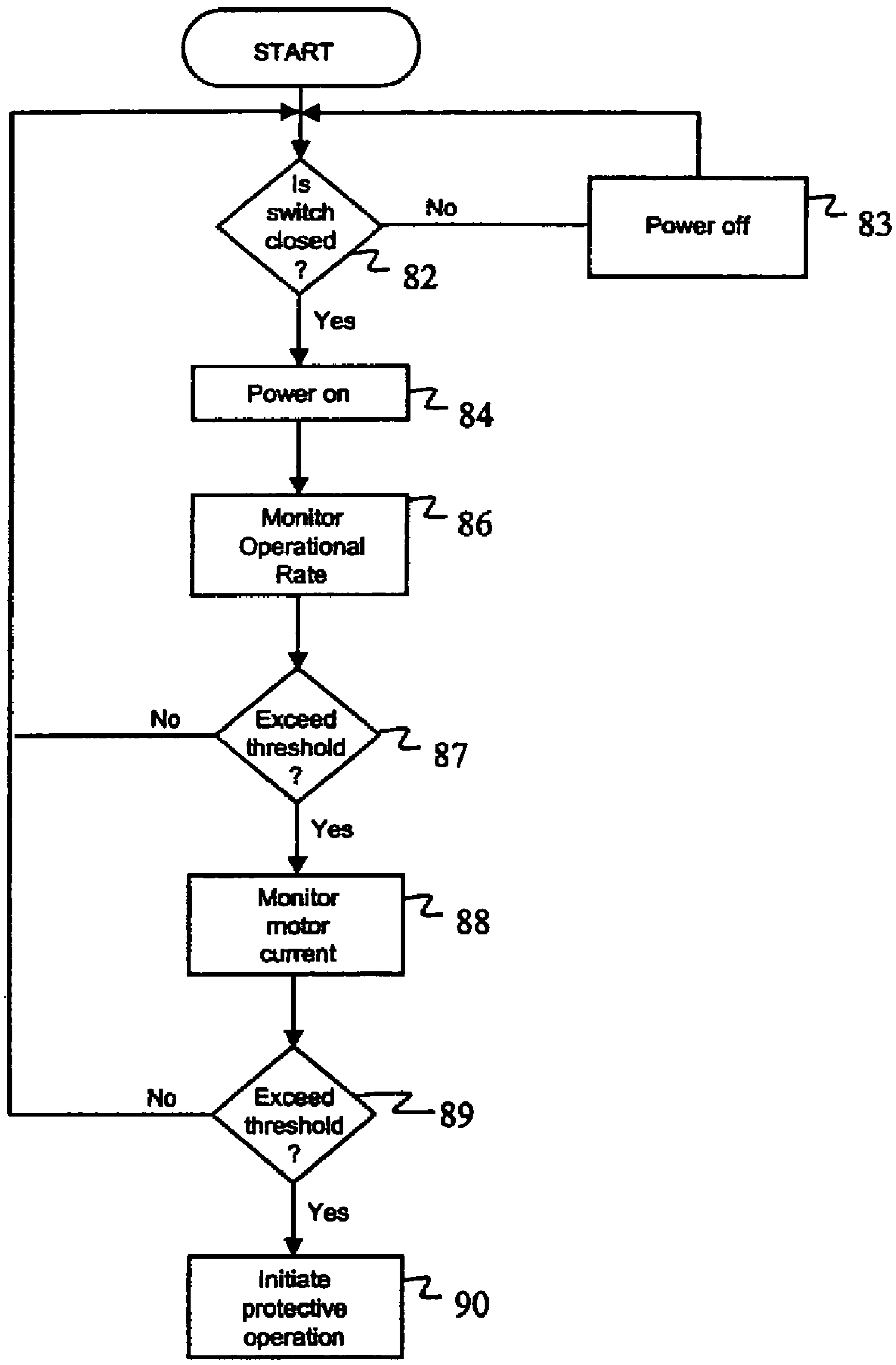

START
Is switch closed ?
No
Power off
83
82
Yes
Power on
84
Monitor Operational Rate
86
No
Exceed threshold ?
87
Yes
Monitor motor current
88
No
Exceed threshold ?
89
Yes
Initiate protective operation
90

FIG. 6

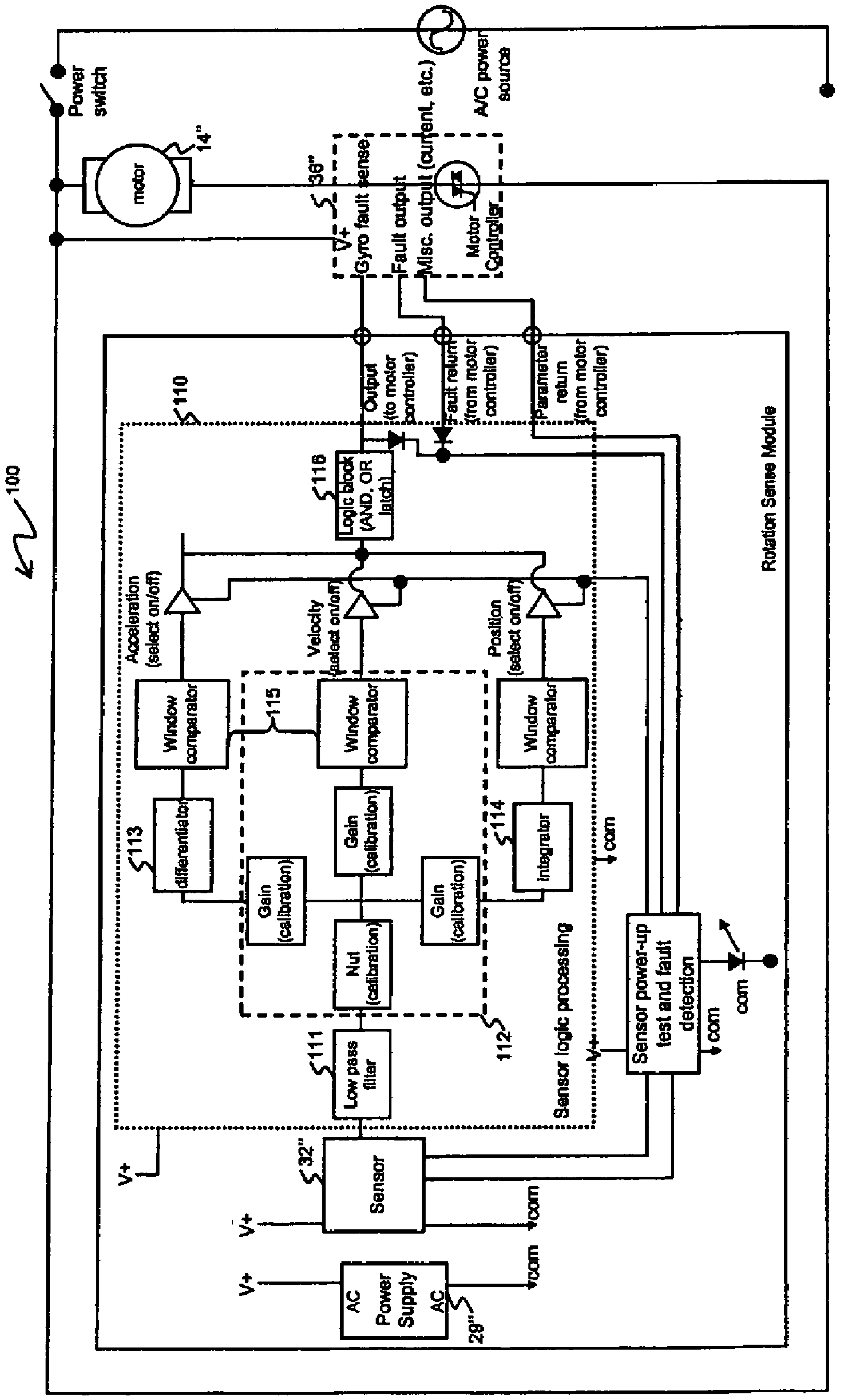

100
Power switch
motor
14"
A/C power source
V+
36"
Gyro fault sense
Fault output
Misc. output (current, etc.)
Motor Controller
Output (to motor controller)
Fault return (from motor controller)
Parameter return (from motor controller)
Rotation Sense Module
110
116
Logic block (AND, OR latch)
Acceleration (select on/off)
Velocity (select on/off)
Position (select on/off)
Window comparator
Window comparator
Window comparator
115
113
differentiator
Gain (calibration)
Gain (calibration)
Gain (calibration)
114
Integrator
Nut (calibration)
111
Low pass filter
112
Sensor logic processing
Sensor power-up test and fault detection
com
V+
32"
Sensor
AC Power Supply AC
29"

FIG. 7

Velocity (deg/sec)	Position (deg) 5	10	15	20	25	30	35	40
10	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode
20	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode
30	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode
40	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode
50	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode
60	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode
70	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode
80	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode
90	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode
100	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode	Protective mode	Protective mode
110	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode	Protective mode	Protective mode
120	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode	Protective mode	Protective mode
130	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode	Protective mode	Protective mode
140	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode	Protective mode	Protective mode
150	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode	Protective mode	Protective mode
160	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode	Protective mode	Protective mode
170	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode	Protective mode	Protective mode
180	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode	Protective mode	Protective mode
190	Normal operation	Normal operation	Normal operation	Normal operation	Protective mode	Protective mode	Protective mode	Protective mode

FIG. 8

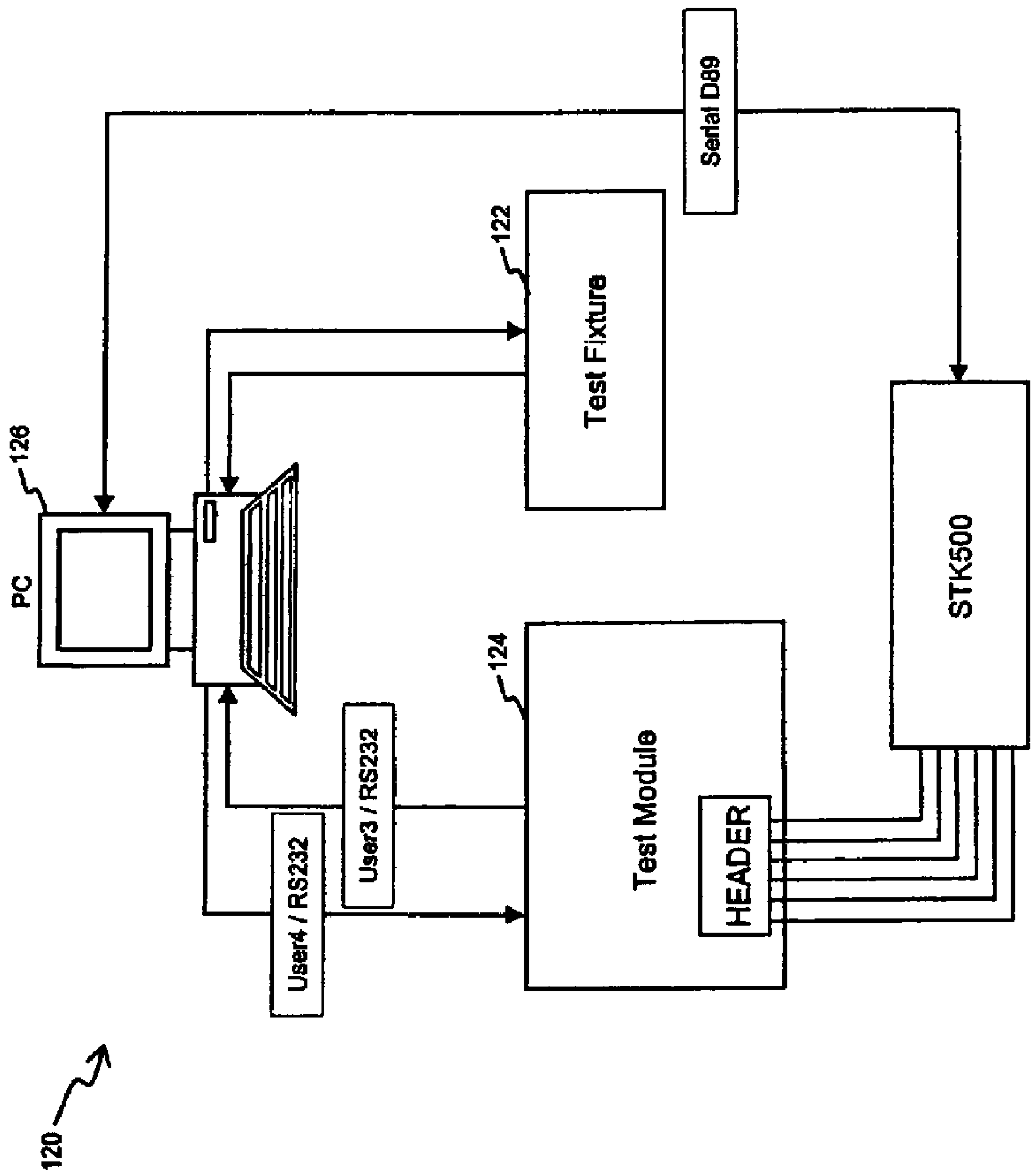
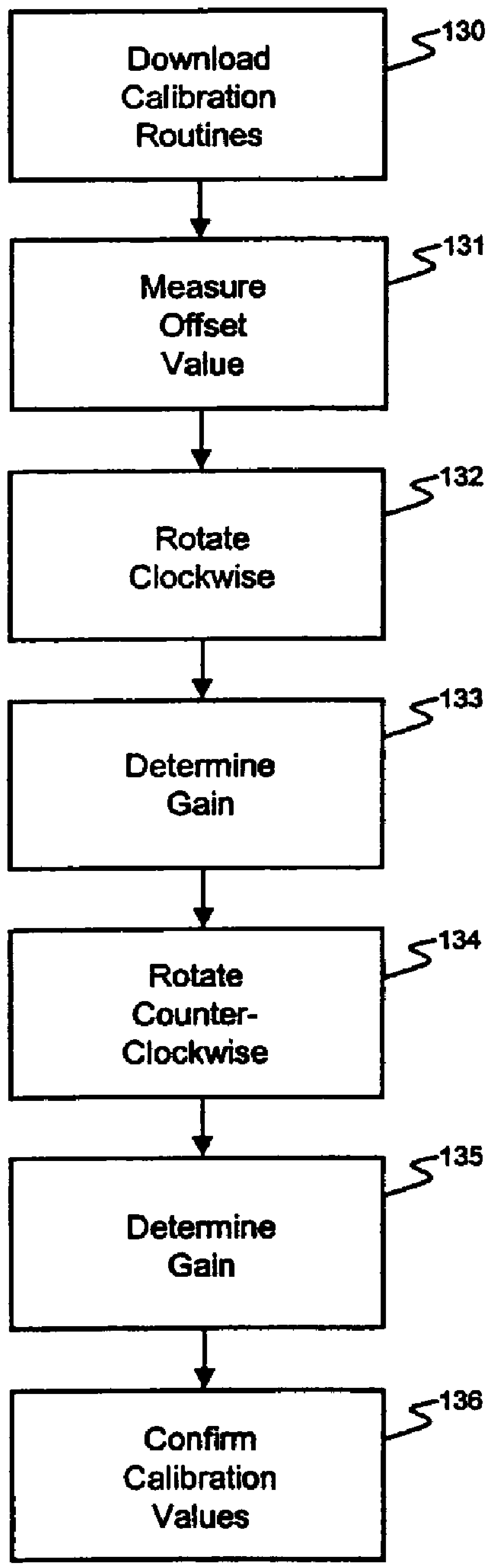

120
PC
126
Test Fixture
122
Serial D89
User4 / RS232
User3 / RS232
124
Test Module
HEADER
STK500

FIG. 9


Download Calibration Routines
130
Measure Offset Value
131
Rotate Clockwise
132
Determine Gain
133
Rotate Counter-Clockwise
134
Determine Gain
135
Confirm Calibration Values
136

POWER TOOL ANTI-KICKBACK SYSTEM WITH ROTATIONAL RATE SENSOR

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a *reissue of U.S. Pat. No. 7,681,659 which is a* continuation of U.S. patent application Ser. No. 11/519,427 filed on Sep. 12, 2006, now U.S. Pat. No. 7,552,781 which in turn is a continuation-in-part of U.S. patent application No. 11/254,146 filed on Oct. 19, 2005, now U.S. Pat. No. 7,410,006 which claims benefit of U.S. Provisional Application No. 60/620,283, filed on Oct. 20, 2004 and U.S. Provisional Application No. 60/675,692 filed on Apr. 28, 2005**[**, The disclosure**]** . *The disclosures* of the above applications **[**is**]** *are* incorporated herein by reference. *More than one reissue application has been filed for the reissue of U.S. Pat. No. 7,681,659. The reissue applications are application Ser. No. 13/423,736 (the present application), Ser. Nos. 13/600,722 and 13/600,927, all of which are continuation reissues of U.S. Pat. No. 7,681,659.*

FIELD

The disclosure relates generally to power tools and, more particularly, to a control system having a rotational rate sensor for detecting the onset of a rotational condition in a power tool.

BACKGROUND

Power tools typically employ a motor that imparts torque to a tool through a spindle. In the case of an electric drill, the motor spindle is coupled through a series of reducing gears to the chuck, which in turn holds the drill bit or other cutting/abrading tool, such as a hole saw, a grinding wheel or the like. Power screwdrivers as well a large rotary hammers work on a similar principle. In each of these cases, the function of the reducing gears or gear train is to reduce the rotational speed of the tool while increasing the rotational torque.

Power routers are somewhat different. The cutting tool of the hand-held router is typically direct coupled to the spindle of the motor. In this case, the full rotational speed of the motor is used without gear reduction to rotate the router bit at high speed. Reciprocating saw and jigsaws use yet another type of gear train that translates the rotational motion of the motor spindle to reciprocating movement.

Generally speaking, all of these power tools may suddenly encounter an impending kickback condition at which time the output torque rapidly rises because of local changes in workpiece hardness, workpiece binding, tool obstruction from burrs and so forth. For example, when drilling a hole with a power drill, some workpieces will develop burrs on the tool exit side of the workpiece. These burrs can engage the flutes of the drill bit, thereby causing a rapid increase in torque as the drill tries to break free. In some instances, the burrs may stop drill bit rotation, thereby causing a strong reaction torque that is imparted to the tool operator as the motor turns the tool in the operator's grasp (rather than turning the drill bit). This reaction is can be problematic if the operator is standing on a ladder and/or holding the tool over their head. A related phenomenon also occurs with power saws. These conditions are hereinafter generally referred to as kickback conditions, regardless of the particular power tool involved or the specific circumstance which give rise to the condition.

Therefore, it is desirable to provide an improved technique for detecting the onset of such kickback conditions in power tools. The statements in this section merely provide background information related to the present disclosure and may not constitute prior art.

SUMMARY

In one aspect of the disclosure, a control system is provided for use in a power tool. The control system includes: a rotational rate sensor having a resonating mass and a controller electrically connected to the rotational rate sensor. The rotational rate sensor detects lateral displacement of the resonating mass and generates a signal indicative of the detected lateral displacement, such that lateral displacement is directly proportional to a rotational speed at which the power tool rotates about an axis of the rotary shaft. Based on the generated signal, the controller initiates a protective operation to avoid undesirable rotation of the power tool.

In another aspect of the disclosure, the control scheme employed by the power tool may initiate different protective operations for different tool conditions.

In different aspect of the disclosure, the control scheme may initiate a protective operations based on input from two different sensors.

In yet another aspect of the disclosure, the control scheme employed by the power tool may initiate protective operations based on the rotational energy experienced by the tool.

For a more complete understanding of the invention, its objects and advantages, reference may be made to the following specification and to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a longitudinal sectional view of an exemplary rotary hammer configured in accordance with the present disclosure;

FIG. **2** is simplified block diagram of an exemplary control system in accordance with present disclosure;

FIG. **3** is a flowchart illustrating an exemplary method for determining the onset of a kickback condition according to the present disclosure;

FIGS. **4**A and **4**B are flowcharts illustrating an exemplary method for determining a kickback condition based on angular displacement according to the present disclosure;

FIG. **5** is a flowchart illustrating an exemplary method for determining a kickback condition based input from two different sensors according to the present disclosure;

FIG. **6** is a block diagram of another exemplary control system in accordance with the present disclosure;

FIG. **7** depicts an exemplary look-up table which may be used by the control system;

FIG. **8** illustrates an exemplary calibration system for a power tool configured with the control system; and

FIG. **9** illustrates an exemplary calibration procedure which may be employed by the control system.

The drawing described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

DETAILED DESCRIPTION

FIG. **1** illustrates an exemplary power tool **10** having a rotary shaft. In this example, the power tool is a hand held rotary hammer. While the following description is provided with reference to a rotary hammer, it is readily understood that the broader aspects of this disclosure are applicable to other types of power tools having rotary shafts, such as drills, circular saws, angle grinders, screw drivers and polishers.

In general, the rotary hammer includes a spindle **12** (i.e., a rotary shaft) drivably coupled to an electric motor **14**. A chuck **16** is coupled at one end of the spindle **12**; whereas a drive shaft **18** of the electric motor **14** is connected via a transmission **22** to the other end of the spindle **12**. These components are enclosed within a housing **18**. Operation of the tool is controlled through the use an operator actuated switch **24** embedded in the handle of the tool. The switch regulates current flow from a power supply **26** to the motor **14**. The power tool may further include a temperature sensor **27**. Although a few primary components of the rotary hammer are discussed above, it is readily understood that other components known in the art may be needed to construct an operational rotary hammer.

The power tool **10** is further configured with a control system **30** for detecting and preventing torque conditions which may cause the operator to lose control of the tool. The control system **30** may include a rotational rate sensor **32**, a current sensor **34**, and a microcontroller **36** embedded in the handle of the power tool **10**. Under certain operating conditions, the power tool **10** may rotate in the operator's grasp. In a rotary hammer, the rotational rate sensor **32** is configured to detect rotational motion of the tool about the longitudinal axis of the spindle **12**. The rotational rate sensor **32** in turn communicates a signal indicative of any rotational motion to the controller **36** for further assessment. For different power tools, it is envisioned that the sensor may be disposed in a different location and/or configured to detect motion along a different axis.

In a preferred embodiment, the operating principle of the rotational rate sensor **32** is based on the Coriolis effect. Briefly, the rotational rate sensor is comprised of a resonating mass. When the power tool is subject to rotational motion about the axis of the spindle, the resonating mass will be laterally displaced in accordance with the Coriolis effect, such that the lateral displacement is directly proportional to the angular rate. It is noteworthy that the resonating motion of the mass and the lateral movement of the mass occur in a plane which is orientated perpendicular to the rotational axis of the rotary shaft. Capacitive sensing elements are then used to detect the lateral displacement and generate an applicable signal indicative of the lateral displacement. An exemplary rotational rate sensor is the ADXRS150 or ADXRS300 gyroscope device commercially available from Analog Devices. Other types of rotational sensors, such as angular speed sensors, accelerometers, etc., are also within the scope of this disclosure.

The microcontroller **36** assesses the rotational motion of the tool to detect rotational conditions which may cause the operator to lose control of the tool. Upon detecting an unacceptable rotational condition, the microcontroller **36** will initiate a protective operation intended to minimize and/or avoid any undesired rotation of the power tool. For instance, when the angular velocity of the tool exceeds some empirically derived threshold, the microcontroller may cut power to the motor. A few exemplary techniques for assessing the rotational condition of the tool are further described below. It is readily understood that other techniques for assessing the rotational condition of the tool are also within the scope of this disclosure.

Operation of an exemplary control circuit **40** is further described below in relation to FIG. **2**. A power supply circuit **29** is coupled to an AC power line input and supplies DC voltage to operate the microcontroller **36'**. The trigger switch **24'** supplies a trigger signal to the microcontroller **36'** which indicates the position or setting of the trigger switch **24'** as it is manually operated by the power tool operator. Drive current for operating the motor **14'** is controlled by a triac drive circuit **42**. The triac drive circuit **42** is, in turn, controlled by a signal supplied by microcontroller **36'**. If desired, the control system **30'** may include a reset circuit **44** which, when activated, causes the microcontroller **36'** to be re-initialized.

The microcontroller **36'** is also supplied with a signal from a current detector circuit **48**. The current detector circuit **48** is coupled to the triac drive circuit **42** and supplies a signal indicative of the conductive state of the triac drive circuit **42**. If for some reason the triac drive circuit **42** does not turn on in response to the control signal from the microcontroller **36'**, this condition is detected by the current detector circuit **48**.

A current sensor **34'** is connected in series with the triac drive circuit **42** and the motor **14'**. In an exemplary embodiment, the current sensor **34'** may be a low resistance, high wattage resistor. The voltage drop across the current sensor **34'** is measured as an indication of actual instantaneous motor current. The instantaneous motor current is supplied to an average current measuring circuit **46** which in turn supplies the average current value to the microcontroller **36'**. The microcontroller **36'** may use the average current to evaluate the rotational condition of the tool.

In operation, the trigger switch **24'** supplies a trigger signal that varies in proportion to the switch setting to the microcontroller **36'**. Based on this trigger signal, the microcontroller **36'** generates a control signal which causes the triac drive circuit **42** to conduct, thereby allowing the motor **14'** to draw current. Motor torque is substantially proportional to the current drawn by the motor and the current draw is controlled by the control signal sent from the microcontroller to the triac drive circuit **42**. Thus, the microcontroller **36'** can control the torque imparted by the motor.

Pulse mode is an exemplary protective operation which may be initiated upon detecting a kickback condition. Upon detecting the onset of a kickback condition, the microcontroller **36'** may operate the motor **14'** in a pulse mode. During pulse mode, the motor current is pulsed at a predetermined frequency with a predetermined on-time. In one exemplary embodiment, the series of current pulses is designed such that the operator may regain control of a twisting tool. For example, the time between pulses may be set between 0.1 and 1 second. Alternatively, the series of current pulses create torque pulses that may have a peak torque that is greater than the average torque delivered by the spindle **12**. In this way, the torque pulses may allow the tool **10** to break through the burrs or workpiece restrictions that are causing the impending kickback condition. Further details regarding this protection operation may be found in U.S. Pat. No. 6,479,958 which is incorporated herein by reference.

Another exemplary protective operation is to reduce the torque imparted to the spindle to a non-zero value that enables an operator of the tool to regain control of the tool. In the context of the control circuit **40** described above, the controller can override the trigger signal from the trigger switch or other operator input commands. Upon detecting a triggering rotational condition, the controller **36'** sends a control signal to the triac drive circuit **46'** which reduces the voltage which in turn reduces the current draw of the motor, thereby reducing the torque imparted to the spindle. For example, the torque could be reduced to 30% of its current operational amount or a predefined fixed torque level. The tool would operate at his reduced level until the operator released the trigger switch and re-engaged it or cycled tool power. Another method would involve resetting torque to its original operation level if the operator regains control of the tool. In this way, the operator has regained control of the tool without terminating or resetting operation of the tool.

Other techniques for reducing the torque imparted to the spindle are also within the scope of this disclosure. For example, DC operated motors are often controlled by pulse width modulation, where the duty cycle of the modulation is proportional the speed of the motor and thus the torque imparted by the motor to the spindle. In this example, the microcontroller may be configured to control the duty cycle of the motor control signal.

Alternatively, the power tool may be configured with a torque transmitting device interposed between the motor and the spindle. In this case, the controller may interface with the torque transmitting device to reduce torque. The torque transmitting device may take the form of a magneto-rheologocical fluid clutch which can vary the torque output proportional to the current fed through a magnetic field generating coil. It could also take the form of a friction plate, cone clutch or wrap spring clutch which can have variable levels of slippage based on a preload holding the friction materials together and thus transmitting torque. In this example, the preload could be changed by driving a lead screw supporting the ground end of the spring through a motor, solenoid or other type of electromechanical actuator. Other types of torque transmitting devices are also contemplated by this disclosure.

In other instances, the protective operation is intended to terminate or reset operation of the tool. Exemplary protective operations of this nature include (but are not limited to) disengaging the motor **14'** from the spindle **12**, braking the motor **14'**, braking the spindle **12**, and disconnecting power to the motor **14'**. Depending on the size and orientation of the tool **10**, one or more of these protective operations may be initiated to prevent undesirable rotation of the tool **10**.

An exemplary method for detecting a rotational condition of the tool is illustrated in FIG. **3**. First, the operator switch is checked at step **52** to determine if the tool is operating. If the switch is not closed, then power is not being supplied to the motor as indicated at **53**. In this case, there is no need to monitor for kickback conditions. Conversely, if the switch is closed, then power is being supplied to the motor as indicated at **54**.

During tool operation, rotational motion of the tool is monitored at **56** based on the signal from the rotational rate sensor. When the rotational rate of the tool exceeds some empirically derived threshold (as shown at **57**), this may indicate the onset of kickback condition; otherwise, processing control returns to the beginning of the algorithm. In addition to rotational rate of the tool about its spindle axis, it is envisioned that the rotational displacement, rotational acceleration, or some combination thereof as derived from the sensor signal may be used to determine the onset of a kickback condition.

Prior to initiating some protective operation, the microcontroller also evaluates the current draw of the motor at **58**. Specifically, the rate of change of the motor current is measured. When the rate of change is positive and exceeds some predetermined threshold, then one or more protective operations are initiated at **60**. If either the rate of change is not positive or the rate of change does not exceeds the threshold, then processing control returns to the beginning of the algorithm. In this case, a sudden change in the current draw is optionally used to confirm the onset of the kickback condition. It is envisioned that inputs from other sensors, such as a temperature sensor, may be used in a similar manner. It is to be understood that only the relevant steps of the control scheme are discussed above, but that other software-implemented instructions may be needed to control and manage the overall operation of the tool.

In another aspect of the present invention, the control scheme employed by the power tool **10** may initiate different protective operations for different tool conditions. For example, the amount of angular displacement experienced by the tool may dictate different protective operations. When angular displacement is within a first range (e.g., less than 31°), the operator is presumed to have control of the tool and thus no protective operations are needed. When the angular displacement exceeds this first range, it may be presumed that the tool has encountered a kickback condition and therefore some protective operation may be needed. In this second range of angular displacement (e.g., between 30° to 90°), the control scheme may initiate a pulse mode in hope of breaking through the restrictions that are causing the impending kickback condition. In contrast, when the angular displacement exceeds the second range (e.g., greater than 90°), it may be presumed that the operator has lost control of the tool. In this instance, a different protective operation may be initiated by the control scheme, such as disconnecting the power to the motor.

Depending on the complexity of the control scheme, three or more ranges of displacement may be defined for a given power tool. Within a range, protective operations may be initiated based on the angular displacement or a combination of parameters, such as angular acceleration, angular velocity, motor current, rate of change of motor current, motor temperature, switch temperature, etc. It is readily understood that the number and size of the ranges may vary for different control schemes and/or different types of tools. It is also envisioned that different protective operations may be initiated based on ranges of other parameters (e.g., ranges of angular velocity). Likewise, one or more protective operations may be associated with different ranges (i.e., tool conditions).

An exemplary method for detecting a rotational condition based on an angular displacement of the power tool is further described below in relation to FIGS. **4**A and **4**B. During tool operation, angular displacement is monitored in relation to a start point (θ_0). In step **61**, this starting point is initialized to zero. Any subsequent angular displacement of the tool is then measured in relation to this reference. Alternatively, the tool may employ a starting point reset function. At power-up, the starting point is set. If the operator repositions the tool (e.g., rotate it at a very slow rate), then the starting point is reset. For example, if the tool is rotated at a rate less than 5 degree per second, then the starting position is reset. Angular displacement is then measured from the new starting point.

Angular displacement of the tool is then monitored at step **62**. In this exemplary embodiment, the angular displacement is measured in relation to the reference value (θ_0) and derived from the rate of angular displacement over time or angular velocity (ω_{TOOL}) as provided by a rotational rate sensor. While the rotational rate sensor described above is presently preferred for determining angular displacement of the tool, it is readily understood that this additional aspect of the present invention is not limited to this type of sensor. On the contrary, angular displacement may be derived from a different type of rotational rate sensor, an acceleration sensor or some other manner for detecting rotational displacement of the tool.

Different protective operations may be initiated based on the amount of angular displacement as noted above. Angular displacement is assessed at steps **64** and **68**. When the angular displacement exceeds some upper threshold (θ_{zone2_min}), then a first protective operation is initiated at step **66**. In this example, power to the motor is disconnected, thereby terminating operation of the tool.

When the angular displacement exceeds some lower threshold (θ_{zone1_min}), then a different protective operation, such as pulsing the motor current, may be initiated at **70**. In this exemplary embodiment, an instantaneous measure of angular velocity must also exceed some minimum threshold before a pulse mode is initiated as shown at step **69**. If neither of these criteria are met, no protective actions are taken and operating conditions of tool continue to be monitored by the control scheme.

During pulse mode, the control scheme continues to monitor tool operating conditions. Hazardous conditions may be monitored as shown at step **72**. For instance, to prevent motor burn up, motor current may be monitored. If the motor current spikes above some predefined threshold, then power to the motor is disconnected at **73**. To protect the tool operator, angular displacement may also be monitored. If angular displacement exceeds a threshold indicative of lost control, then the power to the motor is also disconnected. It is readily understood that other types of hazardous conditions may be monitored.

In addition, pulse mode is only maintained for a brief period of time. A timer is initiated at step **71** and pulse mode continues until the timer has expired as shown at **76**. During this time, the control scheme may also monitor if the restrictions that caused the kickback condition have been overcome as shown at step **74**. If the restrictions are overcome, then pulse mode is discontinued at step **75**. When the timer expires without overcoming the restrictions, then power to the motor is disconnected as shown at **77**.

An exemplary method for detecting a rotational condition based on input from at least two sensors is described below in relation to FIG. **5**. First, the operator switch is checked at step **82** to determine if the tool is operating. If the switch is not closed, then power is not being supplied to the motor as indicated at **83**. In this case, there is no need to monitor for kickback conditions. Conversely, if the switch is closed, then power is being supplied to the motor as indicated at **84**.

During tool operation, rotational motion of the tool is monitored at **86** based on the signal from the rotational rate sensor. When the rotational rate of the tool exceeds some empirically derived threshold (as shown at **87**), this may indicate the onset of kickback condition; otherwise, processing control returns to the beginning of the algorithm. In addition to rotational rate of the tool about its spindle axis, it is envisioned that the rotational displacement, rotational acceleration, or some combination thereof as derived from the sensor signal may be used to determine the onset of a kickback condition.

Prior to initiating some protective operation, the microcontroller also evaluates the current draw of the motor at **88**. Specifically, the rate of change of the motor current is measured. When the rate of change is positive and exceeds some predetermined threshold, then one or more protective operations are initiated at **90**. If either the rate of change is not positive or the rate of change does not exceeds the threshold, then processing control returns to the beginning of the algorithm. In this case, a sudden change in the current draw is used to confirm the onset of the kickback condition. While the above description was provided with reference to a rotational rate sensor and a current sensor, it is readily understood that the broader aspects of the present invention encompass making such a determination may be based on input from other types of sensors.

Determination of a rotational condition may also be based on other types of criteria. For example, a rotational condition may be assessed based on the rotational energy experienced by the power tool. In this example, rotational energy is defined as $E_{\omega\_TOOL}=(I)(\omega_{TOOL})^2$, where I is the moment of inertia and ω_{TOOL} is the angular velocity. For this computation, the rate of angular displacement could be measured by a rotational rate sensor; whereas, the moment of inertia of the tool (I_{TOOL}) could be preprogrammed into the controller based on the mass properties of the power tool (e.g., mass, rotation inertia and a center of gravity position) and a distance measure between the center of gravity position and the spindle axis. Initiating a protective operation based on E_{ω_TOOL} is desirable because the energy condition is not tool specific and therefore could be applied to a variety of anti-kickback applications. Other criteria for determining a kickback condition are also within the broader aspects of the present invention.

FIG. **6** depicts another exemplary control system **100**. The control system is comprised generally of a rotational rate sensor **32"**, sensor processing logic **110**, a motor controller **36"**, a motor **14"** and a power supply **29"**. The rotational sensor **32"** may be a single sensor, such as a gyroscope or accelerometer, or two or more sensors disposed within the tool. Sensor processing logic **110** may be implemented in software or hardware. Likewise, power-up and calibration functions may be performed with hardware, software or combination thereof.

During normal tool operation, sensor output is processed as follows. In this exemplary embodiment, the sensor output is rotational velocity. The sensor output passes through a low pass filter **111** before going into a null point and gain calibration routine **112**. The purpose of the calibration routine is to remove any offset and compensate for any gains of the rate sensor before determining rotational conditions. Through either software or hardware means, the rate signal is then integrated at **113** to get position and derived at **114** to get acceleration. All three of the signals are then input to a comparator **115** which checks whether or not the value has exceeded a defined threshold. A logic block **116** (e.g., AND, OR, etc.) is configured so that any or all of the thresholds must be met before indicating a trip signal which is sent to the motor controller **36"**. Although the tests are shown as comparators on position, rate, or acceleration, it is noted that the tests are not limited to thresholds alone. Combinations of each variable can be used such as if the rate is less than W then position must be greater than X for a trip event to occur. In another example, if rate is greater than Y then position must be greater than Z for a trip to occur.

In lieu of comparison functions, the control system may employ a look-up table as shown in FIG. **7**. In this example, rotational position is charted against rotational velocity. Look-up tables having other parameters and further dimensions are also contemplated. Additionally, the values in the table may indicate the type of protective operation or point to another table for more processing.

FIG. **8** illustrates an exemplary calibration system **120** for a power tool **10** configured with the control system described above. The calibration system **120** is generally comprised of a test fixture **122**, a test module **124**, and a personal computer **126**. To calibrate a power tool, the test module is first removed from the power tool and affixed to the test fixture **122**. The rotational rate sensor along with the software routines which implement the control schemes described above are contained within the test module **124**. The test fixture **122** is generally operable to rotate the test module **124** in a manner that may be experienced when module resides in the power tool. The personal computer **126** is configured to control operation of the test fixture **122** in accordance with a calibration routine as well as to interface with the test module **124** during the calibration process. It is also envisioned that in other configurations the entire power tool may affixed to and rotated by the test fixture.

An exemplary calibration procedure for a power tool is further described in relation to FIG. **9**. First, a calibration routine is downloaded at **130** from the PC into the test module **124**. The calibration routine cooperatively operates with the software routines of the control system to determine calibration values for the control system. The calibration procedure begins with the test module **124** measuring the output of the rotational rate sensor at **131** while the power tool remains stationary. This measured output serves as an offset or null calibration value (i.e., output value of the sensor when angular velocity is zero) for the rotational rate sensor. Next, the personal computer commands the test fixture **132** to rotate the test module **124** (e.g., clockwise) at predefined angular velocity for a predefined period of time. For example, the test fixture **122** may rotate the test module **124** at 50 degrees per second until 50 degrees of rotation is reached. During this movement, the test module is capturing the angular velocity as reported by the rotational rate sensor. The test module will compare the angular velocity **133** as reported by the rotational rate sensor with the known angular velocity at which the test module was rotated by the test fixture to determine a gain value. The gain value is temporarily stored by the test module for subsequent processing.

The personal computer then commands the test fixture **134** to rotate the test module in an opposite direction (e.g., counter-clockwise) at a predefined angular velocity for a predefined period of time. The test module again captures the angular velocity as reported by the rotational rate sensor and compares these captured values **135** with the known angular velocity to determine another gain value. The second gain value is also stored by the test module. Thus, there is a gain value for each direction of tool rotation.

To confirm the calibration values, the personal computer re-executes the calibration procedure at **136**. In other words, the test fixture is commanded to rotate the test module at the predefined angular velocity in one direction and then in the opposite direction. The test module again captures the angular velocity as reported by the rotational rate sensor. At this point, the test module adjusts the measured angular velocity using the applicable calibration values and compares the adjusted values to the known angular velocity at which the test module was rotated by the test fixture. If the adjusted values fall within some defined tolerance of the expected values, these calibration values are sent by the test module to the personal computer. These calibration values can then be downloaded into memory of a power tool. During operation, the control system of the power tool will use the calibration values to adjust the output reported by the rotational rate sensor. It is readily understood that this type of calibration procedure may be undertaken for each power tool or once for each family of power tools.

The above description is merely exemplary in nature and is not intended to limit the present disclosure, application, or uses.

What is claimed is:

1. A method for initiating a protective response in a power tool having a rotary shaft, comprising:

monitoring rotational motion of the power tool about a longitudinal axis of the rotary shaft using a rotational motion sensor disposed in the power tool;

computing angular displacement of the power tool about the axis of the rotary shaft using a controller disposed in the power tool and based on input from the rotational motion sensor;

initiating a protective operation by the controller when an operating condition of the power tool exceeds a threshold and the angular displacement of the power tool falls within a range of angular displacements; and

initiating a protective operation by the controller when the operating condition of the power tool is less than the threshold but the angular displacement of the power tool exceeds the range of angular displacements.

2. The method of claim **1** further comprises initiating a protective operation when angular velocity of the power tool about the axis exceeds a velocity threshold and the angular displacement of the power tool falls within the range of angular displacements.

3. The method of claim **1** further comprises initiating a protective operation when angular displacement of the power tool falls within a range of angular displacements and angular acceleration of the power tool about the axis exceeds an acceleration threshold.

4. The method of claim **1** further comprises arranging the rotational motion sensor at a location in the power tool spatially separated from the rotary shaft.

5. The method of claim **1** further comprises employing a rotational motion sensor that measures rotational velocity based on Coriolis acceleration.

6. The method of claim **1** wherein the protective operation when angular displacement of the power tool falls within a range of angular displacements is different than the protective operation when angular displacement of the power tool exceeds the range of angular displacements.

7. The method of claim **1** wherein the protective operation is selected from the group consisting of pulsing a motor of the power tool, braking the rotary shaft, braking the motor, disengaging the motor from the rotary shaft, discontinuing power delivered to the motor and reducing slip torque of a clutch disposed between the motor and the rotary shaft.

8. A method for initiating a protective response in a power tool having a motor drivably coupled to a rotary shaft to impart rotary motion thereto, comprising:

monitoring rotational motion of the power tool about a longitudinal axis of the rotary shaft using a rotational motion sensor disposed in the power tool;

determining angular displacement of the power tool about the axis of the rotary shaft from a baseline using a controller disposed in the power tool and based on input from the rotational motion sensor;

initiating a protective operation in the power tool by the controller when a first operating condition of the power tool exceeds a first operating threshold and angular displacement of the power tool falls within a first range of angular displacements; and

initiating a protective operation in the power tool by the controller when a second operating condition of the power tool exceeds a second operating threshold and angular displacement of the power tool falls within a second range of angular displacements, where the second operating condition is different than the first operating condition and the second range of angular displacements is mutually exclusive of the first range of angular displacements.

9. The method of claim **8** further comprises initiating a protective operation when angular velocity of the power tool about the axis exceeds a velocity threshold and angular displacement of the power tool falls within the first range of angular displacements.

10. The method of claim **9** further comprises initiating a protective operation when angular velocity of the power tool is less than the velocity threshold and angular displacement of the power tool falls within the second range of angular displacements.

11. The method of claim **8** further comprises arranging the rotational motion sensor at a location in the power tool spatially separated from the rotary shaft.

12. The method of claim **8** further comprises employing a rotational motion sensor that measures rotational velocity based on Coriolis acceleration.

13. The method of claim **8** further comprises periodically resetting the baseline when angular velocity of the power tool about the axis is less than a velocity threshold.

14. The method of claim **8** wherein the protective operation is selected from the group consisting of pulsing a motor of the power tool, braking the rotary shaft, braking the motor, disengaging the motor from the rotary shaft, discontinuing power delivered to the motor and reducing slip torque of a clutch disposed between the motor and the rotary shaft.

15. A method for initiating a protective response in a power tool having a rotary shaft, comprising:

monitoring rotational motion of the power tool about a longitudinal axis of the rotary shaft using a rotational motion sensor disposed in the power tool;

computing angular displacement of the power tool about the axis of the rotary shaft from a baseline using a controller disposed in the power tool and based on input from the rotational motion sensor;

periodically resetting the baseline when angular velocity of the power tool about the axis is less than a velocity threshold;

initiating a protective operation by the controller when an operating condition of the power tool exceeds a threshold and the angular displacement of the power tool falls within a range of angular displacements; and

initiating a protective operation by the controller when the operating condition of the power tool is less than the threshold but the angular displacement of the power tool exceeds the range of angular displacements.

16. A method for controlling operation of a power tool having a rotary shaft, comprising:

monitoring rotational motion of the power tool about a longitudinal axis of the rotary shaft using a rotational motion sensor disposed in the power tool, wherein the rotation motion sensor is further defined as an accelerometer;

computing angular displacement of the power tool about the axis of the rotary shaft based on input from the rotational motion sensor and using a controller disposed in the power tool; and

driving the rotary shaft at a given rotational speed, where the given rotational speed is set to a non-zero value based on the angular displacement of the power tool.

17. The method of claim 16 wherein the computing angular displacement further comprises determining the angular displacement of the power tool in relation to a reference position and driving the rotary shaft at the given rotational speed when the angular displacement from the reference position exceeds a displacement threshold.

18. The method of claim 16 wherein the computing angular displacement further comprises determining the angular displacement of the power tool in relation to a reference position and lowering rotational speed of the rotary shaft to a non-zero value when the angular displacement from the reference position exceeds a displacement threshold.

19. The method of claim 16 further comprises arranging the rotational motion sensor at a location in the power tool spatially separated from the rotary shaft.

20. A method for controlling operation of a power tool having a rotary shaft, comprising:

monitoring rotational motion of the power tool about a longitudinal axis of the rotary shaft using a rotational motion sensor disposed in the power tool, wherein the rotation motion sensor is further defined as a gyroscope;

computing angular displacement of the power tool about the axis of the rotary shaft based on input from the rotational motion sensor and using a controller disposed in the power tool; and

driving the rotary shaft at a given rotational speed, where the given rotational speed is set to a non-zero value based on the angular displacement of the power tool.

21. The method of claim 20 wherein the computing angular displacement further comprises determining the angular displacement of the power tool in relation to a reference position and driving the rotary shaft at the given rotational speed when the angular displacement from the reference position exceeds a displacement threshold.

22. The method of claim 20 wherein the computing angular displacement further comprises determining the angular displacement of the power tool in relation to a reference position and lowering rotational speed of the rotary shaft to a non-zero value when the angular displacement from the reference position exceeds a displacement threshold.

23. The method of claim 20 further comprises arranging the rotational motion sensor at a location in the power tool spatially separated from the rotary shaft.

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