TITLE: METHOD AND APPARATUS FOR CURRENT SENSING OF MULTIPLE LOADS IN AN AUTOMOTIVE VEHICLE

Method and apparatus for monitoring the operation of a plurality of electrical loads in an automotive vehicle with a single current sensor (14). The current sensor (14) detects the change in the total output current associated with the electrical loads and generates an output signal based on the current change. The apparatus also includes a controller (12) which activates each electrical load at a given time to obtain a like plurality of timing signals so that each electrical load receives a portion of the output current. The controller (12) processes the output signal and the timing signals to obtain a diagnostic signal related to an operating condition of at least one of the electrical loads. Finally, the controller (12) controls an operating state of the at least one of the electrical loads based on the diagnostic signal.
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METHOD AND APPARATUS FOR CURRENT SENSING
OF MULTIPLE LOADS IN AN AUTOMOTIVE VEHICLE

The present invention is related to current sensing, and more particularly, to centralised current sensing of multiple loads in an automotive vehicle.

Circuitry designed to sense the current associated with one or more electrical loads are known in the art. As is known, current sensing circuitry can provide for increased control as well as fault diagnosis. For example, United States patent 4,661,717, issued to Nishioka, discloses a load condition determining apparatus capable of detecting normal and abnormal conditions of a load. The apparatus includes a power supply, a drive circuit connected to the power supply and a load circuit, one end of which is connected to the drive circuit. The apparatus also includes a load equivalent circuit connected to the drive circuit, the electrical characteristics of the load equivalent circuit being substantially equal to that of the load circuit. The apparatus further includes a differential amplifier circuit to detect the difference between the input voltages to the differential amplifier circuit in accordance with the conditions of the load circuit and comparing means having first and second comparators connected to the output of the differential amplifier circuit, to determine the normal and abnormal conditions of the load circuit in accordance with the balance and unbalance between the input voltages to the differential amplifier circuit.

United States patent 4,962,350, issued to Fukuda, discloses a load condition detecting and driving system capable of detecting an abnormal condition of the load without being affected by any acceptable variation of the load or change in the voltage supplied by a power source. The system includes switching means having a control terminal, a second terminal of the switching means being coupled to an input terminal of a load, the control terminal being coupled to receive a driving signal for controlling the switching means to apply driving current to the load.
The system further includes coupling means coupled between the input terminal and the control terminal for rendering the switching means non-conductive when the load exhibits a short-circuit condition due to a voltage at the output terminal of the load becoming low because of the short-circuit condition.

Other United States patents of lesser relevance include 3,912,883, issued to Goodyear, 4,774,510, issued to Steinke, 4,894,648, issued to Talbot and 4,931,778, issued to Guajardo.

It is desirable, however, to utilise centralised current sensing of multiple loads wherein single point current sensing identifies normal and abnormal current magnitudes of multiple loads. Such current sensing would have a lower cost than prior art current sensing systems, provide for control, prognostic and diagnostic capabilities while accommodating different numbers and types of loads with appropriate software changes.

It is an object of the present invention to provide an apparatus for low cost, centralised current sensing of multiple loads in an automotive vehicle.

It is a further object of the present invention to provide a method and apparatus for single point current sensing to identify normal and abnormal operating conditions of multiple loads in an automotive vehicle and to provide for control, diagnostic and prognostic capabilities.

According to the invention there is provided an apparatus for monitoring the operation of a plurality of electrical loads in an automotive vehicle, the loads collectively requiring an output current, the apparatus comprising:

- single detecting means for detecting a change in the output current and generating an output signal based on the change; and

- control means for activating each electrical load at a given time to obtain a like plurality of timing signals and so that each activated electrical load receives a portion of the output current, the control means for
processing the output signal and the timing signals to obtain a diagnostic signal related to an operating condition of each activated electrical load.

Further according to the invention there is provided a method of monitoring the operation of a plurality of electrical loads in an automotive vehicle, the electrical loads collectively requiring an output current, the method comprising the steps of:

activating at least one of the electrical loads to obtain at least one timing signal;
detecting a change in the output current to determine an actual current differential; and

 correlating the actual current differential with predetermined acceptable current differentials for the at least one of the electrical loads, to obtain a diagnostic signal related to an operating condition of the at least one of the electrical loads. The method may also comprise the step of controlling the operating state of the at least one of the electrical loads based on the diagnostic signal.

The method may also include the steps of comparing the actual current differential to a plurality of prior actual current differentials to detect a trend, and predicting a future operating condition of the electrical loads based on the comparison.

The invention will now be described further, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of a first embodiment of the current sensing apparatus of the present invention;

Figure 2 is a block diagram of a current sensing circuit for use with the current sensing apparatus shown in Figure 1;

Figure 3 is a block diagram of a second embodiment of the current sensing apparatus of the present invention;

Figures 4a-4c comprise a flow chart illustrating the current sensing methodology for use with the current sensing apparatus shown in Figure 1;

Figure 5 is a flow chart illustrating the current
sensing methodology for use with the current sensing apparatus shown in Figure 3; and

Figure 6 is a graph illustrating a current plot obtained utilising the method and apparatus of the present invention.

Referring now to Figure 1, there is illustrated a current sensing apparatus shown generally by reference numeral 10. In this preferred embodiment, the current sensing apparatus 10 is for use as an on-vehicle application to provide continuous monitoring of the vehicle's electrical loads. As illustrated, the current sensing apparatus 10 includes a microcontroller-based control module 12 and a current sensor 14, which senses the current associated with the activation of a plurality of electrical loads (not specifically illustrated). The control module 12 initiates control signals to the plurality of relays shown generally by reference numeral 16 to activate associated electrical loads. The battery 18 provides power to the various system components.

As best shown in Figure 1, the control module 12 receives DC power from the battery 18 via line 20 and is in electrical communication with the current sensor 14 via lines 22 and 24. The control module 12 preferably includes an application specific integrated circuit (ASIC) 26 which includes current sensing circuitry shown in Figure 2 and described in greater detail below. The control module 12 also includes a microprocessor, RAM and ROM memories, an analog-to-digital (A/D) converter and a digital-to-analog (D/A) converter not specifically illustrated. The line 22 is utilised for current feedback and the line 24 is utilised for calibrating the current sensor offset correction, as explained in greater detail below.

With continuing reference to Figure 1, the current sensor 14 is preferably a toroid. The toroid output voltage has both a negative and positive range (e.g. about -5V to about +5V). A DC offset is utilised to shift the toroid output voltage to a range of about 0V to about +10V, such that the toroid output is essentially at ground potential
(i.e. about 100 mV) at very low sensed currents. Of course, toroids having entirely positive or entirely negative output voltage ranges could also be utilised. Although the current sensor 14 is shown to be a toroid, which provides the advantage of permitting the monitoring of multiple conductors, a simple resistor or the like could be employed as a current sensor where a single conductor functions as a current feed to a plurality of circuits.

In the preferred embodiment, the toroid 14 encircles or surrounds either a single bus or a plurality of electrical conductors shown generally by reference numeral 30. Each of the conductors 30 surrounded by the toroid 14 is associated with a particular electrical load, such as an incandescent lamp, a motor, a solenoid and the like. As shown, the conductors 30 extend from the battery 18 through the toroid 14 to their associated relays shown generally by reference numeral 16. Thus, upon actuation of the relays 16 by the control module 12, the electrical conductors 30 carry current from the battery 18 through the toroid 14 to the electrical loads.

Referring now to Figure 2, there is illustrated a block diagram of a current sensing circuit shown generally by reference numeral 28 for use with the current sensing apparatus 10 shown in Figure 1. In the preferred embodiment, the current sensing circuitry 28 is implemented on the ASIC 26. The toroid 14 includes a Hall effect element 32 for sensing the magnetic field associated with the current \( I_L \) flowing through the electrical conductors 30. The Hall element 32 generates a voltage signal based on the magnitude of the \( I_L \), which is then processed by standard Hall sensor signal conditioning circuitry 34. Generally, the signal conditioning circuitry receives a low voltage signal (e.g. 10 mV) from the Hall element 32 and amplifies the signal to a value of about 5V maximum. The amplified signal from the Hall sensing circuitry 34 is then provided to the non-inverting terminal of a differential amplifier 36. The output of the amplifier 36 is a function of the difference between the signal from the Hall sensing
circuitry 34 and a voltage (i.e. a dc offset adjust) applied to the inverting terminal of the differential amplifier 36. The dc offset adjust is provided to the differential amplifier 36 from a digital-to-analog (D/A) converter 40. The D/A receives digital data from the microcontroller of the control module 12 and converts it into an associated analog voltage, i.e., the dc offset adjust. An amplifier 38 having a gain control adjusted by the control module 12 receives the output from the differential amplifier 36 and generates an analog output. The gain control signal reduces the gain of amplifier 38 when the signal into amplifier 38 is large and increases the gain when the signal into amplifier 38 is small. The analog output of the amplifier 38 is then converted to a corresponding digital representation by the analog-to-digital (A/D) converter (not specifically illustrated) of the control module 12. Gain control maximises the span or range of the A/D, increasing the overall sensitivity of the current sensing apparatus 10 of the present invention. Therefore, based on the current feedback signal from the toroid 14, the control module 12 is capable of determining the amount of current associated with operation of an electrical load. From this information, the control module can determine the actual operating condition, such as an "open" or a "short", of the electrical load.

Depending on the operating condition, the control module controls the operating state of the electrical loads as described in greater detail below.

Referring now to Figure 3, there is illustrated a second embodiment of a current sensing apparatus shown generally by reference numeral 50. In this preferred embodiment, the current sensing apparatus 50 is for use as an off-vehicle application, wherein diagnostic test module 74 and the current sensor 54 are attached to a vehicle when testing is required. Preferably, the current sensing apparatus 50 includes a microcontroller-based control module 52 and a current sensor 54, which senses the current associated with the activation of a plurality of electrical loads (not specifically illustrated). The control module 52
initiates control signals to the plurality of relays shown generally by reference numeral 56 to activate associated loads. The battery 58 provides power to the various system components.

As best shown in Figure 3, the control module 52 receives power from the battery 58 via line 60 and is in electrical communication with the current sensor 54 via lines 62 and 64. The control module 52 includes a microprocessor, RAM and ROM memories, and an analog-to-digital (A/D) converter not specifically illustrated. Preferably, the line 62 is utilised for current feedback and the line 64 is utilised for grounding the current sensor 14.

With continuing reference to Figure 3, the current sensor 54 is preferably a toroid-shaped current clamp having an output voltage range of about 0V to about +10V. The current sensor 54 is removably affixed to a wire harness or the like in a known manner, preferably encircling a plurality of electrical conductors shown generally by reference numeral 70. Each conductor may be associated with a particular electrical load or a number of loads, such as an incandescent lamp, a motor, a solenoid and the like. As shown, the conductors 70 extend from the battery 58 through the toroid current sensor 54 to their associated relays shown generally by reference numeral 56. Thus, upon actuation of the relays by the control module 52, the electrical conductors 70 carry current from the battery 58 to the electrical loads, where the current is sensed by the current sensor 54.

As shown in Figure 3, the current sensor 54 preferably includes a Hall element 72 for sensing the magnetic field associated with the current ($I_L$) flowing through the plurality of electrical conductors 70. The Hall element 72 generates a voltage signal based on the magnitude of the current $I_L$ which is then processed by an off-board diagnostic tester 74. It should be appreciated that the current sensor 54 could have a number of output voltage ranges, such as both negative and positive (i.e. -5V to +5V) and for use therewith the diagnostic tester 74 could
include circuitry substantially similar to the Hall sensing circuitry 34 of the prior embodiment described above with respect to Figure 2.

In this preferred embodiment, the diagnostic tester 74 can be incorporated in a portable, hand-held unit that communicates with the control module 52 through a serial data link 76, such as an ISO 9141 data link. More particularly, the diagnostic tester 74 issues commands through the data link 76 to the control module 52 to activate a particular electrical load. The control module 52 responds and provides data to the diagnostic tester 74 indicative of the expected increase in current flow through the conductors 70 resulting from the activation of the load. Therefore, based on the current feedback signal from the current sensor 54, the diagnostic tester 74 is capable of determining the amount of current associated with operation of an electrical load. From this information, the diagnostic tester 74 can determine the actual operating condition, such as an "open" or a "short", of the electrical load. Depending on the operating condition, the diagnostic tester 74 controls the operating state of the electrical loads as described in greater detail below. As one alternative, the current sensing apparatus 50 could be configured such that the diagnostic tester 74 includes data indicative of the expected increase in current flow through the conductors 70 resulting from the activation of the load.

Referring now to Figures 4a-4c, a flow chart is shown detailing the general operation of the current sensing methodology for use with the current sensing apparatus 10 shown in Figure 1. Since it is for use with an on-vehicle current sensing apparatus, this current sensing methodology is preferably performed routinely during normal vehicle operation. When a current sense operation is initiated, an internal "current sense in progress" flag is set. At step 100 in Figure 4a, the control module 12 checks the status of the flag to determine whether or not a current sense operation is already in progress. If a current sense operation is already in progress, control flow "jumps" to
step 110.

If no current sensing is being performed, at step 102
the control module determines if the particular electrical
load should be activated. For example, the vehicle operator
may have depressed a power window button, signalling the
control module to activate the window motor, thereby raising
or lowering the window. If the load should not be activated
for some reason, control flow exits the current sense
routine and control is returned to main processing at step
132.

If the electrical load should be activated, the control
module 12 reads the analog voltage signal ($V_{OFF}$) from the
toroid 14 at step 104, prior to activation of the load, to
establish a reference current. Thus, the voltage signal
corresponds to the current flow through the conductors 30
prior to activation of a particular electrical load. Also
at step 104, the control module 12 senses the battery
voltage, which is then utilised to scale, or normalize, the
reference current reading ($I_{SCOFF}$).

At step 106, the control module enables the appropriate
output, sending a control signal to the associated relay 16
to activate the particular load. A delay timer is started
at step 108 with the delay value for the specific load
obtained from a look-up table stored in the memory of the
control module 12. The actual amount of delay is largely
unnoticeable by the vehicle operator and varies from load to
load, depending primarily on the electrical characteristics
of the load. For example, if the load is an incandescent
lamp, it is desirable to wait for the in-rush current to
subside prior to sensing the load current. A typical delay
time for an incandescent lamp load is 50 mS. If the load is
capacitive in nature, the delay value is based on the RC
time constant, since it is desirable to wait for the current
to ramp up to a certain level. If the delay time has not
expired, control flow exits from the current sense routine,
freeing the control module to perform "housekeeping"
functions and the like. In this manner, this strategy
provides a real-time aspect to the current sensing
methodology.

The next time the current sense routine is cycled, control flow would immediately jump from step 100 to step 110 to determine if the delay timer had since expired. This control flow jump prevents the delay timer from being reinitiated.

If the delay timer has elapsed at step 110, the magnitude of the load current can be measured. At step 112 in Figure 4b, the control module 12 senses an analog voltage signal \( V_{ON} \) from the toroid 14. This analog voltage signal is proportional to the current flowing through the electrical conductors 30 which includes the current associated with the activated load. The control module 12 again senses the battery voltage which is utilised to obtain a scaled current \( (ISC_{ON}) \).

At step 114, the control module 12 calculates the difference between the scaled off current and the scaled on current, which represents the current associated with the activated load \( (I_L) \). At step 116, the control module 12 determines whether or not the scaled differential current \( (I_L) \) exceeds the maximum allowable current \( (I_{MAX}) \) for that load. The control module 12 thus performs a comparison between the value of load current and a plurality of values stored in a look-up table. Preferably, these maximum table values are established for each type of electrical load based on certain considerations, such as the worst case upper and lower temperatures associated with the location of the load in the vehicle.

In the preferred embodiment, if the differential load current exceeds the maximum allowable current, at step 118 the control module 12 sends an appropriate control signal to the relay 16 and the load is turned off. Additionally, the control module disables the output associated with that electrical load and sets an internal diagnostic trouble code indicative of an electrical "short." The control module thus implements a "software fuse", disabling the output very quickly to avoid blowing a hardware fuse or circuit breaker or allowing any components to be damaged.
If the load current does not exceed the maximum allowable current at step 116, the control module 12 compares the differential load current to a minimum allowable current for that load at step 120. This comparison is also made utilising a look-up table of values established for each type of load based on certain considerations, such as the worst case upper and lower temperature of the location of the load in the vehicle.

If the load current is less than the minimum allowed current, at step 122 the control module 12 sends a control signal to the appropriate relay 16 and the load is turned off. Additionally, the control module 12 quickly disables the output associated for that electrical load and sets a diagnostic trouble code in memory indicative of an electrical "open."

If, however, the load current is within the maximum and minimum allowed currents, the control module 12 begins a prognostic test at step 124 in Figure 4c to predict load failures. As an electric motor ages, internal mechanisms can become rusty and corroded, developing increases in its friction components. As this aging process occurs, the motor draws larger amounts of current during operation. Thus, as load current increases over time, failure of the motor can be predicted.

At step 126, the control module 12 compares the scaled differential load current to an average of the previous N samples. At step 128, the control module 12 determines whether the sampled load currents indicate whether such a trend is occurring. If the sensed load currents indicate a trend, at step 130 the control module 12 sets an appropriate prognostics code in the memory. At step 132, main code processing continues. The temperature of the location of the motor or other load could also be sensed and utilised in the determination of trends, since temperature can affect the amount of current drawn by a load.

Referring now to Figure 5, a flow chart detailing the general operation of the current sensing methodology is shown for use with the current sensing apparatus shown in
Figure 3. Since this is embodiment is for use with an offvehicle current sensing apparatus, the current sensing methodology is performed while the vehicle control module is connected to the diagnostic tester 74.

At step 140, the test module reads the analog voltage signal \( V_{OFF} \) from the current sensor 54, prior to activation of the electrical load, to establish a reference current. Also at step 140, the test module senses the battery voltage \( V_{BATT} \), which is then utilized to scale, or normalize, the reference current reading \( ISC_{OFF} \).

At step 142, the test module 74 issues a command to the control module 52 to turn on the particular electrical load. Prior to proceeding with the current sensing operation, at step 144 the test module 74 waits for the control module 52 to acknowledge the command.

Preferably, the diagnostic tester waits for a "time out" to expire at step 146. If the "time out" period expires before the control module responds to the test module, control flow jumps to step 148 where an appropriate fault sub-routine is executed.

At step 150, a delay timer is started with the delay value for the specific load obtained from a look-up table stored in the memory of the control module 52. Of course, the delay value could be stored in the diagnostic tester 74.

As in the prior embodiment, the actual amount of delay is largely unnoticeable by the vehicle operator and varies from load to load, depending primarily on the electrical characteristics of the load (e.g. resistive, capacitive, etc.). For example, a typical delay time for an incandescent lamp load is 50 mS. Since it is undesirable to sense the current before the delay timer has expired, step 152 is performed continuously until the condition is satisfied.

At step 154, the test module senses an analog voltage signal \( V_{ON} \) from the current sensor 54. This analog voltage signal is proportional to the current flowing through the electrical conductors 70 which includes the current associated with the activated load. The control module senses the battery voltage \( V_{BATT} \) which is then
utilised to scale the current (IS\textsubscript{ON}). Utilising ISC\textsubscript{OFF} and IS\textsubscript{ON}, at step 156 the test module computes the scaled differential load current, which represents the current associated with the activated load.

At step 158, the diagnostic tester 74 determines whether or not the scaled differential load current is acceptable. In making this determination, the diagnostic tester 74 utilises data received from the control module indicative of the expected load current for that particular electrical load. If the load current is within the acceptable range, the operating condition of the load is acceptable and at step 160 the test module issues a command to the control module to turn off the electrical load.

At step 162, the diagnostic tester 74 provides appropriate diagnostic data to the control module regarding the operating condition (acceptable or unacceptable) of the load. Preferably, the control module then utilises this diagnostic data to control the operating state of the electrical load. For example, if the load current was unacceptable, the diagnostic would consist of an appropriate fault code. In response to receipt of the fault code, the control module would disable the appropriate output to ensure no further attempts are made to activate the load. If no further current sensing operations are required to be performed, the diagnostic tester 74 can then be disconnected from the control module.

As an alternative, it should be appreciated that the diagnostic tester 74 could determine the operating condition of an electrical load utilising load impedances. For example, the load impedance could be determined utilising the V\textsubscript{ON/OFF} and ISC\textsubscript{ON/OFF} and then compared to predefined load impedances stored in a look-up table.

Referring now to Figure 6, a graphical illustration is shown of a current plot obtained using the method and apparatus of the present invention. Specifically, the graph illustrates the voltage output from the current sensor as various electrical loads are activated and deactivated. Initially, the voltage output is approximately zero volts,
which is representative of little or no current flowing through the conductors. As the rear window defogger load is activated by the vehicle operator, current is drawn from the battery through an associated electrical conductor. This increased current is sensed by the current sensing apparatus, resulting in the sharp increase in output voltage indicated by reference letter "A".

As the defogger is functioning, the current flow through the conductor and, therefore, the voltage output from the current sensor, remains essentially constant. The voltage output increases, however, with the activation of an additional electrical load, indicated generally by reference letter "B". This increase could correspond to the activation of a window motor in response to the vehicle operator depressing a power window button.

Operation of the window motor results in an increase in the current sensed by the toroid and a corresponding increase in the voltage signal. As the window is moving, the voltage level remains generally steady until the window motor "stalls" resulting in the sharp increase in the voltage generally indicated by reference letter "C". At the conclusion of the window motor stall condition (i.e. the power window button is released), current flow through the electrical motor ceases, resulting in the sharp decrease in the voltage output indicated generally by reference letter "D". As expected, the voltage output returns to a level associated with the continued operation of the rear window defogger. When the defogger is eventually deactivated, the voltage output level drops to approximately zero volts, as indicated generally by reference letter "E".
CLAIMS

1. An apparatus for monitoring the operation of a plurality of electrical loads in an automotive vehicle, the loads collectively requiring an output current, the apparatus comprising:
   single detecting means (14) for detecting a change in the output current and generating an output signal based on the change; and
   control means (12) for activating each electrical load at a given time to obtain a like plurality of timing signals and so that each activated electrical load receives a portion of the output current, the control means for processing the output signal and the timing signals to obtain a diagnostic signal related to an operating condition of each activated electrical load.

2. An apparatus as claimed in claim 1, wherein the control means controls an operating state of each activated electrical load based on the diagnostic signal.

3. An apparatus as claimed in claim 1 or 2, further comprising means for deactivating each activated electrical load and generating an associated fault code if a certain operating condition exists.

4. An apparatus as claimed in any one of claims 1 to 3, further comprising means for predicting a future operating condition of the electrical loads based on the output signal.

5. An apparatus as claimed in claim 1 further comprising means for scaling the output signal based on battery voltage to obtain an adjusted output signal.

6. An apparatus as claimed in claim 5, further comprising means for predicting a future operating condition of the electrical loads based on the adjusted output signal.
7. An apparatus as claimed in any one of the preceding claims wherein the single detecting means is a toroid which encircles a plurality of electrical conductors associated with the electrical loads.

8. The apparatus as claimed claim 1, wherein the detecting means is a resistive element electrically connected in series with at least one electrical conductor associated with the electrical loads.

9. A method of monitoring the operation of a plurality of electrical loads in an automotive vehicle, the electrical loads collectively requiring an output current, the method comprising the steps of:

activating at least one of the electrical loads to obtain at least one timing signal;

detecting a change in the output current to determine an actual current differential; and

correlating the actual current differential with predetermined acceptable current differentials for the at least one of the electrical loads, to obtain a diagnostic signal related to an operating condition of the at least one of the electrical loads.

10. A method as claimed in claim 9 further comprising the step of controlling the operating state of the at least one of the electrical loads based on the diagnostic signal.

11. A method as claimed in claim 9, further comprising the steps of deactivating the at least one of the electrical loads and storing an associated fault code in the memory if a certain operating condition exists.

12. A method as claimed in claim 9, further comprising the steps of:

comparing the actual current differential to a plurality of prior actual current differentials to detect a trend; and
predicting a future operating condition of the at least one of the electrical loads based on the comparison.

13. A method as claimed in claim 9, further comprising the step of:
   scaling the actual current differential based on vehicle battery voltage to obtain an adjusted current differential.

14. A method as claimed in claim 13, further comprising the steps of:
   comparing the adjusted current differential to a plurality of prior adjusted current differentials to detect a trend; and
   predicting a future operating condition of the at least one of the electrical loads based on the comparison.
Current Sense Routine

Is current sense already in progress?

Yes → 100

No → 102

Should load be activated?

No → B

Yes → 104

Read analog voltage proportional to current ($V_{OFF}$). Read $V_{BATT}$ and scale current ($ISC_{OFF}$)

Enable output → 106

Look up delay value for load; initiate delay timer

Is delay timer expired?

No → 108

Yes → 110

A → Fig. 4a

B
Read analog voltage proportional to current ($V_{ON}$). Read battery voltage and scale current ($ISC_{ON}$)

Calculate current differential

$I_L = ISC_{ON} - ISC_{OFF}$

$IL > I_{MAX}$ ?

Yes

Turn off load. Disable output due to "short"; set diagnostic trouble code

No

$IL < I_{MIN}$ ?

Yes

Turn off load. Disable output due to "open"; set diagnostic trouble code

No

D

C

Fig. 4b
Fig. 4c
Fig. 5

Current Sense Routine

140

Read Analog voltage \( (V_{OFF}) \) proportional to current. Read \( V_{BATT} \) and scale current \( (ISC_{OFF}) \)

142

Issue command to turn on load

144

Did module acknowledge?

146

Timeout?

150

Yes

Look up delay value for load; initiate delay timer

152

No

Is delay timer expired?

154

Yes

Read analog voltage proportional to current \( (V_{ON}) \) Read \( V_{BATT} \) and scale current \( (ISC_{ON}) \)

156

Calculate current differential

158

Yes

Is \( I_L \) acceptable?

160

Issue command to turn off load

162

No

Input diagnostic data

End
INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)  
According to International Patent Classification (IPC) or to both National Classification and IPC  
Int.Cl. 5 G01R31/00

II. FIELDS SEARCHED

Minimum Documentation Searched

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Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched

III. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>PATENT ABSTRACTS OF JAPAN vol. 12, no. 235 (P-725) (3082) 6 July 1988 &amp; JP,A,63 27 769 (JIDOSHA KIKI) 5 February 1988 see abstract</td>
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<td>WO,A,9 116 637 (BOSCH) 31 October 1991 see abstract see page 6, paragraph 3; claims 9,11</td>
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<td>EP,A,0 408 867 (MAN) 23 January 1991 see column 3, line 25 - line 44; figure 3</td>
<td>1,8,9</td>
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IV. CERTIFICATION

Date of the Actual Completion of the International Search: 25 AUGUST 1993  
Date of Mailing of this International Search Report: 03.09.93  
International Searching Authority: EUROPEAN PATENT OFFICE  
Signature of Authorized Officer: IWANSSON K.G.
<table>
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<th>Category</th>
<th>Citation of Document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to Claim No.</th>
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| X        | DE,A,4 004 413 (FUJI JUKOGYO)  
23 August 1990  
see column 1, line 14 - column 2, line 10  
see column 3, line 51 - column 5, line 16;  
figures 1,2,3A,5,6C | 1,9                   |
| A        |                                                                              | 7                     |
This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 25/08/93

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