

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
21 September 2006 (21.09.2006)

PCT

(10) International Publication Number
WO 2006/098915 A1

(51) International Patent Classification:
B62D 5/04 (2006.01)

(21) International Application Number:
PCT/US2006/007734

(22) International Filing Date: 3 March 2006 (03.03.2006)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11/078,028 11 March 2005 (11.03.2005) US

(71) Applicant (for all designated States except US): **TRW AUTOMOTIVE U.S. LLC** [US/US]; 34201 Van Dyke Avenue, Sterling Heights, Michigan 48311 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **FARDOUN, Abbas** [US/US]; 7755 Payne Street, Dearborn, Michigan 48126 (US). **MILLER, Joseph** [US/US]; 29168 Forest Hill Drive, Farmington Hills, Michigan 48331 (US).

(74) Agent: **PAVELKO, Douglas; MACMILLAN, SOBANSKI & TODD, LLC**, One Maritime Plaza, Fourth Floor, 720 Water Street, Toledo, Ohio 43604 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

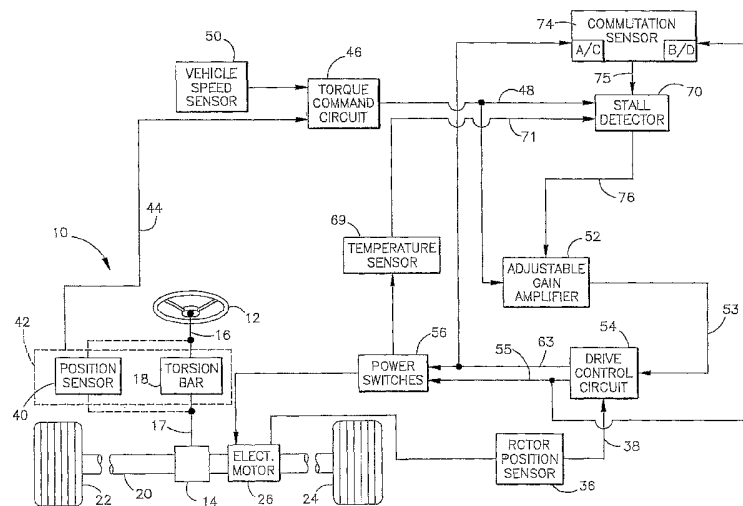
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD AND APPARATUS FOR DETECTING A FAILED TEMPERATURE SENSOR IN AN ELECTRIC ASSIST STEERING SYSTEM



(57) Abstract: A method and system are provided for controlling an electric assist motor in a vehicle steering system during an enablement of an overuse algorithm. Electric power is provided to the electric assist motor of the vehicle steering system via a switching circuit. Temperature of one of at least electric assist motor and power driving circuitry that provides power to the electric assist motor is sensed by a temperature sensor, and a stall detector being responsive to the temperature sensor output signal (69, 70). A determination is made whether the sensed temperature of the one of at least electric assist motor and power driving circuitry is increasing over a predetermined period of time. The electric power provided to electric assist motor is reduced in response to a lack of increase in said sensed temperature.

METHOD AND APPARATUS FOR DETECTING A FAILED TEMPERATURE SENSOR IN AN ELECTRIC ASSIST STEERING SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

5

This application claims priority to U.S. Non-Provisional Application serial number 11/078,028, filed March 11, 2005, the disclosure of which is incorporated herein by reference in its entirety.

10 STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

Not Applicable.

BACKGROUND OF THE INVENTION

15

FIELD OF THE INVENTION

The present invention is directed to an electric assist steering system, and, more particularly, to a method and apparatus for detecting a failed thermistor in an
20 electric assist steering system and controlling the electrical steering motor.

DESCRIPTION OF THE RELATED ART

Electric assist steering systems are well known in the art. In such electric
25 assist steering systems, an electric assist motor, when energized, provides torque assist to aid the driver in turning steerable wheels of the vehicle. The electric assist motor is typically controlled in response to both steering torque applied to the vehicle steering wheel and measured vehicle speed. A controller monitors steering torque and controls a drive circuit to, in turn, control current applied to the electric assist motor. Such
30 drive circuits typically include field effect transistors (FET's) or other forms of solid

state switches operatively coupled between the vehicle battery and the electric assist motor. Current is controlled by pulse width modulation of the FET's or switches.

If steering torque is applied and the steerable wheels are held immovable, such as when the wheels are against a curb, the temperature of both the electric assist motor and the FET's rise. Such a condition is referred to as a stall condition of the electric assist motor. If the stall condition lasts for an extended period, the motor and/or FET's can overheat and fail.

U.S. Pat. No. 6,338,016 to Miller et. al. discloses an electric assist steering system that includes a stall detection apparatus for an electric assist steering system. A temperature sensor monitors the temperature of a power switch. A stall detector operatively reduces power to the electric assist motor to a respective power level for reducing the output torque of the electric assist motor in response to the respective temperature threshold measured.

U.S. Pat. No. 5,517,415 to Miller, which is assigned to TRW, Inc., discloses a stall detection apparatus for an electric assist steering system. A stall detector controls electrical current which is supplied to the electric motor in response to detecting the occurrence of a stall condition. This prevents damage to both the motor and drive circuitry.

U.S. Pat. No. 4,532,567 to Kade discloses an electric assist steering system which measures actual current through the motor. If the measured current exceeds a limit, the motor drive current is reduced.

U.S. Pat. No. 5,097,918 to Daido et al. discloses an electric assist steering system that includes an electric assist motor connected to a steering mechanism through an electromagnetic clutch. The system further includes a sensor for sensing rotational motion of the electric assist motor. When torque is sensed and the rotary sensor indicates that the motor is not rotating, the system disengages the electromagnetic clutch.

U.S. Pat. No. 4,878,004 to Shimizu discloses an electric assist steering system that includes an electric assist motor and a controller for controlling operation

of the motor. The system further includes a current sensor which senses the magnitude of the actual current through the electric assist motor. An average value motor current is determined. The motor is controlled in response to the determined average current value.

5 The above references disclose methods for sensing current supplied to the electric motor for detecting a stall or over-use condition and adjusting the current level supplied to the electric motor for operating the electric motor at an operating level that prevents damage to the electric motor. One method used for detecting power dissipated by the electric motor and motor driving circuitry is to utilize a temperature
10 sensor for monitoring the temperature of the power driving circuitry or the electric motor. Based on a respective temperature threshold reached, the current is reduced. However, none of the systems identify a method for detecting a failed temperature sensor which would result in the electric assist motor operating under full load when it is not desirable to do so. Under such conditions, if the temperature sensor is non-
15 operational, damage to the system and loss of steering assist may occur.

SUMMARY OF THE INVENTION

20 The present invention has the advantage of detecting a failed temperature sensor in an electric assist steering system and controlling the electric power to the electric assist motor in response thereto for protecting the electric assist motor from over-use and damage.

25 In one aspect of the present invention, a method is provided for controlling an electric assist motor in a vehicle steering system during an enablement of an overuse algorithm. Electric power is provided to the electric assist motor of the vehicle steering system via a switching circuit. Temperature of one of at least an electric assist motor and a power driving circuitry that provides power to the electric assist motor is sensed. A determination is made whether the sensed temperature of the one of the at least electric assist motor and power driving circuitry is increasing over a

predetermined period of time. The electric power provided to electric assist motor is reduced in response to the sensed a lack of increase in said sensed temperature.

In yet another aspect of the present invention, a method is provided for controlling an electric assist motor in a vehicle steering system during an enablement of an overuse algorithm. Electric power is provided to the electric assist motor of the vehicle steering system via a switching circuit. Temperature of one of at least an electric assist motor and a power driving circuitry that provides power to the electric assist motor is sensed. A determination is made whether the sensed temperature of the one of the at least electric assist motor and power driving circuitry is increasing over a predetermined period of time. The electric power provided to electric assist motor is reduced in response to the sensed a lack of increase in said sensed temperature. A stall detector receives a sensed temperature signal. A control signal is output for adjusting said electric power provided to said electric assist motor.

In yet another aspect for the previous embodiment of the present invention, a control signal is provided to a gain amplifier for adjusting a received torque command signal indicative of an applied steering torque input.

In yet another aspect for the previous embodiment of the present invention, an adjusted torque command signal is provided to a switching circuit for limiting the electric power to the electric assist motor.

In yet another aspect of the present invention, a method is provided for controlling an electric assist motor in a vehicle steering system during an enablement of an overuse algorithm. Electric power is provided to the electric assist motor of the vehicle steering system via a switching circuit. Temperature of one of at least the electric assist motor and a power driving circuitry that provides power to the electric assist motor is sensed by taking at least two consecutive temperature measurements over a predetermined period of time. A determination is made whether the sensed temperature of the one of at least the electric assist motor and the power driving circuitry is increasing over the predetermined period of time by adding a calibration constant to the second measured temperature and subtracting the second measured

temperature from the first measured temperature and producing a negative temperature difference. The electric power provided to the electric assist motor is reduced in response to a lack of increase in the sensed temperature.

In yet another aspect of the present invention, an apparatus is provided for
5 controlling an electric assist motor in a vehicle steering system during an enablement of an over-use algorithm. A switching circuit provides electric power to the electric assist motor. The electric assist motor provides steering assistance to the vehicle steering system. A torque command circuit provides a torque command signal to the electric assist motor for demanding a respective output torque from the electric assist
10 motor in response an applied steering torque signal. A temperature sensor is coupled to one of at least the electric assist motor and the switching circuit for sensing a temperature of the one of at least the electric assist motor and the switching circuit and for generating an output signal in response to the sensed temperature. A stall detector is responsive to the output signal from the temperature sensor during an enablement of
15 the over-use algorithm and is operable to reduce the electric power to the electric assist motor by adjusting the torque command signal when the sensed temperature of the one of at least the electric assist motor and the switching circuit does not increase over a predetermined period of time.

In yet another aspect for the preceding embodiment of the present invention, an
20 adjustable gain amplifier is coupled to the torque command circuit and the stall detector for modifying the torque command signal received from the torque command circuit in response to the stall detector detecting the sensed constant temperature over the predetermined period of time.

In yet another aspect for the preceding embodiment of the present invention, the
25 torque command signal is modified for reducing the torque output of the electric motor to a predetermined percentage of a maximum steering assistance of the electric assist motor.

In yet another aspect of the present invention, an apparatus is provided for controlling an electric assist motor in a vehicle steering system during an enablement

of an over-use algorithm. A switching circuit provides electric power to the electric assist motor. The electric assist motor provides steering assistance to the vehicle steering system. A torque command circuit provides a torque command signal to the electric assist motor for demanding a respective output torque from the electric assist motor in response an applied steering torque signal. A temperature sensor is coupled to one of at least the electric assist motor and the switching circuit for sensing a temperature of the one of at least the electric assist motor and the switching circuit and for generating an output signal in response to the sensed temperature. A stall detector is responsive to the output signal from the temperature sensor during an enablement of the over-use algorithm and is operable to reduce the electric power to the electric assist motor by adjusting the torque command signal when the sensed temperature of the one of at least the electric assist motor and the switching circuit does not increase over a predetermined period of time. At least two consecutive temperature measurements are taken by the temperature sensor during the predetermined period of time.

15

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram illustrating an electric assist steering system made in accordance with the present invention.

20

Figure 2 is a cross-sectional view of the electric assist motor shown in Figure 1.

Figure 3 is a circuit schematic diagram of a portion of the power switches shown in Figure 1.

Figure 4 is a flowchart showing a stall detection process for use with the system of Figure 1.

25

Figure 5 is a flowchart showing an alternative stall detection process for use with the system of Figure 1.

Figure 6 is a flowchart showing a thermistor failure detection processes for use with the system of Figure 1.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

5

FIG. 1 illustrates a preferred embodiment of a vehicle electric assist steering system **10** in accordance with the present invention. The system **10** includes a vehicle steering wheel **12** connected to an input shaft **16** and a pinion gear **14** connected to a pinion shaft **17**. The input shaft **16** is coupled to the pinion shaft **17** through a torsion bar **18**. The torsion bar **18** twists in response to torque applied to the vehicle steering wheel **12** to permit relative rotation between the input shaft **16** and the pinion shaft **17**. Stops, not shown, limit the amount of relative rotation between the input shaft **16** and the pinion shaft **17** in a manner known in the art.

The pinion gear **14** has a set of helical gear teeth (not shown) which meshingly engage a set of straight cut gear teeth (not shown) on a linear steering member or rack **20**. The rack **20** is coupled to vehicle steerable wheels **22**, **24** with steering linkage in a known manner. The pinion gear **14** together with the rack **20** forms a rack and pinion gear set. When the steering wheel **12** is turned, the rack and pinion gear set converts the rotary motion of the steering wheel into linear motion of the rack **20**. When the rack **20** moves linearly, the steerable wheels **22** and **24** pivot about their associated steering axis and the vehicle is steered.

An electric assist motor **26** is drivingly connected with the rack **20** through, preferably, a ball-nut drive arrangement (not shown). It will be understood and appreciated that the apparatus and method of the present invention are equally applicable to other types of drive arrangements. The motor **26**, when energized, provides assist to aid in steering movement of the rack **20**. In a preferred embodiment of the present invention, the motor **26** is a variable reluctance motor. A variable reluctance motor is preferred because of its relatively small size, low friction, and high torque-to-inertia ratio.

The motor **26** includes a stator **28** (FIG. 2) having a plurality of stator poles **30**. Associated with each stator pole **30** is a stator coil (not shown) wrapped around the stator pole. The motor **26** also includes a rotor **32** having a plurality of rotor poles **34**. In the preferred embodiment, the motor **26** is a four phase motor which includes eight
5 stator poles **30** and six rotor poles **34**.

The stator poles **30** are arranged so as to be energized in pairs designated Aa, Bb, Cc, and Dd. When a pair of stator poles **30** is energized, the rotor **32** moves so as to minimize the reluctance between the energized stator poles and the rotor poles **34**. Minimum reluctance occurs when a pair of rotor poles **34** is aligned with the
10 energized stator poles **30**. For example, in the position of the motor **26** illustrated in FIG. 2, there is minimum reluctance between the pair of stator poles Aa and the rotor poles **34** which are aligned with the stator poles Aa. Once minimum reluctance is achieved, as determined by the relative position of the rotor and stator, the energized stator poles **30** are de-energized and an adjacent pair of stator poles is energized to
15 continue to cause rotation of the rotor **32**.

The direction of rotation of the rotor **32** is controlled by the sequence in which the stator poles **30** are energized. For example, to rotate the rotor **32** clockwise from its position in FIG. 2, the stator pole pair Dd is next energized. To rotate the rotor **32** counterclockwise from the position illustrated in FIG. 2, the stator pole pair
20 Bb is next energized.

The torque produced by the motor **26** is controlled by the amount of current through the stator coils. A preferred manner for controlling a variable reluctance motor so as to control motor torque and direction is fully disclosed in U.S. Pat. No. 5,257,828 to Miller et al., and assigned to TRW Inc., the disclosure of which is fully incorporated
25 herein by reference.

As illustrated in FIG. 1, a rotor position sensor **36** senses the position of the rotor **32** relative to the stator **28** and provides a rotor position signal **38** indicative of that relative position. In the preferred embodiment, the rotor position sensor **36** is a discrete sensor. It is contemplated that, alternatively, operating parameters of the

motor 26 can be used to sense rotor position. For example, rotor position can be determined by monitoring the current through the stator coils associated with unenergized stator poles 30. One suitable arrangement for sensing rotor position without a discrete sensor is disclosed in U.S. Pat. No. 5,072,166, which is incorporated
5 herein by reference.

Referring back to FIG. 1, a shaft position sensor 40 is connected with the input shaft 16 and the output shaft 17. The shaft position sensor 40 in combination with the torsion bar 18 forms a torque sensor indicated schematically at 42. The shaft position sensor 40 provides a signal 44 indicative of the relative rotational position
10 between the input shaft 16 and the output shaft 17. The relative rotational position between the input shaft 16 and the output shaft 17 is indicative of the steering torque applied by the vehicle operator to the vehicle steering wheel 12. Therefore, the output signal 44 of the shaft position sensor 40 is indicative of the steering torque applied to the vehicle steering wheel 12 and is referred to as the applied steering torque signal.

The applied steering torque signal 44 is connected to a torque command circuit 46. The torque command circuit 46 determines the assist torque desired from the motor 26. The assist torque determined by the torque command circuit 46 is a function of two parameters: (i) the value of the applied steering torque signal 44, and (ii) vehicle speed. A vehicle speed sensor 50 provides a vehicle speed signal to the
15 torque command circuit 44 indicative of the vehicle speed. Typically, the amount of torque assist desired from the motor 26 decreases as vehicle speed increases. This is referred to in the art as speed proportional steering.

The torque command circuit 46 provides a torque command signal 48 indicative of the torque assist value which is desired from the assist motor 26. The
25 torque command signal 48 is output to an adjustable gain amplifier 52. The adjustable gain amplifier 52 amplifies the torque command signal 48 and outputs an amplified torque command signal 53.

The amplified torque command signal 53 is connected to a drive control circuit 54. Preferably, the drive control circuit 54 is a microprocessor or

microcomputer. Alternatively, the drive control circuit **54** may be an integrated circuit or part of a larger control circuit configured to control the electric assist motor **26**. The rotor position signal **38** is also connected to the drive control circuit **54**. The drive control circuit **54** utilizes the amplified torque command signal **53** and the rotor position signal **38** to determine the required motor energization current and motor energization sequence to achieve the requested steering direction. The drive control circuit **54** outputs motor control signals **55** and **63** to a set of power switches **56**. The motor control signals **55** and **63** control which stator pole pair (i.e., Aa, Bb, Cc, or Dd) or pairs are energized and also control the energization current. Although a pair of control lines is shown, each pole pair typically has its own associated control line, i.e., there are four control lines between the drive control circuit **54** and the power switches **56**. It will be appreciated that the apparatus and method of the present invention also is applicable to other drive control and power switching arrangements, such as where each stator pole pair is controlled by two or more power switches.

The power switches **56** are pulse width modulated to control the motor current. To ensure smooth operation of the motor **26**, the position of the rotor **30** can be estimated at predetermined times between actual rotor position measurements. This estimation is made on the basis of certain known conditions and certain assumptions. Suitable methods of rotor position estimation are described in an IEEE paper entitled "A Simple Motion Estimator For VR Motors" by W. D. Harris and J. H. Lang, IEEE Industry Applications Society Annual Meeting, October 1988 and in a paper entitled "A State Observer for Variable Reluctance Motors: Analysis and Experiments" by A. Lumsdaine, J. H. Lang, and M. J. Balas, 19th ASILOMAR Conference on Circuits, Systems & Computers, Nov. 6-8, 1985. The disclosures of both of these papers are incorporated herein by reference.

FIG. 3 illustrates a power switch circuit of the power switches **56** associated with one stator coil pair Aa. One side of the stator coil Aa is connected to electrical ground through a main drive switch **58**. The other side of the stator coil Aa is connected to the vehicle battery through a switch **62** and an LC filter network **60**. The

drive control circuit **54** (FIG. 1) outputs the motor control signals **55** and **63** to the control terminal of the switch **58** and switch **62**, respectively. The motor control signals **55** and **63** are pulse width modulated by the drive control circuit **54** to control the current through the stator coil pair Aa. Diodes **64** and **65** provide fly-back current control. Zener diodes **66** and **67** provide over voltage protection.

Referring back to FIG. 1, the motor **26** is energized through control of the power switches **56** to cause the rotor **32** to rotate in the desired direction with the desired torque. Rotation of the rotor **32** results in linear movement of the rack **20**. Linear movement of the rack **20** results in turning of the vehicle steerable wheels **22** and **24** to steer the vehicle.

To detect a motor stall condition for the purpose of preventing overheating of the motor **26** or the solid state switches **58** and **62** in the switch circuit, the system **10** includes a stall detector **70**. The stall detector **70** is operative to control the amount of electrical power being supplied to the electric motor **26** by the power switches **56** in response to a motor stall condition.

A temperature sensor **69**, preferably a thermistor, is coupled with the switches **56** for detecting a temperature condition of the switches. The temperature sensor **69** provides an output signal **71** to the stall detector **70** which has a value indicative of the temperature condition of the switches **56**. The stall detector **70** continually monitors the temperature of the switches **56** through the output signal **71** from the temperature sensor **69**.

The stall detector **70** is responsive to the temperature condition of the switches **56**. In particular, the action provided by the stall detector **70** during the existence of a stall condition varies as a function of the switch temperature condition.

The operation of the stall detector **70**, (i.e., whether it is enabled or disabled) also may be contingent upon temperature. For example, when the temperature condition of the switches **56** is greater than or equal to a first predetermined threshold temperature, the stall detector **70** is enabled. Conversely, the stall detector **70** is

disabled when the temperature condition of the switches **56** is less than the first temperature threshold.

Preferably, when the stall detector **70** is enabled, such as may be based on switch temperature, and a stall condition is detected, the stall detector **70** is operative
5 to reduce electrical power to the motor **26** to a first level. Further, upon determining the existence of a stall condition and upon determining the temperature condition of the switches **56** is greater than the first threshold but less than a second threshold, the stall detector **70** is effective to reduce electrical power to a second level. The second level is different and preferably lower than the first operative level. If the temperature
10 condition of the switches is equal to or exceeds the second temperature threshold, the stall detector **70** is operative to reduce the power applied to the motor to yet a different third level. Illustrative examples of the stall detector **70** controlling the electrical power supplied to the electric motor **26** follow.

Provided the stall detector **70** is enabled, it determines whether a stall
15 condition exists. U.S. 6,333,016 Patent to Miller et. al., which discloses methods for determining whether an electric assist motor is in a stall condition is incorporated by reference in entirety herein.

The flowcharts for detecting stall conditions are shown in Fig. 4 and 5 and described fully in the U.S. 6,333,016 Patent to Miller et. al. herein incorporated by
20 reference. Those skilled in the art should also appreciate that the embodiment of FIG. 5 detects over-use of the electric assist steering system. Such over-use occurs, for example, when high motor torque is commanded for an extended period of time even though the motor is moving. Those skilled in the art will appreciate that a stall condition may be an over-use condition, such as where the temperature of the power
25 switches **56** exceed the threshold temperature.

The control processes shown in FIGS. 4 and 5 could be implemented in a single stall and over-use detector **70**. In such an implementation, the stall and over-use detector **70** would determine that a stall or over-use condition exists when either or both of the two processes indicates the existence of a stall or over-use condition. In

effect, a stall condition is detected as the result of a torque command being greater than a threshold value and no motor commutation for a predetermined time period and an over-use condition is the result of the integrated torque command exceeding a threshold value.

5 It is also desirable to include self-diagnostic features in the drive control circuit to insure proper operation of the assist arrangement. Such a diagnostic arrangement for an electric assist steering system is fully described in U.S. Pat. No. 4,660,671, to Behr et al., and assigned to TRW Inc., which is hereby incorporated herein by reference.

10 Fig. 6 illustrates a method for detecting a failed thermistor and provide limited steering assist by the electric assist motor during an over-use condition. An over-use algorithm used for detecting a stall condition is utilized to detect whether a thermistor is non-operational (i.e., failed). The stall or over-use algorithms utilize the thermistor (i.e., temperature sensor) to detect the temperature of a power driving
15 circuitry (e.g., switching circuit, power control circuit) or the electric steering assist motor. Based on the whether the temperature sensed is above or below a respective temperature threshold, the electrical current is reduced for limiting the torque output of the electrical assist motor. However, a non-operational thermistor may eventually lead to a stall condition of the electric assist motor which may result in the loss of assisted
20 steering. Thus, the detection of a non-operational thermistor, and subsequent response thereto, minimizes the risk of damage to the electric assist steering system.

 In step 130, a control process begins where the electric steering assist system is activated. In step, 131, a counter is set to zero. The counter records the consecutive number of times a set of temperature measurements are measured and
25 remain unchanged. The electric assist motor, as discussed earlier, outputs a torque which assists to aid in the lateral movement of the rack which consequently moves the steerable wheels. The output torque of the electric assist motor is in direct proportion to the electric current drawn by the electric assist motor. An increase in the output torque (high steering efforts at low speed) requires an increase in the electric current

supplied to the electric assist motor. Such increases in the electrical current drawn by the electric assist motor will increase the temperature of power driving circuitry (e.g., switching circuit, power control circuit) or the electric steering assist motor.

Conversely, a decrease in the temperature indicates a decrease in the electric current
5 drawn by the electric assist motor. A constant temperature sensed by the thermistor indicates that the electric motor is drawing a constant amount of electrical power and outputting a constant torque. During a temperature measurement by an over-use condition detection algorithm where the integral of torque demand is increasing (over-use algorithm is running or active), a constant temperature may indicate that the
10 thermistor is non-functional.

In step 133, a first voltage measurement (V_{t0}), at a time t_0 , is output from the thermistor and stored in the memory of the controller. When temperature changes, the resistance of the thermistor changes in a predictable way which in turn affects the voltage. From this voltage, a temperature value is obtainable. In step 134, a
15 determination is made whether the over-use algorithm is running. Activation of the over-use algorithm indicates that preliminary conditions are present in which high electric motor torque commands may be occurring for an extended period of time even though the motor is rotating. If the over-use algorithm is not activated, then conditions for over-use is are not presently an issue and detection of the failed thermistor is not
20 required. If the determination is made in step 134 that the over-use algorithm is not activated, then a return is made to step 133 to read an initial thermistor voltage again. If the determination in step 134 is made that the over-use algorithm is currently active, then a next voltage measurement (V_{t1}) at time t_1 is recorded in step 135. Preferably, the voltage measurement V_{t1} is taken about two seconds after voltage measurement
25 V_{t0} . Alternatively, any suitable time interval may be utilized. The time intervals may be fixed or variable. In step 136, a determination is made whether the temperature measurements (V_{t0}) and (V_{t1}) indicate an increase in temperature. The following is used to determine whether an increase in temperature has occurred:

$$\text{(Eq. 1) } V_{t0} - (V_{t1} + \delta) > 0$$

Where δ is a calibration constant that is preferably equal to 5 times the noise level. The thermistor voltage is a direct correlation of the temperature measured. The delta constant (δ) is a constant representing background electrical noise that may be present within the electrical circuit at the time temperature measurements are taken. During an over-use condition, it is assumed that the voltage output from the thermistor is constantly increasing based on the operation of the motor at the respective high loads. That is, as the electric motor continuously operates under high loads, the internal operating temperature of the motor increases while the efficiency of the electrical motor decreases thereby requiring higher voltage to maintain the operating output torque. As a result, it can be expected that during an over-use condition the increase in electrical current drawn by the electrical motor to maintain the output torque results in an increase in the temperature. If a temperature difference between the temperature measurements (V_{t0}) and (V_{t1}) is not positive, then it is assumed that the temperature is not increasing. However, floor noise present in the first temperature measurement (V_{t0}) that may not be present in the second temperature measurement (V_{t1}) would falsely provide a positive result (in Eq. 1) by indicating an increase in temperature when in fact, the increase was the result of floor noise. Adding the delta constant (δ) to the second temperature measurement (V_{t1}) prior to calculating the temperature difference reduces the chance that floor noise will create a positive result.

If the determination is made that the temperature differential from Eq. 1 is positive, then an assumption is made that the thermistor is operational and a return is made to step 132 to reset the counter and sense for a next set of voltage measurements to monitor and determine the functionality of the thermistor. If the determination is made that result is not positive, then a counter (K) is incremented in step 137. A determination is made in step 138 whether the counter (K) is greater than 2. If the counter (K) is not greater than two, then a return is made to step 133 to sense for a next set of temperature measurements. If the determination is made in step 138 that

the counter (K) is greater than two, then it is determined that the thermistor has failed. Alternatively, any other predetermined count number other than two consecutive measurements may be used for determining operation of the thermistor. In step 139, the torque command signal is set so that the adjustable gain amplifier limits the

5 electric current provided to the electric motor for outputting only a fraction of the electric assist motor's maximum available steering assist output. For example, a gain limit may be set at 20% of the maximum gain. Whatever the reduced level, it should be such that the electric assist motor may operate for an extended duration of time at this reduced maximum output without damaging the motor or producing a stall

10 condition. This allows limited steering assist by the electric assist motor while operating the power steering assist system with a failed thermistor during an over-use condition.

From the above description of the invention, those skilled in the art will perceive improvements, changes and modifications. For example, the reduction of

15 electric power, as well as its subsequent increase, has been described as an incremental stepping function over time. It will be appreciated that, alternatively, the control system might provide a time-based ramping function to increase and decrease the electric power. The ramping function may be implemented either as an analog or digital control. These and other similar improvements, changes and modifications

20 within the skill of the art are intended to be covered by the appended claims.

TABLE OF REFERENCE NUMBERS

	10 vehicle electric assist steering system
	12 vehicle steering wheel
5	14 pinion gear
	16 input shaft
	17 pinion shaft
	18 torsion bar
	20 rack
10	22, 24 vehicle steerable wheels
	26 electric assist motor
	28 stator
	30 plurality of stator poles
	32 rotor
15	34 plurality of rotor poles
	36 rotor position sensor
	38 rotor position signal
	40 shaft position sensor
	42 torque sensor
20	44 signal
	46 torque command circuit
	48 torque command signal
	52 adjustable gain amplifier
	53 amplified torque command signal
25	54 drive control circuit
	55 motor control signal
	56 power switches
	58 main drive switch
	60 LC filter network

- 62 switch
- 63 motor control signal
- 64 Diode
- 65 Diode
- 5 66 Zener diode
- 67 Zener diode
- 69 temperature sensor
- 70 stall detector
- 71 output signal

What is claimed is:

1. A method for controlling an electric assist motor in a vehicle steering system during an enablement of an overuse algorithm, said method comprising the steps of:
- 5 providing electric power to said electric assist motor of said vehicle steering system via a switching circuit;
- sensing a temperature of one of at least said electric assist motor and a power driving circuitry that provides power to said electric assist motor;
- 10 determining whether said sensed temperature of said one of at least said electrical assist motor and said power driving circuitry is increasing over a predetermined period of time; and
- reducing said electric power provided to said electric assist motor in response to a lack of increase in said sensed temperature.
- 15
2. The method of claim 1 further including the steps of:
- receiving a sensed temperature signal by a stall detector; and
- outputting a control signal for adjusting said electric power provided to said electric assist motor.
- 20
3. The method of claim 2 further including the step of providing said control signal to a gain amplifier for adjusting a received torque command signal indicative of an applied steering torque input.
- 25
4. The method of claim 3 further including the step of providing said adjusted torque command signal to a switching circuit for limiting electric power to said electric assist motor.

5. The method of claim 2 wherein said step of reducing said electric power is further defined by reducing an output of said electric assist motor to a predetermined percentage of a maximum steering assistance output.

5 6. The method of claim 5 wherein said predetermined percentage is about 20%.

7. The method of claim 1 wherein said step of determining whether said sensed temperature is increasing includes taking a plurality of temperature
10 measurements, and sensing an increase in temperature for a predetermined number of consecutive temperature measurements by the plurality of temperature measurements.

8. The method of claim 7 wherein said predetermined number of consecutive temperature measurements include at least two consecutive temperature
15 measurements.

9. The method of claim 8 wherein said predetermined number of consecutive temperature measurements is taken at fixed time intervals.

20 10. The method of claim 9 wherein said fixed time intervals are about two second intervals.

11. The method of claim 8 wherein said predetermined number of consecutive temperature measurements is taken at variable time intervals.

25

12. A method for controlling an electric assist motor in a vehicle steering system during an enablement of an overuse algorithm, said method comprising the steps of:

providing electric power to said electric assist motor of said vehicle steering system via a switching circuit;

sensing a temperature of one of at least said electric assist motor and a power driving circuitry that provides power to said electric assist motor by taking at least two
5 consecutive temperature measurements over a predetermined period of time;

determining whether said sensed temperature of said one of at least said electric assist motor and said power driving circuitry is increasing over said predetermined period of time by adding a calibration constant to said second measured temperature and subtracting said second measured temperature from said first measured
10 temperature and producing a negative temperature difference; and

reducing said electric power provided to said electric assist motor in response to a lack of increase in said sensed temperature.

13. An apparatus for controlling an electric assist motor in a vehicle steering
15 system during an enablement of an over-use algorithm, the apparatus comprising:

a switching circuit for providing electric power to said electric assist motor, said electric assist motor providing steering assistance to said vehicle steering system;

a torque command circuit for providing a torque command signal to said electric assist motor for demanding a respective output torque from said electric assist
20 motor in response an applied steering torque signal;

a temperature sensor coupled to one of at least said electric assist motor and said switching circuit for sensing a temperature of said one of at least said electric assist motor and said switching circuit and for generating an output signal in response to said sensed temperature; and

25 a stall detector responsive to said output signal from said temperature sensor during an enablement of said over-use algorithm and being operable to reduce said electric power to said electric assist motor by adjusting said torque command signal when said sensed temperature of said one of at least said electric assist motor and said switching circuit does not increase over a predetermined period of time.

14. The apparatus of claim 13 further comprising an adjustable gain amplifier, coupled to said torque command circuit and said stall detector for modifying said torque command signal received from said torque command circuit in response to said stall detector detecting said sensed constant temperature over said predetermined period of time.

15. The apparatus of claim 14 wherein said torque command signal is modified for reducing said torque output of said electric motor to a predetermined percentage of a maximum steering assistance of said electric assist motor.

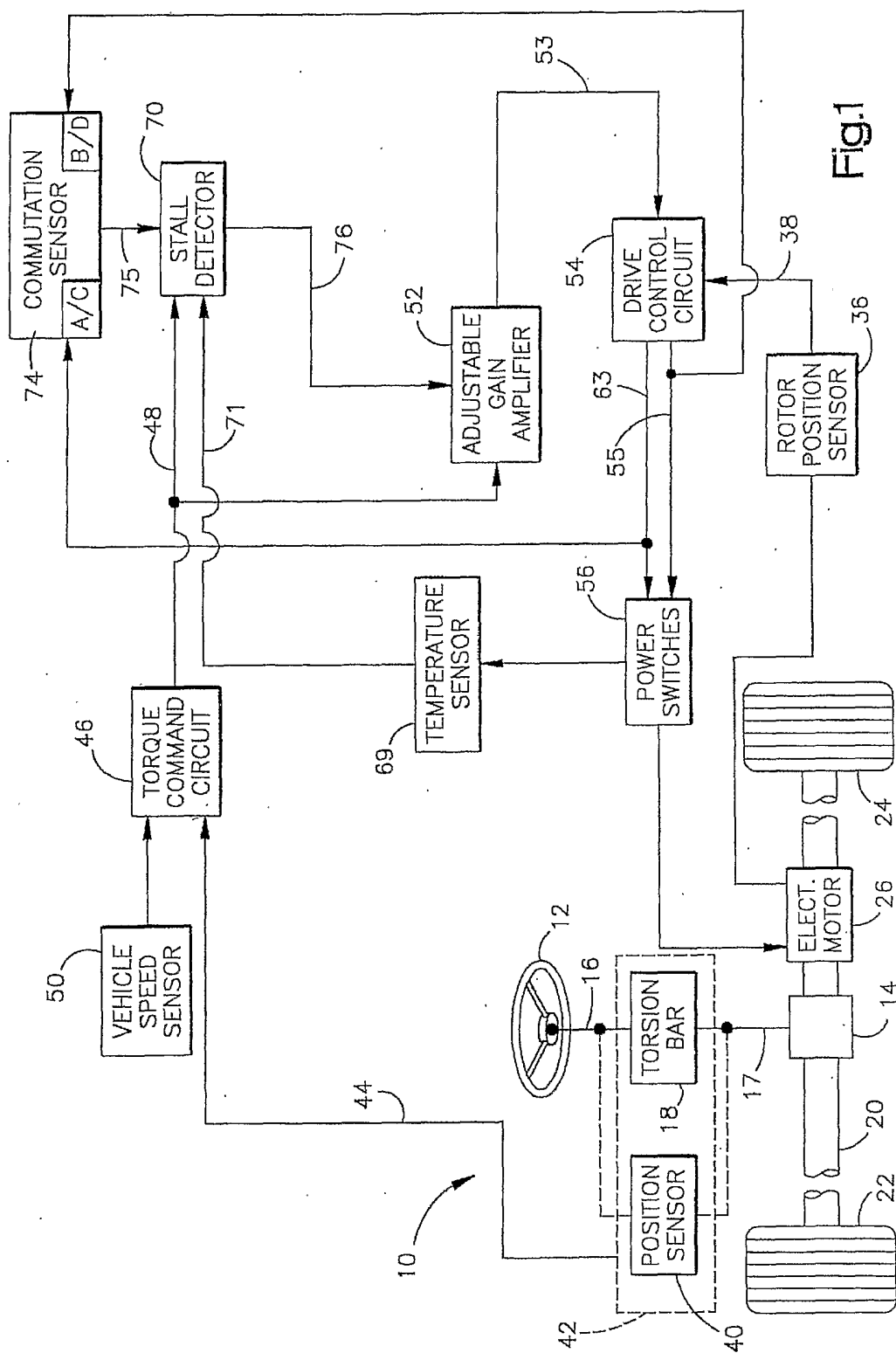
16. The apparatus of claim 15 wherein said predetermined percentage is about 20%.

17. The apparatus of claim 13 wherein at least two consecutive temperature measurements are taken by said temperature sensor during said predetermined period of time.

18. The apparatus of claim 17 wherein said consecutive temperature measurements are taken at fixed time intervals.

19. The apparatus of claim 18 wherein said fixed time intervals are about two second intervals.

20. The apparatus of claim 17 wherein said temperature measurements are taken at variable time intervals.



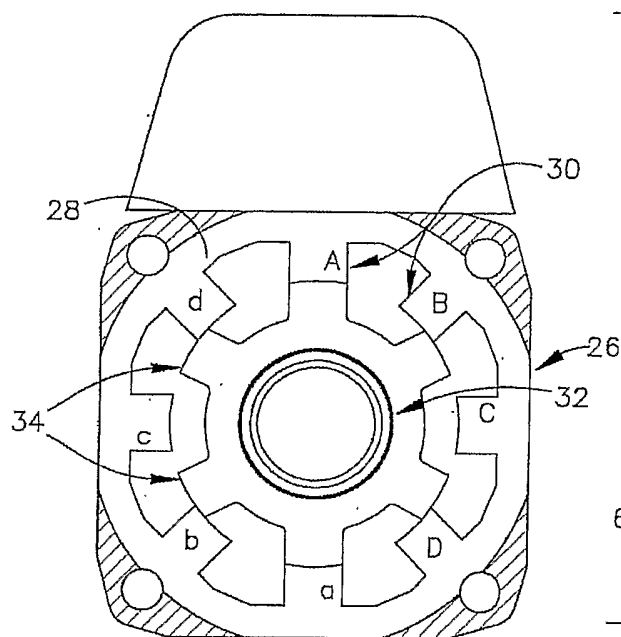


Fig.2

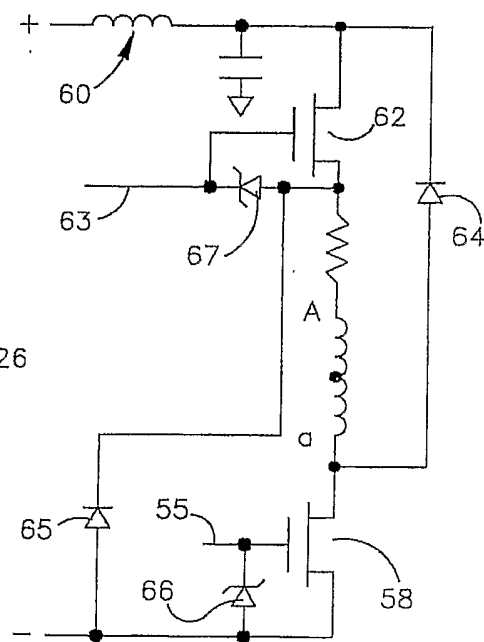


Fig.3

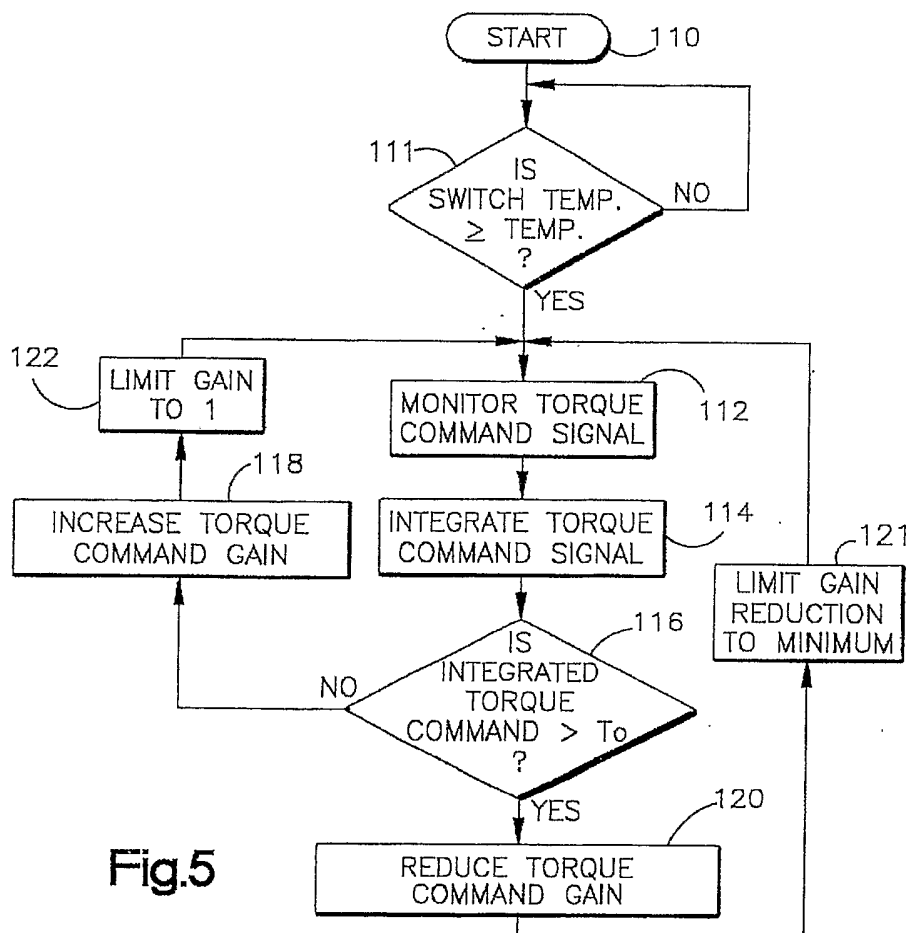


Fig.5

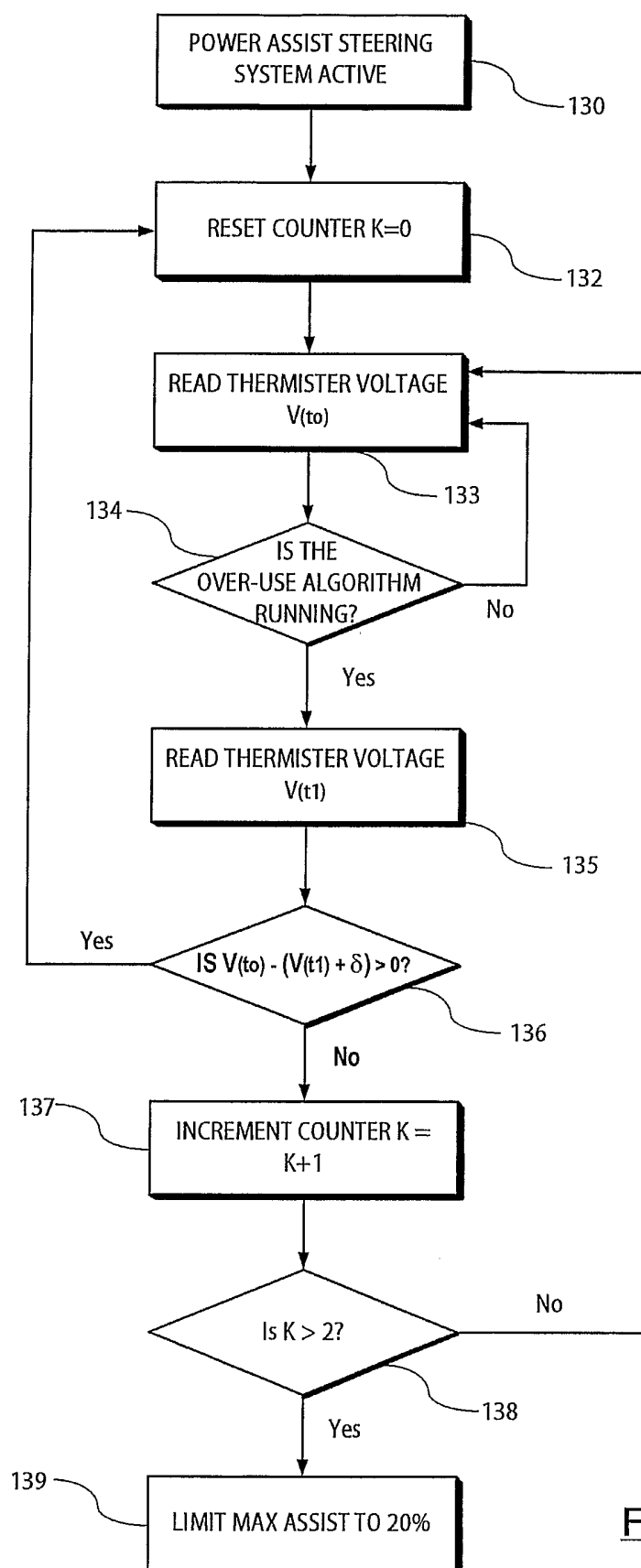
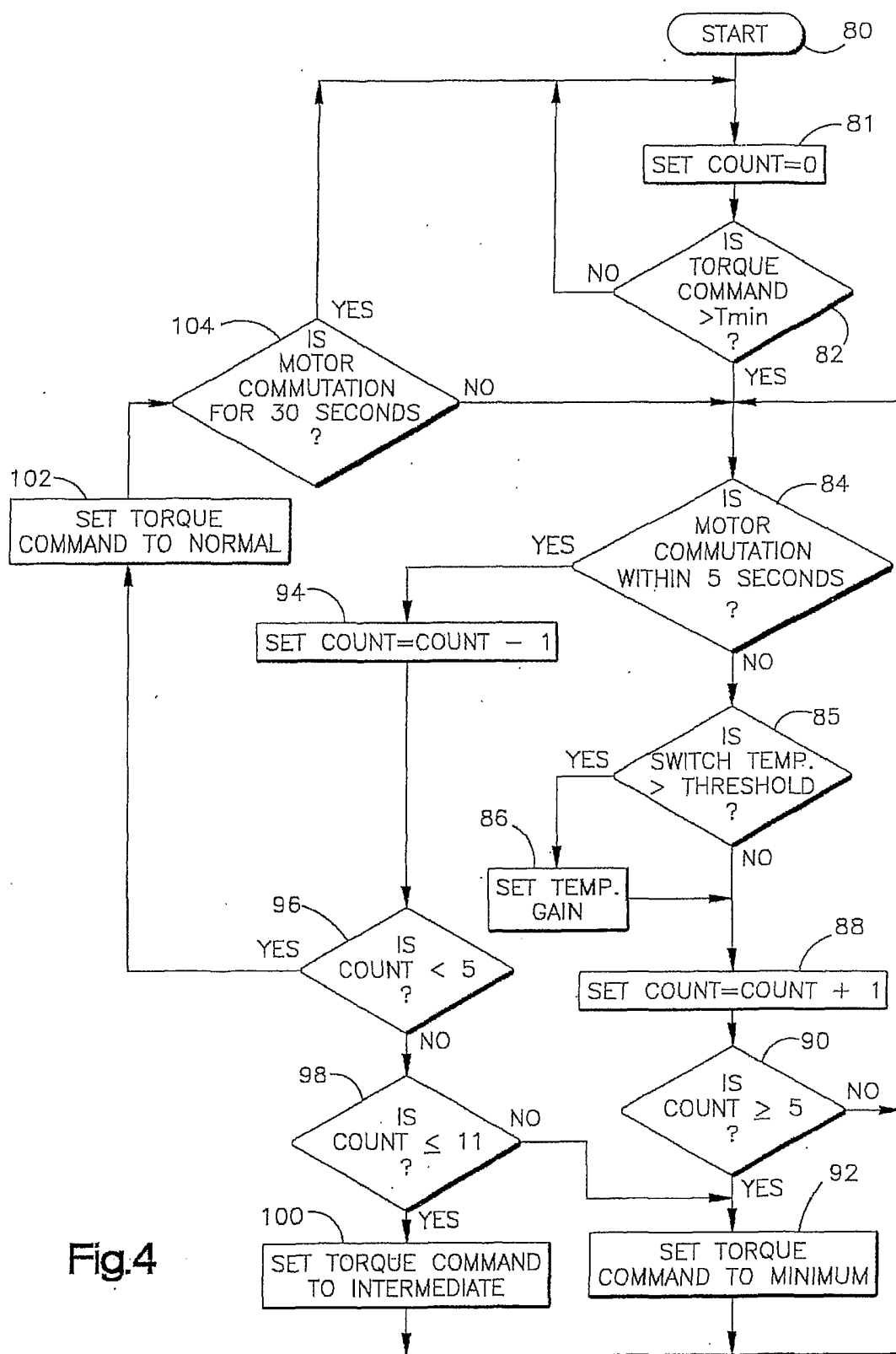


Fig. 6



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2006/007734

A. CLASSIFICATION OF SUBJECT MATTER

INV. B62D5/04

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B62D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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

EP0-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 284 541 A (DELPHI TECHNOLOGIES, INC) 19 February 2003 (2003-02-19) paragraphs [0004] - [0007], [0009] - [0099]; claims 1-181; figures 1-12	1-20
X	PATENT ABSTRACTS OF JAPAN vol. 2003, no. 09, 3 September 2003 (2003-09-03) -& JP 2003 134869 A (DELPHI TECHNOLOGIES INC), 9 May 2003 (2003-05-09) abstract	1-20
	----- -/--	

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

☒ See patent family annex.

* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

14 June 2006

Date of mailing of the international search report

22/06/2006

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Tiedemann, D

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2006/007734

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 2003, no. 07, 3 July 2003 (2003-07-03) -& JP 2003 070285 A (DELPHI TECHNOLOGIES INC), 7 March 2003 (2003-03-07)	1,7-12
Y	abstract	2-6, 13-20
Y	----- US 5 517 415 A (MILLER ET AL) 14 May 1996 (1996-05-14) cited in the application column 1, line 55 - column 2, line 28	2-20
A	column 3, line 51 - column 8, line 51; claims 1-22; figures	1
X	----- US 6 338 016 B1 (MILLER JOSEPH D ET AL) 8 January 2002 (2002-01-08) cited in the application	1-6, 13-20
Y	column 1, line 64 - column 2, line 29 column 2, line 50 - column 11, line 13; claims 1-18; figures 1-4	7-12
X	----- US 5 257 828 A (MILLER ET AL) 2 November 1993 (1993-11-02)	1,7-12
Y	column 2, line 16 - column 3, line 14 column 3, line 65 - column 11, line 64; claims 1-7; figures 1-12	2-6, 13-20
A	----- US 6 088 661 A (POUBLON ET AL) 11 July 2000 (2000-07-11) cited in the application column 2, line 1 - column 4, line 62; claims; figures	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2006/007734

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 1284541	A	19-02-2003	JP 2003116291 A	18-04-2003
			US 2003076061 A1	24-04-2003
JP 2003134869	A	09-05-2003	EP 1285841 A1	26-02-2003
			US 2003076065 A1	24-04-2003
JP 2003070285	A	07-03-2003	EP 1286456 A1	26-02-2003
			US 2003071594 A1	17-04-2003
US 5517415	A	14-05-1996	BR 9504458 A	20-05-1997
			DE 69523715 D1	13-12-2001
			DE 69523715 T2	01-08-2002
			DE 69532213 D1	08-01-2004
			DE 69532213 T2	30-09-2004
			EP 0709278 A1	01-05-1996
			JP 2898236 B2	31-05-1999
			JP 8207801 A	13-08-1996
			JP 3383226 B2	04-03-2003
			JP 11198846 A	27-07-1999
US 6338016	B1	08-01-2002	BR 0000153 A	20-03-2001
			EP 1035001 A2	13-09-2000
			JP 3256211 B2	12-02-2002
			JP 2000264232 A	26-09-2000
US 5257828	A	02-11-1993	NONE	
US 6088661	A	11-07-2000	NONE	