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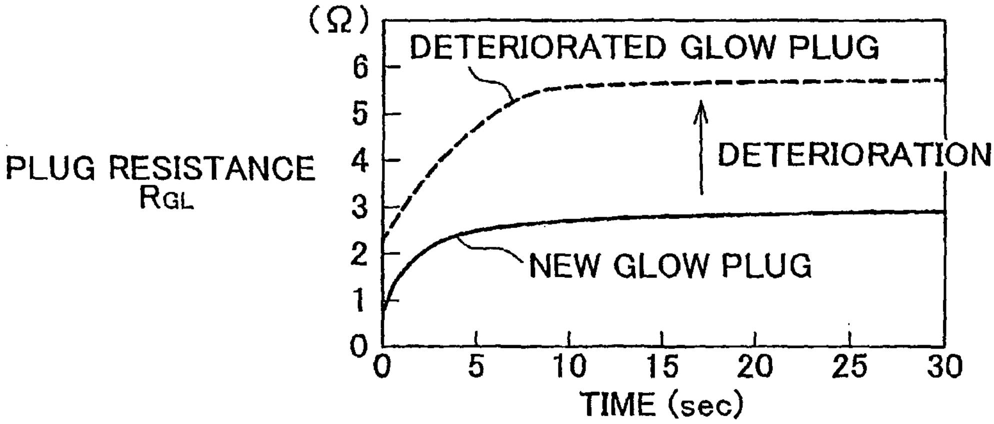
(54) Glow plug deterioration determination system

(57) A glow plug deterioration determination system 1 includes: a glow plug 40; a GCU 30 that controls energization of the glow plug 40 from a power supply 10 by driving switch means T_1 to T_4 to open and close in accordance with a drive signal SI issued by an ECU 20; a self-diagnosis unit (DIU) 32 that detects an abnormality between the glow plug 40, the switch means T_1 to T_4, and the GCU 30 and transmits a self-diagnosis signal DI to the ECU 20; and current detecting means S_1 to S_4 for detecting a plug current I_{GL} flowing through the glow plug 40, wherein the DIU 32 includes deterioration level determining means 330 for determining whether the glow plug 40 is in a deteriorated condition by comparing a plug current converted voltage Vi that is proportionate to the plug current I_{GL} with a plurality of voltage thresholds $Vref_1$ to $Veef_n$.

FIG. 3B



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The invention relates to a glow plug deterioration determination system for determining deterioration of a glow plug provided in each cylinder of a diesel combustion engine.

2. Description of the Related Art

[0002] Japanese Patent Application Publication No. 2001-66329 (JP-A-2001-66329), Japanese Patent Application Publication No. 2008-31979 (JP-A-2008-31979), and Japanese Patent Application Publication No. 2008-297925 (JP-A-2008-297925) disclose, as an abnormality detection apparatus for detecting a disconnection abnormality, an overcurrent abnormality, and so on in a glow plug that assists ignition in a diesel combustion engine, an apparatus that detects an abnormality in a glow plug by monitoring a current flowing through the glow plug using a current sensor or a current sensing resistor provided between the glow plug and switch means for controlling energization of the glow plug.

[0003] Further, Japanese Patent Application Publication No. 2003-247721 (JP-A-2003-247721) and Japanese Patent Application Publication No. 2005-147533 (JP-A-2005-147533) disclose a technique in which a ceramic glow plug formed by burying a heat generator constituted by a conductive ceramic (for example, a ceramic resistor having tungsten carbide as a main component and containing silicon nitride and so on) that generates heat when energized as a heat generator in a support constituted by an insulating ceramic (for example, a ceramic insulator having silicon nitride as a main component and containing molybdenum disilicide and so on) is used as a glow plug having a superior rapid heating property.

[0004] When a ceramic glow plug is used continuously over a long period, a resistance value thereof may increase gradually due to migration, in which a grain boundary component of the conductive ceramic diffuses toward an electrode due to a thermal load, and an increase in a porous quality of the conductive ceramic, and as a result, it may become impossible to obtain a desired heat generation temperature. It is therefore necessary to monitor deterioration of the ceramic glow plug during use.

[0005] However, in addition to variation in the resistance value of the ceramic glow plug corresponding to the heat generation temperature, a heat absorption amount thereof varies according to variation in a flow rate of an in-cylinder air flow, a fuel spray amount, and so on within a combustion chamber in which the glow plug is provided in accordance with engine operating conditions, and this heat absorption amount variation likewise leads to variation in the heat generation temperature of the glow plug. Furthermore, a voltage V_{BATT} of a battery for driving the glow plug varies according to a battery capacity, a load condition of a starter or the like driven at the same time as the glow plug, and so on. Therefore, to detect the deterioration condition of the ceramic glow plug accurately, a plug resistance R_{GL} of the glow plug must be calculated by transmitting a plug voltage V_{GL} applied to each glow plug and a plug current I_{GL} flowing through each glow plug to an electronic control unit (ECU) for controlling an engine operation, and moreover, the operating conditions of the engine must be taken into account.

[0006] In the related art, the plug voltage V_{GL} and plug current I_{GL}, which are detected in analog fashion, are converted into digital data and transmitted to an engine ECU via serial communication means, whereupon a deterioration determination is performed in the ECU. To calculate the plug resistance R_{GL} accurately, approximately ten bits of the respective data must be obtained and precision must be secured therein. Data are typically transmitted in eight-bit units, and therefore, in order to transmit ten bits of data, sixteen bits of data including six bits of dummy data are transmitted. In the case of a four-cylinder engine, for example, a total data amount transmitted to detect variation in a glow plug resistance value precisely is therefore 8 bits $\times$ 2 $\times$ 2 types $\times$ 4 cylinders = 128 bits. Hence, a large amount of time is required to complete transmission of all of the data, and in the meantime, the engine operating conditions may vary such that the glow plug deterioration determination is late. Furthermore, an expensive, high-throughput microprocessor unit (MPU) must be used in the ECU to process the large amount of data.

SUMMARY OF INVENTION

[0007] The invention provides a glow plug deterioration determination system which is capable of determining deterioration of a glow plug quickly.

[0008] A first aspect of the invention relates to a glow plug deterioration determination system including: a glow plug attached to a cylinder of a diesel combustion engine to generate heat when energized; an electronic control unit (ECU) for controlling an operation of the diesel combustion engine; a glow plug energization control unit (GCU) that controls an energization of the glow plug from a power supply by driving switch means to open and close in accordance with a drive signal that is issued by the ECU in accordance with an operating condition of the diesel combustion engine; current detecting means for detecting a plug current flowing through the glow plug; and a self-diagnosis unit (DIU) including deterioration level determining means for determining whether the glow plug is in a deteriorated condition by comparing the plug current detected by the current detecting means with a plurality of thresholds.

[0009] In the determination system according to this aspect, the deterioration level determining means may transmit a deterioration level expressing a result of the determination as to whether the glow plug is in the deteriorated condition in binary to the ECU.

[0010] In the determination system according to this aspect, the ECU may determine, on the basis of the deterioration level, whether the deterioration level belongs to a normal region or a deterioration region in accordance with a combustion characteristic of the diesel combustion engine.

[0011] The determination system according to this aspect may further include voltage converting means for converting the plug current flowing through the glow plug into a voltage and outputting the voltage, and the current detecting means may detect the plug current on the basis of a plug current converted voltage, which is the voltage converted from the plug current by the voltage converting means.

[0012] In the determination system according to this aspect, the voltage converting means may include a differential amplifier into which an upstream side voltage and a downstream side voltage of a current sensing resistor interposed between the power supply and the glow plug are input, and the output plug current converted voltage may be proportionate to the plug current.

[0013] In the determination system according to this aspect, the deterioration level determining means may include: a plurality of resistors connected in series between the power supply and earth; and a comparator that compares voltage thresholds prorated according to the plurality of resistors with the plug current converted voltage and outputs the plug current converted voltage when the plug current converted voltage is lower than the respective voltage thresholds, and the deterioration level may be determined according to an output from the comparator.

[0014] In the determination system according to this aspect, the plurality of resistors may be a deterioration level upper limit determining resistor, (n-1) deterioration level prorating resistors and a deterioration level lower limit determining resistor.

[0015] In the determination system according to this aspect, the deterioration level determining means may convert the output from the comparator into a binary self-diagnosis signal and output the binary self-diagnosis signal to the ECU.

[0016] In the determination system according to this aspect, the deterioration level determination means may classify the deterioration level in a range of four ranks to sixteen ranks, and the self-diagnosis signal may be constituted by a range of two bits to four bits.

[0017] In the determination system according to this aspect, the cylinder of the diesel combustion engine may be provided in a plurality, and the glow plug may be attached to each of the plurality of cylinders.

[0018] In the determination system according to this aspect, the DIU may detect abnormalities of the glow plug and the GCU and transmit the abnormality to the ECU.

[0019] With the above configuration, only the determination results indicating the deterioration levels of the respective glow plugs, which are determined instantaneously by the analog logic of the deterioration determination means provided in the GCU, are transmitted from the GCU to the electronic control system to perform a deterioration determination on the glow plugs, and therefore the deterioration level determination results can be transmitted quickly. Further, the allowable range of the glow plug deterioration levels differs according to the actual combustion characteristic of the diesel combustion engine, and therefore, using map processing or the like, the electronic control system may determine, from the transmitted data indicating the respective deterioration levels and the data input into the electronic control system in relation to operating conditions such as the engine rotation speed and the engine water temperature, whether each deterioration level input from the deterioration determination circuit belongs to the normal region or the deterioration region in accordance with the applied diesel combustion engine. As glow plug deterioration progresses, the plug resistance increases, leading to a reduction in the plug current flowing through the glow plugs, and therefore the plug current converted voltage decreases gradually in accordance with the reduction in the plug current. When the plug current converted voltage falls below the voltage thresholds of the respective comparators, the comparators are activated sequentially, and in accordance with the binarized self-diagnosis signals, the comparator that has been activated most recently can be expressed in the form of a deterioration level. Note that the deterioration level determining means may be provided independently for each glow plug, or single deterioration level determination means may be shared such that input of the plug current converted voltages from the respective glow plugs is switched in succession. The respective deterioration conditions of the glow plugs can be determined instantaneously by comparing the plug current converted voltages, which are obtained by converting the plug currents detected by the current detecting means into voltages using the voltage converting means, with the plurality of voltage thresholds, and the results can be transmitted to the electronic control system in the form of deterioration level signals. Further, the power supply voltage is prorated for input as the voltage thresholds to be compared with the plug current converted voltages, and therefore variation in the power supply voltage can be canceled out. As a result, the deterioration level can be determined in accordance with variation in the plug resistance accompanying progression in the deterioration of the glow plug without being affected by variation in the power supply voltage.

BRIEF DESCRIPTION OF DRAWINGS

[0020] The foregoing and further objects, features and advantages of the invention will become apparent from the following description of example embodiments with reference to the accompanying drawings, wherein like numerals are used to represent like elements and wherein:

FIG. 1 is a schematic diagram showing the overall constitution of a glow plug energization control system including a glow plug deterioration determination system according to an embodiment of the invention;
FIG. 2 is a block diagram showing a specific example of the glow plug deterioration determination system according to this embodiment of the invention;
FIGS. 3A to 3C show variation due to deterioration of a glow plug, wherein FIG. 3A is a characteristic diagram relating to a temperature characteristic, FIG. 3B is a characteristic diagram relating to a plug resistance, and FIG. 3C is a characteristic diagram relating to a plug current;
FIGS. 4A and 4B show a relationship between a resistance value and an engine rotation speed with respect to glow plug deterioration, wherein FIG. 4A is a characteristic diagram showing temporal variation in the plug resistance and FIG. 4B is a characteristic diagram showing variation in a deterioration region and a normal region relative to the engine rotation speed;
FIG. 5 is an image of serial data according to the related art, showing information amounts relating to a plug voltage and a plug current required to detect the plug resistance;
FIGS. 6A to 6C show an example in which a deterioration level is classified into seven ranks in the deterioration determination system according to this embodiment of the invention, wherein FIG. 6A shows binary numbers indicating the deterioration level, FIG. 6B is an image of serial data indicating transmission information amounts, and FIG. 6C shows specific examples of thresholds and determination results;
FIG. 7 is a communication image showing results of this embodiment of the invention and a comparative example;
FIG. 8 is a deterioration determination flowchart executed by an electronic control system on the basis of the deterioration level of the glow plug, which is determined by the deterioration determination system according to this embodiment of the invention; and
FIG. 9 is a deterioration level threshold calculation map according to this embodiment.

DETAILED DESCRIPTION OF EMBODIMENTS

[0021] Referring to FIG. 1, an outline of a glow plug deterioration determination system 1 according to an embodiment of the invention will be described. In the glow plug deterioration determination system 1, a drive signal SI is issued from an electronic control unit (ECU) 20 for controlling an operation of a diesel combustion engine 50 using a glow plug 40 (GL_1, GL_2, GL_3, GL_4) attached to each cylinder of the diesel combustion engine 50 as a load, a drive unit 31 that controls opening/closing of semiconductor power elements T_1, T_2, T_3, T_4 such as MOSFETs or IGBTs, which are interposed between a power supply 10 such as a battery and the glow plugs 40 via switch means, in accordance with the drive signal SI is provided in a GCU 30 for controlling energization and disconnection of the glow plugs 40, and deterioration level determining means for determining deterioration conditions of the glow plugs 40 is provided in a DIU 32 that detects an abnormality in a drive system extending from the power supply 10 to the glow plugs 40 and transmits a self-diagnosis signal DI to the ECU 20. Note that in this embodiment, a four-cylinder engine provided with four glow plugs 40 will be described as an example of the diesel combustion engine 50, but this embodiment of the invention is not limited to a four-cylinder engine. The glow plug 40 is a ceramic glow plug formed by burying a heat generator constituted by a conductive ceramic (for example, a ceramic resistor having tungsten carbide as a main component and containing silicon nitride and so on) that generates heat when energized as a heat generator in a support constituted by an insulating ceramic (for example, a ceramic insulator having silicon nitride as a main component and containing molybdenum disilicide and so on).

[0022] The glow plug deterioration determination system 1 is constituted by the power supply 10, which is a vehicle-installed battery, for example, the ECU 20 for controlling driving of the engine, and the GCU 30 for controlling energization of the glow plugs 40 (GL_1 to GL_4) provided in the respective cylinders of the diesel combustion engine 50 in accordance with the drive signal SI issued from the ECU 20 in accordance with operating conditions of the diesel combustion engine 50. The GCU 30 is constituted by the switch means T_1, T_2, T_3, T_4 including semiconductor power elements such as metal-oxide semiconductor field-effect transistors (MOSFETs) or insulated gate bipolar transistors (IGBTs), which are opened and closed to control power supply and cutoff from the power supply 10 to the glow plugs 40, a drive control unit (DCU) 31 that drives the switch means T_1, T_2, T_3, T_4 to open and close while issuing drive signals G_1, G_2, G_3, G_4 that are offset by predetermined intervals in accordance with the drive signal SI issued from the ECU 20, current detecting means S_1, S_2, S_3, S_4 such as a current sensing resistor (shunt resistor) Rs, and the DIU 32 including a deterioration level determination circuit 330 as the deterioration level determining means for determining the deterioration condition of the glow plugs 40 (GL_1 to GL_4) from plug currents I_{GL} flowing through the respective glow plugs 40 (GL_1 to GL_4), which are detected by the current detecting means S_1, S_2, S_3, S_4.

[0023] Upstream side voltages V_{a1}, V_{a2}, V_{a3}, V_{a4} of the shunt resistor Rs are input into non-inverting input terminals + of differential amplifiers 321, 322, 323, 324 provided as voltage converting means, downstream side voltages V_{b1}, V_{b2}, V_{b3}, V_{b4} of the shunt resistor Rs are input into inverting input terminals - of the differential amplifiers 321, 322, 323, 324, and plug current converted voltages Vi_1 to Vi_4 amplified in proportion to plug currents I_{GL1} to I_{GL4} flowing through the respective glow plugs 40 (GL_1 to GL_4) are output. The plug current converted voltages $Vi_{(1\ to\ 4)}$ output from the differential amplifiers 321, 322, 323, 324 are input into the deterioration level determination circuit 330, whereupon the deterioration conditions of the glow plugs 40 are determined. A determination result obtained by the deterioration level determination circuit 330 is transmitted to the ECU 20 as a part of the self-diagnosis signal DI. Transmission of the drive signal SI from the ECU 20 to the GCU 30 and transmission of the self-diagnosis signal DI from the GCU 30 to the ECU 20 are performed via a serial interface.

[0024] The power supply 10 is divided into a control voltage +B supplied to a control circuit and a drive voltage BATT for driving a load. The control voltage +B is supplied to the ECU 20 and the GCU 30 via a fuse 121 and a main relay (MRY) 120, while the drive voltage BATT is supplied to the GCU 30 via a fuse 131 and a glow relay (GRY) 130.

[0025] When a main switch 11 is closed, the main relay MRY 120 closes such that the control voltage +B is supplied to the ECU 20 and the GCU 30. Simultaneously, the glow relay GRY 131 closes such that the drive voltage BATT is supplied to the GCU 30. Information relating to engine operating conditions including an engine water temperature TW, a crank angle CA, a rotation speed NE, a throttle opening SL, and a glow plug temperature Tg, which are detected by operating condition detecting means such as a water temperature sensor, a crank angle sensor, a rotation speed sensor, a throttle sensor, and a glow plug temperature sensor, for example, none of which is shown in the drawings, is input into the ECU 20, whereupon the ECU 20 issues the drive signal SI with a duty ratio that has been calculated to adjust a heat generation amount of the glow plugs 40 to a desired value.

[0026] Referring to FIG. 2, the deterioration level determination circuit 330 will be described in further detail. The deterioration determination circuit 330 is constituted by a deterioration level upper limit determining resistor R_1, a deterioration level lower limit determining resistor R_2 and (n-1) deterioration level prorating resistors R, which are disposed in series between the power supply 10 and earth (ground) to prorate a battery voltage V_{BATT} according to predetermined voltages, n comparators CMP_1 to CMP_n for comparing the plug current converted voltage Vi differentially amplified by the differential amplifier 321 (322, 323, 324) with voltage thresholds $Vref_1$ to $Vref_n$, an encoder 331 for converting the output of the comparators CMP_1 to CMP_n into a binary diagnostic code, and a diagnostic code output interface 332 for outputting the diagnostic code converted by the encoder 331 to the ECU 20 as a part of the self-diagnosis signal DI.

[0027] As deterioration of the glow plug 40 progresses, the plug resistance R_{GL} gradually increases, leading to a gradual reduction in the plug current I_{GL} flowing through the glow plug 40. Accordingly, a differentially amplified voltage Vi proportionate to the plug current I_{GL} detected by the current detecting means S 1 is input into the inverting input terminals - of the comparators CMP_1 to CMP_n while the voltage thresholds $Vref_1$ to $Vref_n$, which correspond to deterioration levels LV_1 to LV_n, are input into the non-inverting input terminals + of the comparators CMP_1 to CMP_n. The voltage thresholds $Vref_1$ to $Vref_n$ are obtained by connecting the deterioration level upper limit determining resistor R_1, the deterioration level lower limit determining resistor R_2, and the (n-1) deterioration level prorating resistors R in series and prorating the battery voltage V_{BATT} according to thresholds corresponding to deterioration levels.

[0028] As deterioration of the glow plug 40 progresses, the plug resistance R_{GL} increases, leading to a reduction in the plug current I_{GL} flowing through the glow plug 40, and therefore the plug current converted voltage Vi also decreases gradually. When the plug current converted voltage Vi falls below the voltage thresholds $Vref_1$ to $Vref_n$ of the respective comparators CMP_1 to CMP_n, the comparators CMP_1 to CMP_n are activated sequentially, and in accordance with the diagnostic code binarized by the encoder 331, the comparator CMP_1 to CMP_n that has been activated most recently is expressed as the deterioration level LV_1 to LV_n. Note that the deterioration level determination circuit 330 may be provided independently for each glow plug 40 (GL_1 to GL_4), or a single deterioration level determination circuit 330 may be shared by the glow plugs GL_1 to GL_4 such that input of the plug current converted voltages Vi_1 to Vi_4 from the respective glow plugs GL_1 to GL_4 is switched in succession.

[0029] According to this embodiment, the respective deterioration conditions of the glow plugs 40 can be determined instantaneously by comparing the differentially amplified voltages Vi, which are proportionate to the plug currents I_{GL1} to I_{GL4} detected by the current detecting means S_1 to S_4, with the plurality of voltage thresholds $Vref_1$ to $Vref_n$, expressing the results as levels L_0 to L_n, and transmitting corresponding deterioration level signals LV_1 to LV_4 to the ECU 20. Further, the battery voltage V_{BATT} is prorated for input as the voltage thresholds $Vref_1$ to $Vref_n$ to be compared with the differentially amplified voltages Vi, and therefore variation in the battery voltage V_{BATT} can be canceled out. As a result, the deterioration level can be determined in accordance with variation in the plug resistance R_{GL} accompanying progression in the deterioration of the glow plug 40, without being affected by variation in the battery voltage V_{BATT}.

[0030] Referring to FIGS. 3 and 4, variation in the plug resistance R_{GL} accompanying deterioration of the glow plug 40 and the difficulty of measuring this variation will be described. FIG. 3A shows a temperature characteristic of the glow plug 40 in a new condition during idling and a temperature characteristic of the glow plug 40 in an advanced state of deterioration during idling. As shown in FIG. 3A, in a new condition, a desired temperature is reached in several seconds, whereas in an advanced state of deterioration, a heat generation temperature does not rise sufficiently, and when the glow plug 40 continues to be used in this state, a misfire may occur in the diesel combustion engine 50. FIG. 3B shows a resistance characteristic of the glow plug 40 in a new condition during idling and a resistance characteristic of the glow plug 40 in an advanced state of deterioration during idling. As shown in FIG. 3B, in a ceramic glow plug, a resistance value increases (from 1 Ω to 2 Ω, for example) following energization. In addition, the resistance value rises further (from 2 Ω to 6 Ω, for example) due to deterioration. It must therefore be determined whether an increase in the plug resistance R_{GL} is due to energization or deterioration. Further, the plug resistance R_{GL} stabilizes at a constant value within approximately 10 to 20 seconds following the start of energization in both a new condition and a deteriorated condition. FIG. 3C shows a current characteristic of the glow plug 40 in a new condition during idling and a current characteristic of the glow plug 40 in an advanced state of deterioration during idling. As shown in FIG. 3C, in a ceramic glow plug, an inrush current takes a large value of several tens of A, and following energization, the plug current I_{GL} flowing through the glow plug decreases (to or below 6A, for example). In addition, the plug current I_{GL} decreases further (to or below 2A, for example) when deterioration progresses.

[0031] FIG. 4A shows variation in the plug resistance R_{GL} due to variation in the engine rotation speed. As shown in FIG. 4A, an increase in the engine rotation speed leads to a reduction in the plug resistance R_{GL}. The reason for this is that during high-speed rotation, an in-cylinder air flow generated in a combustion chamber is strong and a fuel spray amount is large, leading to an increase in a heat absorption amount, and therefore the heat generation temperature of the glow plug 40 decreases, leading to a reduction in the plug resistance R_{GL}. The plug resistance R_{GL} varies according to the operating conditions of the diesel combustion engine 50 during measurement of the plug resistance R_{GL}, and it must therefore be determined whether the variation in the plug resistance R_{GL} is due to deterioration of the glow plug 40 or variation in the operating conditions of the diesel combustion engine 50. Hence, as shown in FIG. 4B, the proportion of a normal region in which the glow plug 40 is determined to be normal and the proportion of a deterioration region in which the glow plug 40 is determined to be in a state of advanced deterioration vary according to the rotation speed NE of the diesel combustion engine 50. Furthermore, in this embodiment, detection of the plug currents (I_{GL1} to I_{GL4}) by the current detecting means S_1 to S_4 or reading of the detection results for the purpose of determining deterioration of the glow plugs 40 (GL_1 to GL_4) may be performed following engine startup or when the plug current I_{GL} has stabilized, i.e. 10 to 20 seconds after the start of energization of the glow plugs 40.

[0032] In a comparative example, when an attempt is made to transmit plug voltages V_{GL1}, V_{GL2}, V_{GL3}, V_{GL4} (0 to 14 V, for example) applied to the glow plugs 40 (GL_1 to GL_4) and the plug currents I_{GL1}, I_{GL2}, I_{GL3}, I_{GL4} (0 to 127 A, for example) flowing through the respective glow plugs 40 (GL_1 to GL_4) with a full-range precision of 1/100, an information amount of approximately ten bits is required for each datum. In serial communication, transmission is typically performed in eight-bit units, and therefore, when an attempt is made to calculate the plug resistance R_{GL} with a high degree of precision from the plug voltages V_{GL1}, V_{GL2}, V_{GL3}, V_{GL4} and the plug currents I_{GL1}, I_{GL2}, I_{GL3}, I_{GL4}, the total data amount transmitted to the ECU 20, as shown in FIG. 5, is 16 bits × two types × four cylinders = 128 bits (D_{0a1} to D_{15a1}, D_{0b1} to D_{15a1}, D_{0a2} to D_{15a2}, D_{0b2} to D_{15a2}, D_{0a3} to D_{15a3}, D_{0b3} to D_{15a3}, D_{0a4} to D_{15a4}, D_{0b4} to D_{15a4}). A computing power of an integrated circuit (IC) used by the GCU 30 is normally low, and therefore the ECU 20, which is constituted by an MPU, for example, requires advanced processing power.

[0033] In the glow plug deterioration determination system 1 according to this embodiment, on the other hand, as shown by J_1 to J_3 in FIG. 6A, the determination result can be expressed by classifying the deterioration level into eight ranks constituted by three bits of information, namely a normal level (L_0, 000), a deterioration level 1 (L_1, 001), a deterioration level 2 (L_2, 010), a deterioration level 3 (L_3, 011), a deterioration level 4 (L_4, 100), a deterioration level 5 (L_5, 101), a deterioration level 6 (L_6, 110), and a deterioration level 7 (L_7, 111) such that when the deterioration levels LV_1 to LV_4 are determined in relation to the glow plugs 40 (GL_1 to GL_4) and transmitted as serial data; a total data amount of sixteen bits is sufficient to cover the transmitted data, as shown in FIG. 6B. FIG. 6C shows a specific example serving as a first example of the deterioration determination system 1, in which $R_1 = 4 \cdot R$, $R_2 = 4 \cdot R$, and $n = 7$ are set and the deterioration level is classified into eight ranks.

[0034] Referring to FIG. 7, effects of this embodiment will be described through comparison with the comparative example. As described above, in the comparative example, when the plug resistance R_{GL} is calculated from the plug voltage V_{GL} and the plug current I_{GL}, the required total data amount reaches 128 bits, and when eight bits are transmitted per second, it takes sixteen seconds to transmit all of the data, as shown in FIG. 7A. Therefore, during data transmission, the operating conditions of the diesel combustion engine 50 cannot be modified. Alternatively, the operating conditions may vary before the deterioration determination has been completed on all of the glow plugs 40, leading to instability in the plug resistance R_{GL} serving as the determination reference, and as a result, it may be impossible to perform the deterioration determination. According to this embodiment, on the other hand, only the determination results indicating the deterioration levels LV_1 to LV_4 of the respective glow plugs 40 (GL_1 to GL_4), which are determined instantaneously by an analog logic of the deterioration determination circuit 330 provided in the GCU 30, are transmitted from the GCU 30 to the ECU 20 to perform the deterioration determination on the glow plugs 40 (GL_1 to GL_4), and therefore the total data amount is no greater than sixteen bits. Hence, when eight bits of data are transmitted per second, the deterioration level determination results relating to all of the glow plugs 40 (GL_1 to GL_4) can be transmitted completely in two seconds, as shown in FIG 7B.

[0035] Further, an allowable range (000 to 111) of the deterioration levels LV_1 to LV_4 of the glow plugs 40 differs according to an actual combustion characteristic of the diesel combustion engine 50, and therefore the ECU 20 may determine, from the transmitted data indicating the respective deterioration levels LV_1 to LV_4 in relation to the normal level (000) to the deterioration level 7 (111) and the data input into the ECU 20 in relation to the operating conditions, such as the engine rotation speed NE and the engine water temperature TW (for example, by performing map processing on these data), whether each deterioration level LV_1 to LV_4 (000 to 111) belongs to the normal region or the deterioration region in accordance with the combustion characteristic of the diesel combustion engine 50.

[0036] In this embodiment, the deterioration level is classified into eight ranks, but depending on a communication environment of the applied diesel combustion engine and the throughput of the ECU, the deterioration level may be classified in a range of four ranks to sixteen ranks. When the deterioration level is classified in four ranks, namely a normal level (00), a deterioration level 1 (01), a deterioration level 2 (10), and a deterioration level 3 (11), only two bits of data are required for each glow plug, and even when the deterioration level is classified in sixteen ranks from a normal level (0000) to a deterioration level 15 (1111), only four bits of data are required for each glow plug.

[0037] Referring to FIGS. 8 and 9, a deterioration determination control method for performing a deterioration determination in accordance with the combustion characteristic of the applied diesel combustion engine using the deterioration levels of the glow plugs determined by the glow plug deterioration determination system 1 according to this embodiment and specific examples of deterioration level thresholds used during the determination will now be described. Note that here, a case in which the deterioration level is classified in eight ranks from 000 to 111 will be described as an example. The ECU 20 performs the deterioration determination in accordance with a control flow such as that shown in FIG. 8 on the basis of deterioration level signals LV_1, LV_2, LV_3, LV_4 transmitted from the GCU 30. In glow plug deterioration determination startability determination processing executed in step S100, a determination as to whether the engine rotation speed is in a stable condition is made by determining whether or not a state in which engine rotation speed variation is within 200 rpm has been established continuously for five seconds or more. When a stable condition is established, the glow plug deterioration determination is substantially begun.

[0038] When it is determined in step S100 that variation in the engine rotation speed NE is within 200 rpm and a stable condition is therefore established (S100 Yes), the routine advances to step S110. When it is determined that variation in the engine rotation speed NE is greater than 200 rpm due to acceleration or deceleration (S100 No), this indicates that the engine rotation speed is unstable, making it difficult to perform the glow plug deterioration determination accurately, and therefore S100 is repeated until the engine rotation speed NE stabilizes. In glow plug energization condition determination processing executed in step S110, a determination is made as to whether or not an effective voltage V_{GLE} applied to the glow plugs has remained unchanged for at least ten seconds, and when the effective voltage V_{GLE} has remained unchanged for at least ten seconds, it is determined that the glow plug deterioration determination is possible (S110 Yes), whereupon the routine advances to step S120. When the effective voltage V_{GLE} applied to the glow plugs varies within ten seconds (S110 No), this may indicate instability in the power supply voltage V_{BATT} due to variation in the battery capacity, variation in a charge amount from an alternator, and so on, making it difficult to perform the deterioration determination on the glow plugs 40 accurately, and therefore the processing of steps S100 and S110 is repeated until the effective voltage V_{GLE} stabilizes. In deterioration level threshold calculation processing executed in step S120, a threshold LV_{REF} for determining the deterioration condition of the glow plugs from the deterioration level signals LV_i to LV_4 is calculated from the engine rotation speed NE and the glow plug energization effective voltage V_{GLE} in accordance with a map prepared in advance, such as that shown in FIG. 9. In deterioration level determination processing executed in step S130, the deterioration determination is implemented on the glow plugs 40 (GL_1 to GL_4) by comparing the deterioration levels (L0, 000 to L7, 111) of the respective glow plugs 40 (GL_1 to GL_4), represented by the deterioration level signals LV_1 to LV_4 transmitted from the GCU 30, with the threshold LV_{REF} calculated in step S120. When the deterioration level (L0, 000 to L7, 111) is higher than the deterioration level threshold, it is determined that the glow plug is in a deteriorated condition (S130 Yes), and therefore the routine advances to step S140. When the deterioration level is lower than the deterioration level threshold LV_{REF}, it is determined that the glow plug is in the normal region (S130 No), and therefore the processing of steps S100 to S130 is repeated until it is determined that the glow plug has deteriorated. When the deterioration level exceeds the deterioration level threshold such that the glow plug is determined to have deteriorated in step S 140, appropriate processing such as issuing a warning or recording diagnostic information is performed to provide notification that the glow plug is in a deteriorated condition, whereupon the deterioration determination is terminated.

[0039] For example, in a case where the deterioration determination processing is begun when the engine rotation speed NE is in an idling condition at 500 rpm and the glow plug energization effective voltage V_{GLE} is 12 V, the deterioration level threshold LV_{REF} is 5. Assuming that the deterioration level signals LV_1 to LV_4 transmitted from the GCU 30 to the ECU 20 are (000010110001), the deterioration level signals LV_1, LV_2, LV_3, LV4 of the glow plugs 40 (GL_1, GL_2, GL_3, GL_4) indicate deterioration levels 0, 2, 6, 1, respectively, and therefore only the deterioration level of the glow plug 40 (GL_3), which is higher than the deterioration level threshold LV_{REF} of 5, is determined to belong to the deterioration region, while the deterioration levels of the other glow plugs 40 (GL_1, GL_2, GL_4) are determined to belong to the normal region.

[0040] In this embodiment, the shunt resistor Rs is used as the current detecting means (S_1 to S_4) for detecting the plug current I_{GL} flowing through the glow plugs 40 (GL_1 to GL_4), but the current detecting means (S_1 to S_4) used in the invention is not limited to the shunt resistor Rs, and as long as a voltage that is proportionate to the plug current I_{GL} flowing through the glow plugs 40 can be output by converting the plug current I_{GL} into the plug current converted voltage Vi using voltage converting means for converting the plug current I_{GL} into a voltage, current detecting means such as a current sensor or a sense metal-oxide semiconductor (MOS) may be employed.

[0041] Note that in a typical high emission engine, in which emissions exceed legal limits when the heat generation temperature falls below a desired temperature due to only slight glow plug deterioration, deterioration may be determined at a low deterioration level, whereas in a low emission engine, in which the glow plug need only function as an ignition aid during startup, deterioration need not be determined even at a high deterioration level.

[0042] While some embodiments of the invention have been illustrated above, it is to be understood that the invention is not limited to details of the illustrated embodiments, but may be embodied with various changes, modifications or improvements, which may occurs to those skilled in the art, without departing from the scope of the invention.

Claims

1. A glow plug deterioration determination system (1) **characterized by** comprising:

   a glow plug (40) attached to a cylinder of a diesel combustion engine (50) to generate heat when energized;
   an electronic control unit (20) for controlling an operation of the diesel combustion engine;
   a glow plug energization control unit (30) that is arranged to control an energization of the glow plug from a power supply (10) by driving switch means (T_1 to T_4) to open and close in accordance with a drive signal that is issued by the electronic control unit in accordance with an operating condition of the diesel combustion engine;
   current detecting means (S_1 to S_4) for detecting a plug current flowing through the glow plug; and
   a self-diagnosis unit (32) including deterioration level determining means (330) for determining whether the glow plug is in a deteriorated condition by comparing the plug current detected by the current detecting means with a plurality of thresholds.

2. The determination system according to claim 1, wherein the deterioration level determining means is arranged to transmit a deterioration level expressing a result of the determination as to whether the glow plug is in the deteriorated condition in binary to the electronic control apparatus.

3. The determination system according to claim 2, wherein the electronic control apparatus is arranged to determine, on the basis of the deterioration level, whether the deterioration level belongs to a normal region or a deterioration region in accordance with a combustion characteristic of the diesel combustion engine.

4. The determination system according to claim 2 or 3, further comprising voltage converting means converting the plug current flowing through the glow plug into a voltage and outputting the voltage,
   wherein the current detecting means is arranged to detect the plug current on the basis of a plug current converted voltage, which is the voltage converted from the plug current by the voltage converting means.

5. The determination system according to claim 4, wherein the voltage converting means includes a differential amplifier (321, 322, 323, 324) into which an upstream side voltage and a downstream side voltage of a current sensing resistor interposed between the power supply and the glow plug are input, and the output plug current converted voltage is proportionate to the plug current.

6. The determination system according to claim 4 or 5, wherein the deterioration level determining means comprises:

   a plurality of resistors (R_1, R_2, R) connected in series between the power supply and earth; and
   a comparator (CMP_1 to CMP_n) that is arranged

to compare voltage thresholds prorated according to the plurality of resistors with the plug current converted voltage and outputs the plug current converted voltage when the plug current converted voltage is lower than the respective voltage threshold, and
the deterioration level is determined according to an output from the comparator.

7. The determination system according to 6, wherein the plurality of resistors are a deterioration level upper limit determining resistor, (n-1) deterioration level prorating resistors and a deterioration level lower limit determining resistor.

8. The determination system according to claim 6 or 7, wherein the deterioration level determining means is arranged to convert the output from the comparator into a binary self-diagnosis signal and outputs the binary self-diagnosis signal to the electronic control apparatus.

9. The determination system according to claim 8, wherein the deterioration level determination means is arranged to classify the deterioration level in a range of four ranks to sixteen ranks, and
the self-diagnosis signal is constituted by a range of two bits to four bits.

10. The determination system according to claim 1, further comprising voltage converting means for converting the plug current flowing through the glow plug into a voltage and outputting the voltage,
wherein the current detecting means is arranged to detect the plug current on the basis of a plug current converted voltage, which is the voltage converted from the plug current by the voltage converting means.

11. The determination system according to claim 10, wherein the voltage converting means includes a differential amplifier (321, 322, 323, 324) into which an upstream side voltage and a downstream side voltage of a current sensing resistor interposed between the power supply and the glow plug are input, and the output plug current converted voltage is proportionate to the plug current.

12. The determination system according to any one of claims 1 to 11, wherein the cylinder of the diesel combustion engine is provided in a plurality, and the glow plug is attached to each of the plurality of cylinders.

13. The determination system according to any one of claims 1 to 12, wherein the self-diagnosis unit is arranged to detect abnormalities of the glow plug and the glow plug energization control unit and to transmit the abnormality to the electronic control apparatus.

FIG. 1

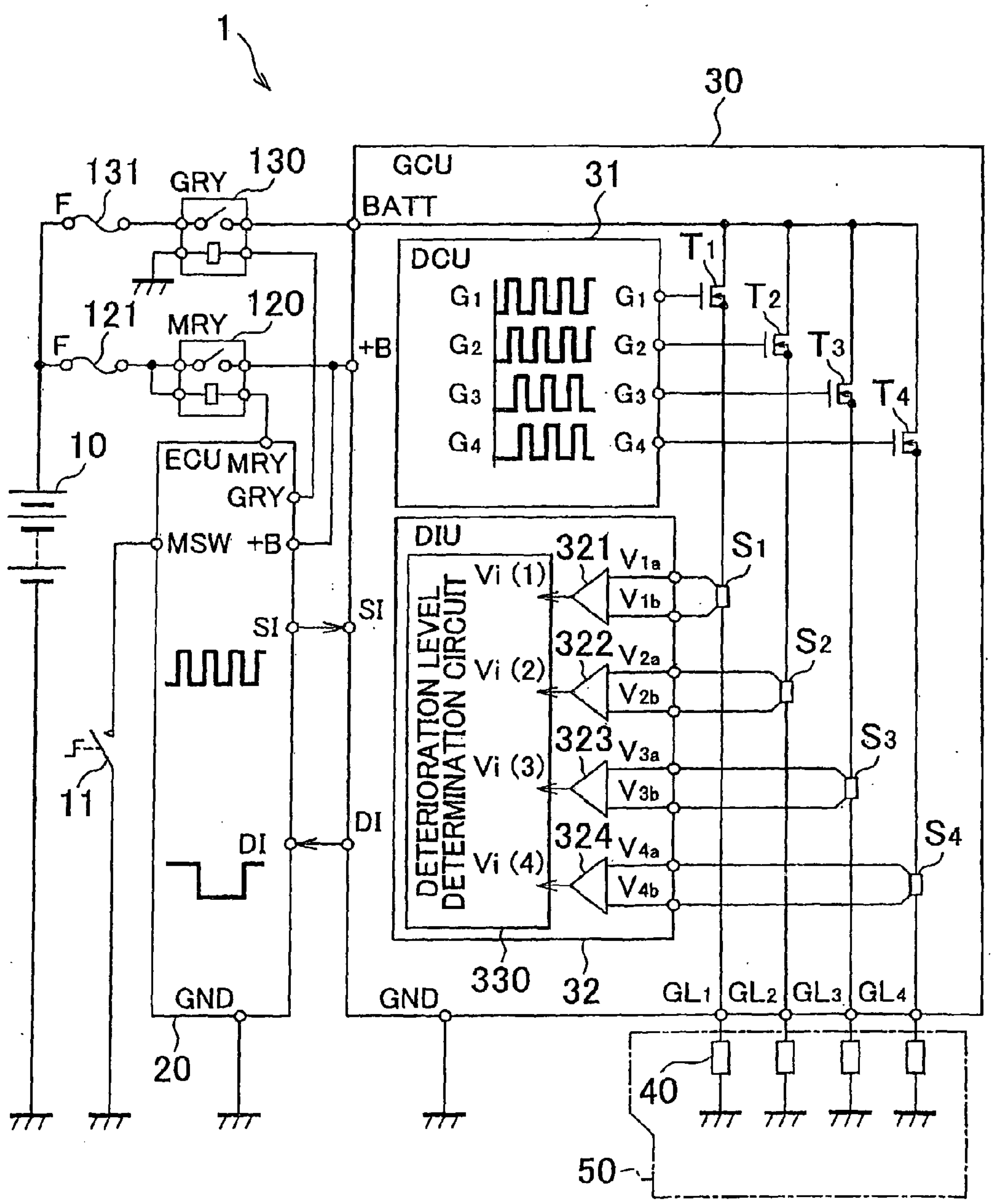

1
30
GCU
BATT
31
131
GRY
130
F
DCU
T1
G1
G2
G3
G4
T2
T3
T4
121
MRY
120
F
+B
10
ECU
MRY
GRY
MSW
+B
SI
DI
DIU
321
V1a
V1b
Vi (1)
S1
322
V2a
V2b
Vi (2)
S2
323
V3a
V3b
Vi (3)
S3
324
V4a
V4b
Vi (4)
S4
DETERIORATION LEVEL DETERMINATION CIRCUIT
11
330
32
GND
GL1
GL2
GL3
GL4
20
40
50

FIG. 2

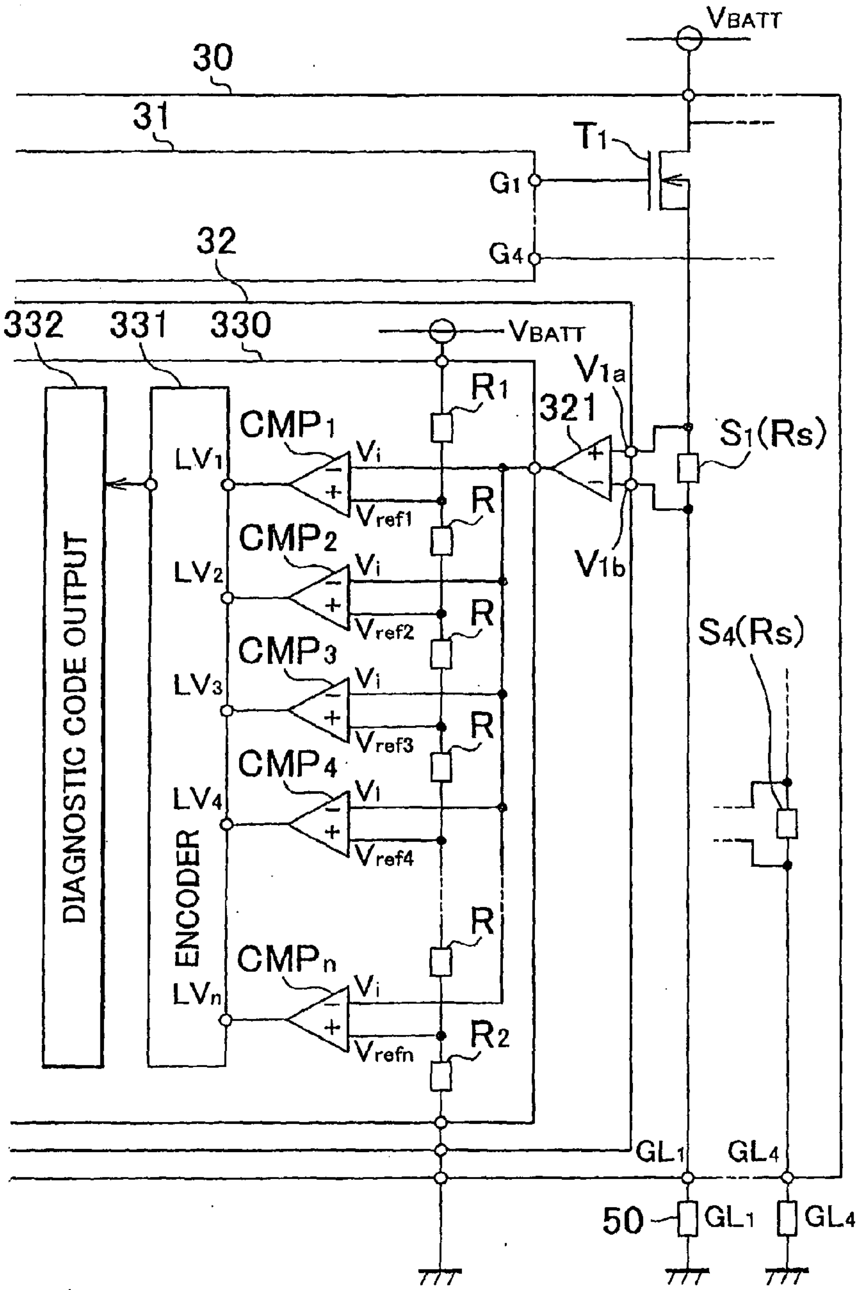

VBATT
30
31
T1
G1
G4
32
332
331
330
VBATT
R1
V1a
321
S1(Rs)
CMP1
Vi
LV1
Vref1
R
CMP2
V1b
LV2
Vref2
R
S4(Rs)
CMP3
LV3
Vref3
R
CMP4
LV4
Vref4
R
DIAGNOSTIC CODE OUTPUT
ENCODER
CMPn
LVn
Vrefn
R2
GL1
GL4
50
GL1
GL4

FIG. 3A

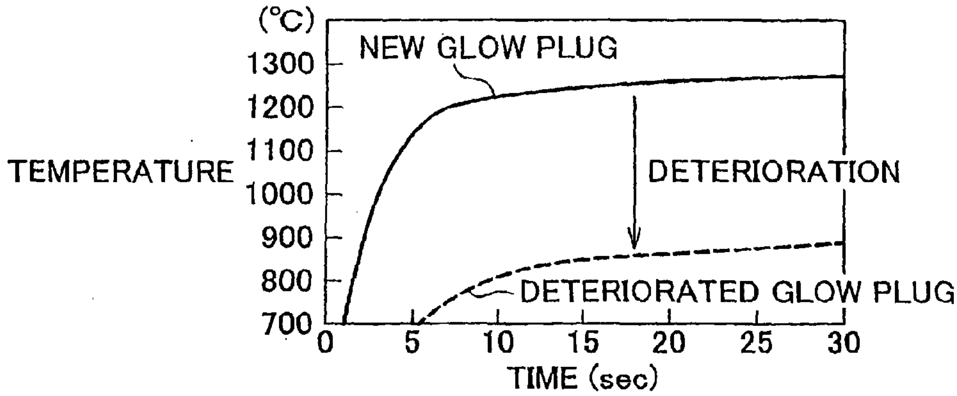


FIG. 3B

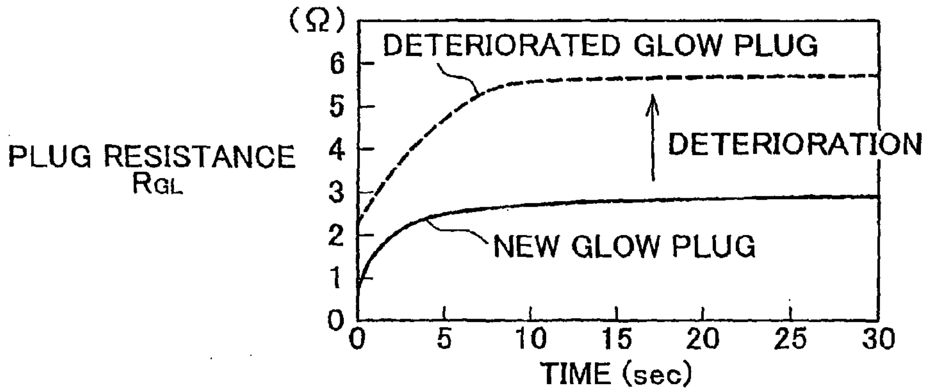


FIG. 3C

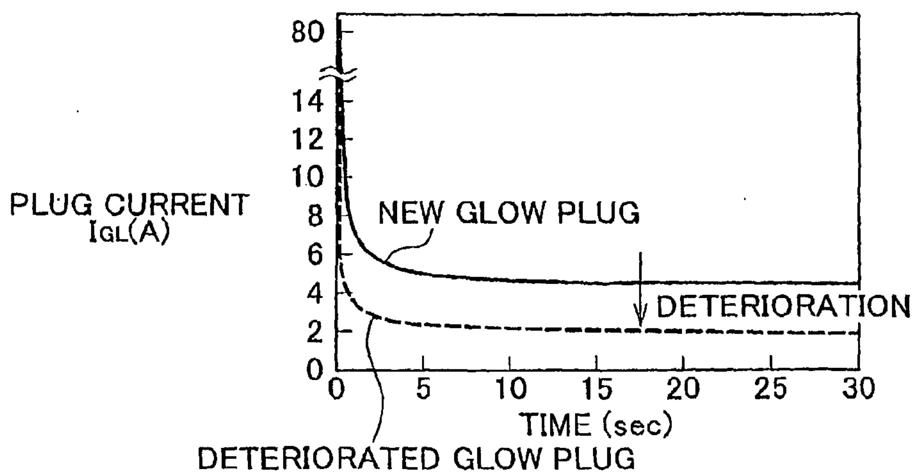


FIG. 4A

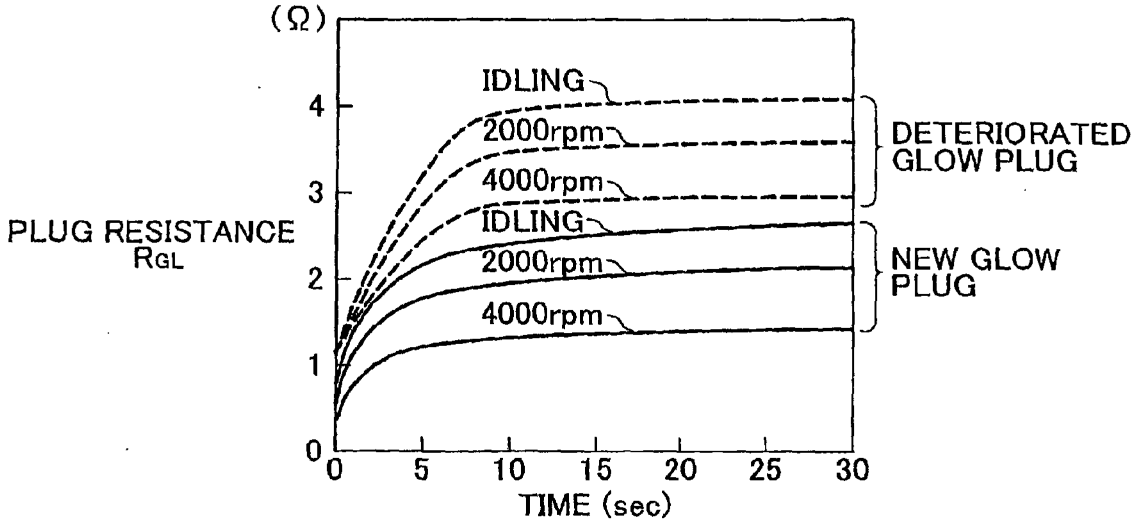

(Ω)
PLUG RESISTANCE
RGL
IDLING
2000rpm
4000rpm
IDLING
2000rpm
4000rpm
DETERIORATED GLOW PLUG
NEW GLOW PLUG
0
1
2
3
4
0
5
10
15
20
25
30
TIME (sec)

FIG. 4B

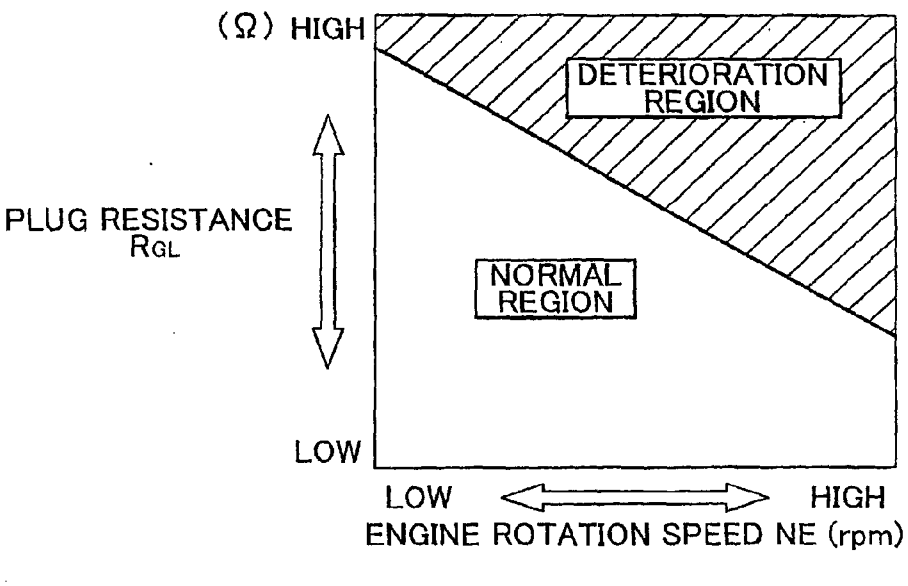

(Ω) HIGH
PLUG RESISTANCE
RGL
LOW
DETERIORATION REGION
NORMAL REGION
LOW
HIGH
ENGINE ROTATION SPEED NE (rpm)

FIG. 5

RELATED ART

GLOW VOLTAGE V_{GL1}	D_{0a1}	D_{1a1}	D_{2a1}	D_{3a1}	D_{4a1}	D_{5a1}	D_{6a1}	D_{7a1}	D_{8a1}	D_{9a1}	D_{10a1}	D_{11a1}	D_{12a1}	D_{13a1}	D_{14a1}	D_{15a1}
GLOW CURRENT I_{GL1}	D_{0b1}	D_{1b1}	D_{2b1}	D_{3b1}	D_{4b1}	D_{5b1}	D_{6b1}	D_{7b1}	D_{8b1}	D_{9b1}	D_{10b1}	D_{11b1}	D_{12b1}	D_{13b1}	D_{14b1}	D_{15b1}
GLOW VOLTAGE V_{GL2}	D_{0a2}	D_{1a2}	D_{2a2}	D_{3a2}	D_{4a2}	D_{5a2}	D_{6a2}	D_{7a2}	D_{8a2}	D_{9a2}	D_{10a2}	D_{11a2}	D_{12a2}	D_{13a2}	D_{14a2}	D_{15a2}
GLOW CURRENT I_{GL2}	D_{0b2}	D_{1b2}	D_{2b2}	D_{3b2}	D_{4b2}	D_{5b2}	D_{6b2}	D_{7b2}	D_{8b2}	D_{9b2}	D_{10b2}	D_{11b2}	D_{12b2}	D_{13b2}	D_{14b2}	D_{15b2}
GLOW VOLTAGE V_{GL3}	D_{0a3}	D_{1a3}	D_{2a3}	D_{3a3}	D_{4a3}	D_{5a3}	D_{6a3}	D_{7a3}	D_{8a3}	D_{9a3}	D_{10a3}	D_{11a3}	D_{12a3}	D_{13a3}	D_{14a3}	D_{15a3}
GLOW CURRENT I_{GL3}	D_{0b3}	D_{1b3}	D_{2b3}	D_{3b3}	D_{4b3}	D_{5b3}	D_{6b3}	D_{7b3}	D_{8b3}	D_{9b3}	D_{10b3}	D_{11b3}	D_{12b3}	D_{13b3}	D_{14b3}	D_{15b3}
GLOW VOLTAGE V_{GL4}	D_{0a4}	D_{1a4}	D_{2a4}	D_{3a4}	D_{4a4}	D_{5a4}	D_{6a4}	D_{7a4}	D_{8a4}	D_{9a4}	D_{10a4}	D_{11a4}	D_{12a4}	D_{13a4}	D_{14a4}	D_{15a4}
GLOW CURRENT I_{GL4}	D_{0b4}	D_{1b4}	D_{2b4}	D_{3b4}	D_{4b4}	D_{5b4}	D_{6b4}	D_{7b4}	D_{8b4}	D_{9b4}	D_{10b4}	D_{11b4}	D_{12b4}	D_{13b4}	D_{14b4}	D_{15b4}

FIG. 6A

DETERMINATION	J_1	J_2	J_3
NORMAL LEVEL (L_0)	0	0	0
DETERIORATION LEVEL 1 (L_1)	0	0	1
DETERIORATION LEVEL 2 (L_2)	0	1	0
DETERIORATION LEVEL 3 (L_3)	0	1	1
DETERIORATION LEVEL 4 (L_4)	1	0	0
DETERIORATION LEVEL 5 (L_5)	1	0	1
DETERIORATION LEVEL 6 (L_6)	1	1	0
DETERIORATION LEVEL 7 (L_7)	1	1	1

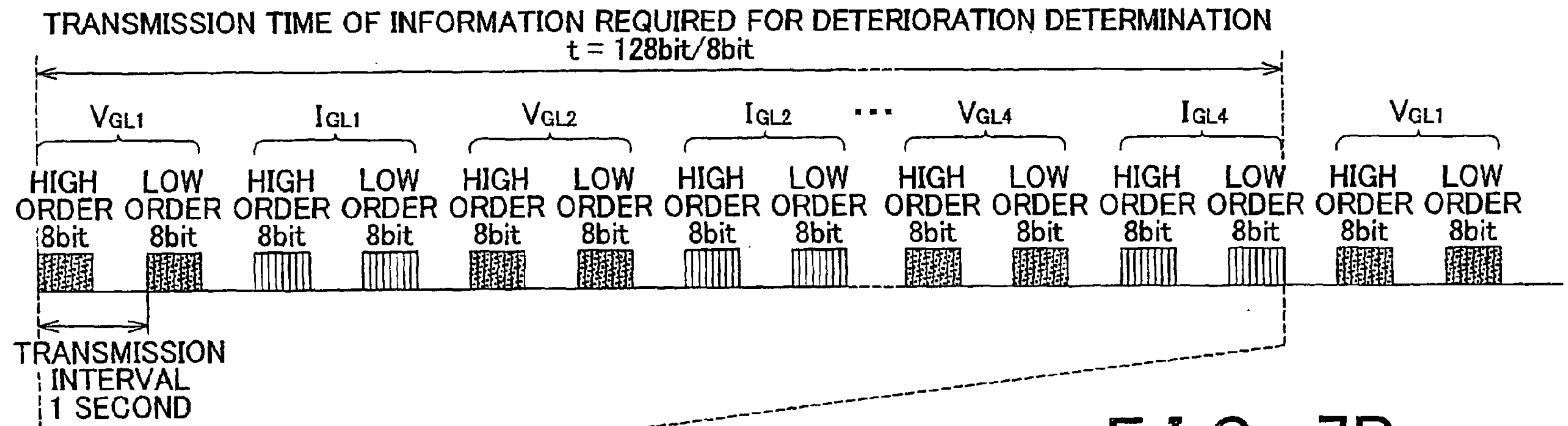
FIG. 6B

		LV_1			LV_2			LV_3			LV_4			
		J_1	J_2	J_3	J_1	J_2	J_3	J_1	J_2	J_3	J_1	J_2	J_3	

FIG. 6C

FIRST EXAMPLE				
Vref (V)	Vi (V)	I_{GL} (A)	R_{GL} (Ω)	DETERMINATION
	AT LEAST 10.0	AT LEAST 5.0	AT MOST 2.8	NORMAL
10.0	9.0～10.0	4.5～5.0	2.8～3.1	DETERIORATION LEVEL 1
9.0	8.0～9.0	4.0～4.5	3.1～3.5	DETERIORATION LEVEL 2
8.0	7.0～8.0	3.5～4.0	3.5～4.0	DETERIORATION LEVEL 3
7.0	6.0～7.0	3.0～3.5	4.0～4.7	DETERIORATION LEVEL 4
6.0	5.0～6.0	2.5～3.0	4.7～5.6	DETERIORATION LEVEL 5
5.0	4.0～5.0	2.0～2.5	5.6～7.0	DETERIORATION LEVEL 6
4.0	AT MOST 4.0	AT MOST 2.0	AT LEAST 7.0	DETERIORATION LEVEL 7

F I G . 7A


TRANSMISSION TIME OF INFORMATION REQUIRED FOR DETERIORATION DETERMINATION
t = 128bit/8bit
V_{GL1}
I_{GL1}
V_{GL2}
I_{GL2}
V_{GL4}
I_{GL4}
V_{GL1}
HIGH ORDER 8bit
LOW ORDER 8bit
TRANSMISSION INTERVAL 1 SECOND

F I G . 7B

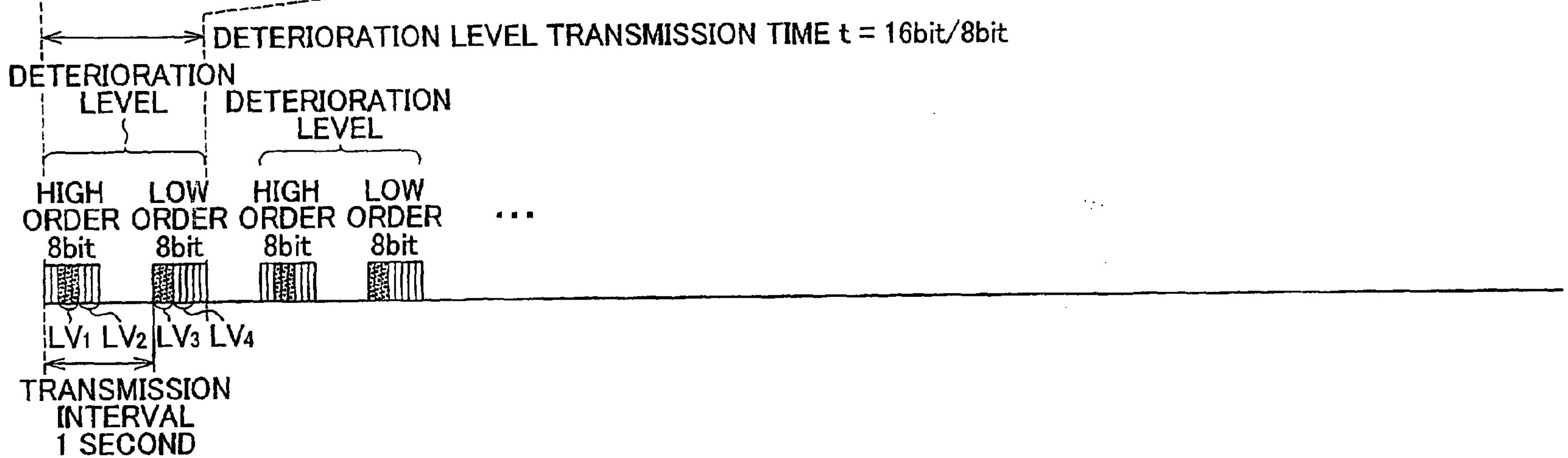

DETERIORATION LEVEL TRANSMISSION TIME t = 16bit/8bit
DETERIORATION LEVEL
DETERIORATION LEVEL
HIGH ORDER 8bit
LOW ORDER 8bit
LV_1 LV_2 LV_3 LV_4
TRANSMISSION INTERVAL 1 SECOND

FIG. 8

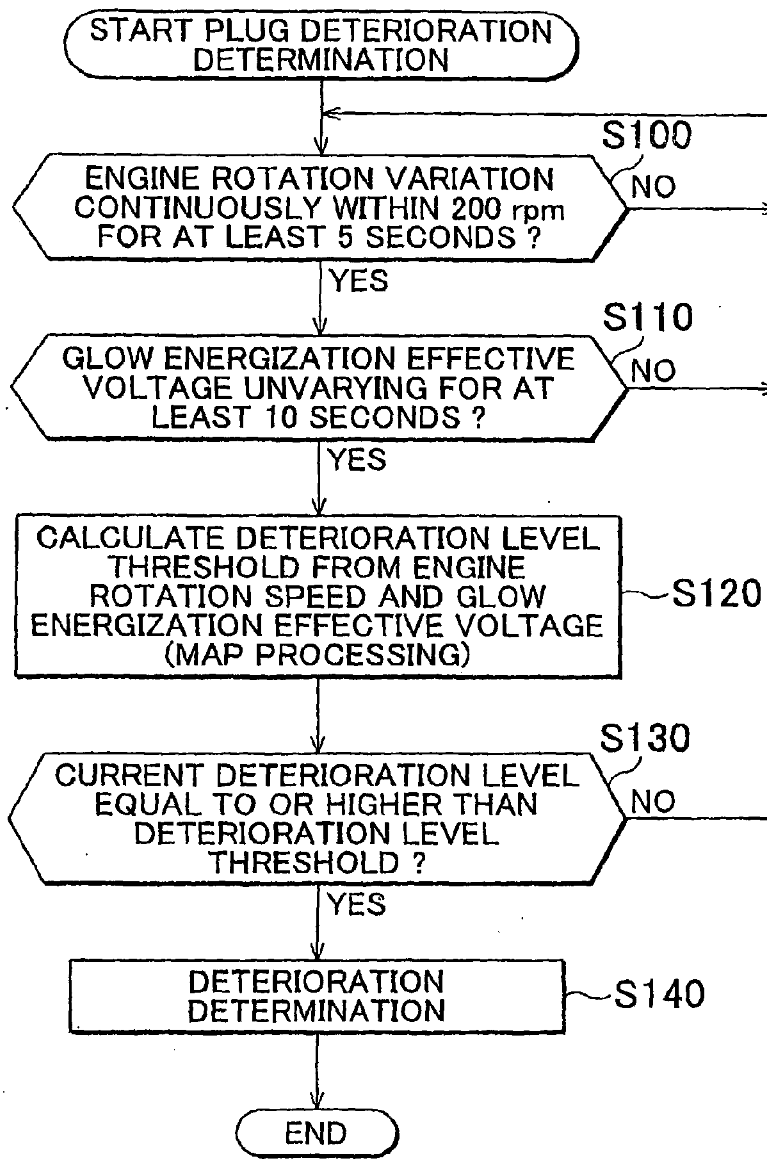

START PLUG DETERIORATION DETERMINATION
S100
ENGINE ROTATION VARIATION CONTINUOUSLY WITHIN 200 rpm FOR AT LEAST 5 SECONDS ?
NO
YES
S110
GLOW ENERGIZATION EFFECTIVE VOLTAGE UNVARYING FOR AT LEAST 10 SECONDS ?
NO
YES
CALCULATE DETERIORATION LEVEL THRESHOLD FROM ENGINE ROTATION SPEED AND GLOW ENERGIZATION EFFECTIVE VOLTAGE (MAP PROCESSING)
S120
S130
CURRENT DETERIORATION LEVEL EQUAL TO OR HIGHER THAN DETERIORATION LEVEL THRESHOLD ?
NO
YES
DETERIORATION DETERMINATION
S140
END

FIG. 9

DETERIORATION LEVEL THRESHOLD MAP

GLOW ENERGIZATION EFFECTIVE VOLTAGE V_{GLE} (V)	ENGINE ROTATION SPEED NE (rpm) 0	500	1000	1500	2000	3000
9	4	3	3	2	1	1
10	5	4	4	3	2	2
11	5	4	4	3	3	2
12	5	5	5	4	3	3
13	6	6	5	5	4	4
14	6	6	6	5	5	4
15	6	6	6	6	5	5

REFERENCES CITED IN THE DESCRIPTION

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- JP 2008031979 A **[0002]**
- JP 2008297925 A **[0002]**
- JP 2003247721 A **[0003]**
- JP 2005147533 A **[0003]**