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(54) **IGNITION ASSIST DEVICE AND ION CURRENT DETECTION SYSTEM**

(57) [Objective] To accurately detect ion current generated as a result of combustion in an internal combustion engine.

[Means for Solution] An ignition assist device 10 includes a housing 12; a ceramic member 11 disposed in the housing 12 and having a distal end portion 11a exposed from the housing 12; and a heat-generating element 20 and an ion detection electrode 30 which are embedded in the ceramic member 11 in such a manner as to be electrically insulated from each other. The ignition assist device 10 further includes an ion detection terminal portion 31 for applying an ion detection voltage to the ion detection electrode 30, and two heat-generating-element terminal portions 21 and 22 disposed at such positions as to not come into contact with the internal combustion engine and adapted to supply electricity to the heat-generating element 20.

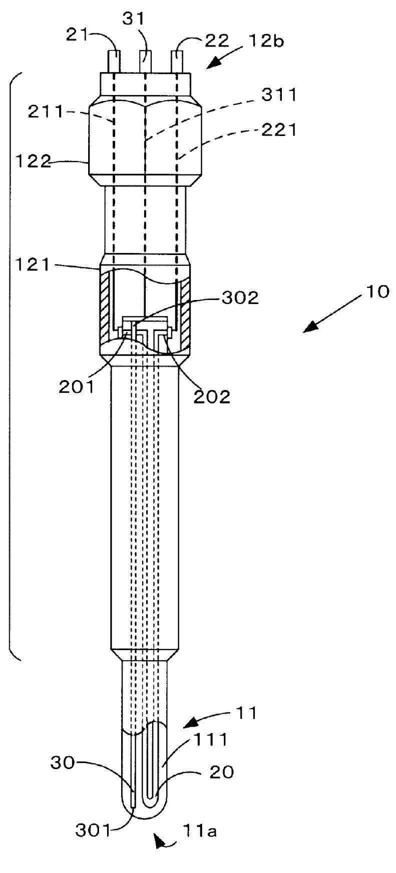

FIG. 2

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Description

[Technical Field]

[0001] The present invention relates to an ignition assist device for assisting ignition in an internal combustion engine, more specifically, to an ignition assist device used to detect ion current, and to an ion current detection system which includes the ignition assist device.

[Background Art]

[0002] In order to cope with recent regulations with regard to exhaust gas components of an internal combustion engine, for example, a technique for detecting the condition of combustion in the internal combustion engine has been proposed. A known technique for detecting the condition of combustion in the internal combustion engine has focused attention on the amount of ions generated as a result of combustion in the internal combustion engine. This technique detects the amount of generated ions in the form of the magnitude of ion current. Generally, the detection of ion current requires a detecting electrode; however, space around a cylinder head in the internal combustion engine is limited. In order to cope with the problem, a proposed technique (refer to, for example, Patent Document 1) incorporates an ion detection electrode in a glow plug used to assist start-up of a diesel engine.

[Prior Art Document]

[Patent Document]

[0003] [Patent Document 1] Japanese Patent No. 3605965

[0004] However, the amount of ions generated as a result of combustion in the internal combustion engine is small; thus, current detectable through the ion detection electrode is small. The conventional technique has failed to sufficiently study this fact and thus has encountered difficulty in accurately detecting ion current by use of a simple detection circuit.

[Summary of the Invention]

[Problem to be Solved by the Invention]

[0005] Therefore, a technique for accurately detecting ion current generated as a result of combustion in the internal combustion engine has been desired.

[Means for Solving the Problem]

[0006] The present invention has been conceived to solve the above problem and can be embodied in the following modes.

[0007] A first mode provides an ignition assist device for an internal combustion engine. The ignition assist device for the internal combustion engine according to the first mode comprises a housing; a ceramic member disposed in the housing and having a distal end portion exposed from the housing; and a heat-generating element and an ion detection electrode which are embedded in the ceramic member in such a manner as to be electrically insulated from each other. The ignition assist device further comprises an ion detection terminal portion for applying an ion detection voltage to the ion detection electrode, and two heat-generating-element terminal portions disposed at such positions as to not come into contact with the internal combustion engine and adapted to supply electricity to the heat-generating element.

[0008] Since the ignition assist device according to the first mode comprises those two heat-generating-element terminal portions for supplying electricity to the heat-generating element which are disposed in noncontact with the internal combustion engine, ion current generated as a result of combustion in the internal combustion engine can be accurately detected.

[0009] The ignition assist device according to the first mode may further comprise an ion detection conductor path whose one end is electrically connected to one end of the ion detection electrode and whose other end is electrically connected to the ion detection terminal portion; a first heat-generating-element conductor path whose one end is electrically connected to one of two end portions of the heat-generating element and whose other end is electrically connected to one of the two heat-generating-element terminal portions; and a second heat-generating-element conductor path whose one end is electrically connected to the other one of the two terminal portions of the heat-generating element and whose other end is electrically connected to the other one of the two heat-generating-element terminal portions. In this case, the ion detection electrode and the heat-generating element are connected to the ion detection terminal portion and to the two heat-generating-element terminal portions, respectively, while being electrically insulated from each other.

[0010] The ignition assist device according to the first mode may be configured as follows: the ignition assist device has a proximal end portion located opposite the distal end portion, and the ion detection terminal portion and the two heat-generating-element terminal portions are disposed at the proximal end portion. In this case, connection to the ion detection terminal portion and to the two heat-generating-element terminal portions is facilitated, and contact can be prevented between the internal combustion engine and the two heat-generating-element terminal portions.

[0011] In the ignition assist device according to the first mode, the proximal end portion may be that portion of the ignition assist device which is exposed from the internal combustion engine when the ignition assist device is attached to the internal combustion engine. In this case, connection to the ion detection terminal portion and to the two heat-generating-element terminal portions is facilitated. Also, the two heat-generating-element terminal portions are exposed from the internal combustion engine and are thus prevented from coming into contact with the internal combustion engine.

[0012] A second mode provides an ion current detection system for detecting current flowing as a result of generation of ions in a combustion chamber of an internal combustion engine. The ion current detection system comprises

an ignition assist device attached to the internal combustion engine and comprising an ion detection electrode and a heat-generating element which are embedded in a ceramic member in such a manner as to be electrically insulated from each other, an ion detection terminal portion for applying an ion detection voltage to the ion detection electrode, and two heat-generating-element terminal portions disposed at such positions as to not come into contact with the internal combustion engine and adapted to supply electricity to the heat-generating element;

an ion current detection circuit comprising a first terminal electrically connected to the ion detection terminal portion, and a second terminal electrically connected to the internal combustion engine; and

a heat-generating-element circuit comprising a first terminal electrically connected to one of the two heat-generating-element terminal portions, and a second terminal electrically connected to the other one of the two heat-generating-element terminal portions.

[0013] In the ion current detection system according to the second mode, since the ignition assist device has the two heat-generating-element terminal portions disposed at such positions as to not come into contact with the internal combustion engine and adapted to supply electricity to the heat-generating element, ion current generated as a result of combustion in the internal combustion engine can be accurately detected.

[0014] The ion current detection system according to the second mode may be configured as follows: the ion current detection circuit and the heat-generating-element circuit have respective power supplies independent of each other and are electrically independent of each other. In this case, the ion current detection circuit can detect ion current without being electrically affected by the heat-generating-element circuit, at all times.

[0015] The ion current detection system according to the second mode may further comprise a switching element for electrically connecting a second terminal of the heat-generating-element circuit and the internal combustion engine to each other or electrically disconnecting the second terminal of the heat-generating-element circuit and the internal combustion engine from each other and may be configured such that, at least in detection of ion current by the ion current detection circuit, the switching element electrically disconnects the internal combustion engine and the second terminal of the heat-generating-element circuit from each other. In this case, since the internal combustion engine and the second terminal of the heat-generating-element circuit are electrically disconnected from each other, the ion current detection circuit can detect ion current without being electrically affected by the heat-generating-element circuit.

[0016] The ion current detection system according to the second mode may be configured as follows: the ignition assist device has a distal end portion located toward the combustion chamber of the internal combustion engine and a proximal end portion located opposite the distal end portion, and the ion detection terminal portion and the two heat-generating-element terminal portions are disposed at the proximal end portion. In this case, connection to the ion detection terminal portion and to the two heat-generating-element terminal portions is facilitated, and contact can be prevented between the internal combustion engine and the two heat-generating-element terminal portions.

[0017] The ion current detection system according to the second mode may be configured such that the proximal end portion is that portion of the ignition assist device which is exposed from the internal combustion engine when the ignition assist device is attached to the internal combustion engine. In this case, connection to the ion detection terminal portion and to the two heat-generating-element terminal portions is facilitated. Also, the two heat-generating-element terminal portions are exposed from the internal combustion engine and are thus prevented from coming into contact with the internal combustion engine.

[0018] The present invention can also be embodied in an ion current detection method, an ion current detection program, and a reading medium for computer use in which an ion current detection program is stored. The reading media for computer use to which the present invention can be applied include optical recording media such as CDR, magnetic recording media such as a hard disk, and semiconductor recording media such as a flash memory.

[Brief Description of the Drawings]

[0019]

[FIG. 1] Explanatory view schematically showing the appearance of a glow plug used in common in embodiments of the present invention.

[FIG. 2] Explanatory view schematically showing a major internal structure of the glow plug shown in FIG. 1.

[FIG. 3] Explanatory view showing a state in which the glow plug shown in FIG. 1 is attached to an internal combustion engine.

[FIG. 4] Explanatory diagram showing an ion current detection system according to a first mode of the present invention which uses the glow plug shown in FIG. 1.

[FIG. 5] Explanatory diagram showing an example of a conventional ion current detection circuit.

[FIG. 6] Explanatory diagram showing a difference in detected ion current between the ion current detection system according to the first mode and the conventional ion current detection circuit.

[FIG. 7] Explanatory diagram showing an ion current detection system according to a second mode of the present invention which uses the glow plug of the embodiment.

[Modes for Carrying out the Invention]

[0020] A mode of an ignition assist device according to the present invention will next be described while referring to a glow plug used as an ignition assist device for a diesel engine (internal combustion engine). FIG. 1 schematically shows the appearance of a glow plug used in common in embodiments of the present invention. FIG. 2 schematically shows a major internal structure of the glow plug shown in FIG. 1.

Configuration of glow plug:

[0021] A glow plug 10 used in common in the embodiments includes a ceramic member 11, a housing 12, first and second heat-generating-element terminal portions 21 and 22, and an ion detection terminal portion 31. The glow plug 10 is attached, for use, to the internal combustion engine.

[0022] The ceramic member 11 has a generally rodlike shape having a hemispheric distal end portion 11a and is disposed in the housing 12 in such a manner that the distal end portion 11a is exposed from the housing 12. The ceramic member 11 has a support body 111, a heat-generating resistor 20, and an ion detection electrode 30 for detecting ions. The heat-generating resistor 20 and the ion detection electrode 30 are embedded in the support body 111. The support body 111, the heat-generating resistor 20, and the ion detection electrode 30 are formed simultaneously by sintering. The support body 111, the heat-generating resistor 20, and the ion detection electrode 30 are formed of a heat-resistant ceramic composition which contains silicon nitride (Si_3N_4). Another composition such as an electrically conductive ceramic composition is added to the heat-resistant ceramic composition as appropriate according to applications. The ceramic member 11 is also called a ceramic heater.

[0023] The support body 111 is required to have sufficient electrical insulation. The support body 111 predominantly contains silicon nitride, which is an insulating ceramic composition, and may contain metal nitride (e.g., titanium (Ti) nitride) or metal carbide (e.g., zirconium (Zr) carbide) as an electrically conductive ceramic composition, and rare-earth oxide (e.g., ytterbium (Yb) oxide or erbium (Er) oxide) and aluminum (Al) oxide as a sintering aid.

[0024] The heat-generating resistor 20 and the ion detection electrode 30 predominantly contain an electrically conductive ceramic composition, thereby having electrical conductivity. For example, the heat-generating resistor 20 and the ion detection electrode 30 may contain 55% by mass to 70% by mass tungsten carbide, 28% by mass to 35% by mass silicon nitride, and 2% by mass to 10% by mass balance of erbium oxide (Er_2O_3) and silicon oxide (SiO_2). The heat-generating resistor 20 and the ion detection electrode 30 may be formed of the same composition or different compositions. The heat-generating resistor 20 and the ion detection electrode 30 are electrically insulated from each other by means of the support body 111.

[0025] The heat-generating resistor 20 has a shape resembling the letter U and has a first end portion 201 which is grounded, and a second end portion 202 which is connected to a power supply. The heat-generating resistor 20, including lead portions, in the present embodiment is formed of a ceramic composition as follows: a ceramic composition used to form an approximately U-shaped portion is increased in resistance to thereby form a heat generating portion, and a ceramic composition used to form the remaining portion is reduced in resistance to thereby form an electrically conductive portion. Generally, grounding in a vehicle equipped with an internal combustion engine means body earth; conventionally, one end portion of the heat-generating resistor is electrically connected to the cylinder head of the internal combustion engine through the housing 12. The heat-generating resistor can be said to be a heat-generating element.

[0026] The ion detection electrode 30 has a first end portion 301 open-ended toward the distal end portion 11a of the ceramic member 11, and a second end portion 302 connected to the ion current detection circuit. The ion detection electrode 30, including lead portions, in the present embodiment is formed of a ceramic composition having low resistance. The lead portions may be formed of a metal wire such as a tungsten wire.

[0027] The housing 12 includes a threaded portion 121 and a tool engagement portion 122. The housing 12 is formed into a generally cylindrical shape from a metal material having electrical conductivity. The housing 12 can be formed of a metal material of any type such as carbon steel or stainless steel. The housing 12 is also called a metallic shell.

[0028] The threaded portion 121 is externally threaded and is threadingly engaged with an internally threaded portion of a glow plug attachment hole formed in the cylinder head of the internal combustion engine, whereby the glow plug 10 is attached to the internal combustion engine. The tool engagement portion 122 allows a plug wrench to be engaged therewith or to be disengaged therefrom when the glow plug 10 is to be attached to or detached from the internal combustion engine. The plug wrench engaged with the tool engagement portion 122 applies torque to the glow plug 10 to thereby attach or detach the glow plug 10. The tool engagement portion 122 generally has a hexagonal shape, but may have another shape.

[0029] A proximal end portion 12b of the housing 12 is located opposite an end portion of the housing 12 from which the distal end portion 11a of the ceramic member 11 is exposed. The proximal end portion 12b has the first and second heat-generating-element terminal portions 21 and 22 electrically connected to the first and second end portions 201 and 202 of the heat-generating resistor 20 through a first internal conductor path 211 and through a second internal conductor path 221, respectively, and the ion detection terminal portion 31 electrically connected to the second end portion 302 of the ion detection electrode 30 through a third internal conductor path 311. The proximal end portion 12b can also be called a connector attachment portion to which a plug connector is attached for establishing the electrical connection of an external circuit to the first and second heat-generating-element terminal portions 21 and 22 and to the ion detection terminal portion 31. The proximal end portion 12b is exposed from the internal combustion engine in a state in which the glow plug 10 is attached to the internal combustion engine (cylinder head). Thus, the first and second heat-generating-element terminal portions 21 and 22 and the ion detection terminal portion 31 are disposed at such positions as to not come into contact with the internal combustion engine. The first, second, and third internal conductor paths 211,221, and 311 are formed of, for example, a tungsten wire and can also be called a first heat-generating-element conductor path, a second heat-generating-element conductor path, and an ion detection conductor path, respectively.

[0030] In the glow plug 10 according to the present embodiment, the first end portion 201 of the heat-generating resistor 20 is electrically insulated from the cylinder block (internal combustion engine) rather than electrically connected to the cylinder block through the housing 12.

Attachment of glow plug 10 to internal combustion engine:

[0031] A state in which the glow plug 10 according to the present embodiment is attached to the internal combustion engine will next be described. FIG. 3 schematically shows a state in which the glow plug 10 according to the present embodiment is attached to the internal combustion engine. For the purpose of easy understanding, FIG. 3 shows only those components of the internal combustion engine related to the glow plug 10; specifically, a cylinder head 50 and a combustion chamber 51 defined by the cylinder head 50 and a cylinder block (not shown). The internal combustion engine further includes a fuel injection system, intake and exhaust valves, pistons, etc. An engine control unit controls fuel injection timing of the fuel injection system, timing of operation (heating) of the glow plug 10, etc., on the basis of environmental conditions of operation, such as requirement of load input from an accelerator pedal, atmospheric temperature, and engine oil temperature.

[0032] The glow plug 10 according to the present embodiment is fixedly attached by means of the threaded portion 121 being threadingly engaged with a threaded portion 502 formed at a glow plug attachment portion 501 of the cylinder head 50. FIG. 3 omits illustration of ridges and roots of the threaded portions 121 and 502. In a state in which the glow plug 10 is attached to the cylinder head 50, the distal end portion 11a of the ceramic member 11 of the glow plug 10 is exposed to the combustion chamber 51. Thus, when the heat-generating resistor 20 generates heat as a result of application of electricity, generated heat is easily transmitted to the interior of the combustion chamber 51 and heats the interior of the combustion chamber 51 or fuel injected from the fuel injection system, thereby assisting ignition of fuel.

[0033] As a result of combustion of fuel, a large amount of ions are generated within the combustion chamber 51. When voltage for detection of ion current is applied between the ion detection electrode 30 and the cylinder head 50, the ion detection electrode 30 captures negative ions, whereas the cylinder head 50 captures positive ions. As a result, a current path is formed between the ion detection electrode 30 and the cylinder head 50. From the amount of current flowing through the current path, the amount of ions generated within the combustion chamber 51 can be obtained. The detection of ion current will be described in detail herein later.

[0034] The configuration of the glow plug 10 shown in FIG. 3 will be described in detail. The ceramic member 11 is supported by a distal end portion of the housing 12 through an annular ring 123 formed of metal. The first end portion 201 of the heat-generating resistor 20 is electrically connected, through an electrical conduction terminal 212, to the first internal conductor path 211 disposed externally of the ceramic member 11, whereas the second end portion 202 of the heat-generating resistor 20 is electrically connected, through an electrical conduction terminal 222, to the second internal conductor path 221 located externally of the ceramic member 11. The second end portion 302 of the ion detection electrode 30 is electrically connected, through an electrical conduction terminal 312, to the third internal conductor path 311 disposed externally of the ceramic member 11. The first internal conductor path 211 is electrically connected to the first heat-generating-element terminal portion 21; the second internal conductor path 221 is electrically connected to the second heat-generating-element terminal portion 22; and the third internal conductor path 311 is electrically connected to the ion detection terminal portion 31. The proximal end portion 12b of the housing 12 having the first and second heat-generating-element terminal portions 21 and 22 and the ion detection terminal portion 31 is that portion of the glow plug 10 which is exposed from the cylinder head 50 when the glow plug 10 is attached to the cylinder head 50 (internal combustion engine). As is apparent from FIG. 3, in the glow plug 10 according to the present embodiment, the first end portion 201 of the heat-generating resistor 20 is connected to the first heat-generating-element terminal portion 21 and is electrically disconnected (insulated) from the cylinder head 50. As mentioned previously, grounding in a vehicle equipped with an internal combustion engine generally means body earth. The cylinder head of the internal combustion engine is also grounded to the body. Therefore, grounding to the internal combustion engine and grounding to the body are electrically the same.

Detection of ion current:

[0035] The detection of ion current by use of the glow plug 10 according to the present embodiment will next be described. FIG. 4 schematically shows an ion current detection system 80 according to a first mode which uses the glow plug 10 according to the present embodiment. FIG. 5 shows an example of a conventional ion current detection circuit. FIG. 6 shows the difference in detection of ion current between the ion current detection system 80 according to the first mode and the conventional ion current detection circuit.

Configuration of ion current detection system 80 according to first mode:

[0036] The ion current detection system 80 according to the first mode includes an ion current detection circuit 60 and a glow plug circuit 70. The ion current detection system 80 according to the first mode, together with an internal combustion engine, is mounted for use in a vehicle. The ion current detection circuit 60 includes an ion current detection control unit 61, an ion current detection voltmeter 62, an ion current detection resistance 63, an ion current detection power supply 64, a grounding cutoff switch 65, an ion current detection switch 66, and external connection terminals 601 and 602. The glow plug circuit 70 includes a glow plug control unit 71, an activation switch 72, and external connection terminals 701 and 702. FIG. 4 further shows a body 54 serving as earth, and a vehicle power supply 56. The cylinder head 50 is grounded to the body 54 through a grounding line. The glow plug circuit 70 can also be called a heat-generating-element circuit.

[0037] The glow plug circuit 70 is a control circuit for applying a heat generating voltage to the glow plug 10 and is connected to the first and second heat-generating-element terminal portions 21 and 22 of the glow plug 10 through the external connection terminals 701 and 702, respectively. The external connection terminal 701 is grounded to the body 54 through a grounding line 703, whereas the external connection terminal 702 is connected to the positive terminal of the vehicle power supply 56 through a battery wiring line 704. The vehicle power supply 56 is, for example, a 12 V or 24 V lead storage battery, and the negative terminal thereof is grounded to the body 54. The activation switch 72 is disposed in the battery wiring line 704 and opens/closes the glow plug circuit 70 in response to a control signal from the glow plug control unit 71. That is, when, on the basis of conditions input from various sensors of the vehicle, the glow plug control unit 71 judges that activation (heat generation) of the glow plug 10 is required, the glow plug control unit 71 sends a circuit closing signal to the activation switch 72 to apply voltage from the vehicle power supply 56 to the heat-generating resistor 20. As a result, the glow plug circuit 70 is closed; thus, the heat-generating resistor 20 generates heat to thereby heat the combustion chamber 51, whereby ignition of fuel injected into the combustion chamber can be assisted. The timing of assisting ignition of fuel; i.e., the timing of closing the activation switch 72, is not limited to cold time such as at the time of startup of an internal combustion engine, but assisting ignition of fuel can be performed as appropriate during operation of the internal combustion engine in response to operating conditions of the internal combustion engine in order to optimize combustion. For the purpose of clear description, the present embodiment uses the glow plug control unit 71; however, glow plug control may be performed by an engine control unit which comprehensively controls operating conditions of the engine such as fuel injection.

[0038] The ion current detection circuit 60 detects, as a current value, the amount of ions generated within the combustion chamber 51 as a result of combustion of fuel and is connected to the ion detection terminal portion 31 and to the cylinder head 50 through the external connection terminals 601 and 602, respectively. The ion current detection resistance 63, the ion current detection power supply 64, and the ion current detection switch 66 are disposed in an internal wiring line which electrically connects the external connection terminals 601 and 602. The opening and closing of the ion current detection switch 66 is controlled by the ion current detection control unit 61. In a mode of not detecting ion current (ordinary mode), the ion current detection switch 66 receives an opening signal from the ion current detection control unit 61 and is thus opened, so that current does not flow through the ion current detection circuit 60. In a mode of detecting ion current, the ion current detection switch 66 receives a closing signal from the ion current detection control unit 61 and is thus closed, so that current flows through the ion current detection circuit 60; as a result, an electrical potential difference arises between the opposite ends of the ion current detection resistance 63. The ion current detection voltmeter 62 connected to the opposite ends of the ion current detection resistance 63 obtains the electrical potential difference between the opposite ends of the ion current detection resistance 63 and sends the obtained electrical potential difference to the ion current detection control unit 61. On the basis of the obtained electrical potential difference and the resistance (e.g., 500 kΩ) of the ion current detection resistance 63, the ion current detection control unit 61 can calculate (detect) ion current. Desirably, the ion current detection power supply 64 is a DC high-voltage source to supply a voltage of, for example, 150 V to 500 V. The ion current detection power supply 64 can be implemented by raising the voltage of, for example, a 12 V lead storage battery provided as a DC power supply separately from the vehicle power supply 56 or by performing AC-DC conversion and then voltage conversion on AC current generated by an alternator as a result of running of a vehicle.

[0039] In the ion current detection system 80 according to the first mode, the ion current detection circuit 60 includes the grounding cutoff switch 65 in the grounding line 703 connected to the first heat-generating-element terminal portion 21 of the glow plug 10. The opening and closing of the grounding cutoff switch 65 is controlled by the ion current detection control unit 61. When the grounding cutoff switch 65 is opened, the electrical connection (grounding) between the cylinder head 50 and the first heat-generating-element terminal portion 21; i.e., the heat-generating resistor 20, of the glow plug 10 is cut off.

[0040] The process of detecting ion current by use of the ion current detection circuit 60 will next be described. When the above-mentioned glow plug control unit 71 is to apply voltage (electricity) to the glow plug 10, the ion current detection control unit 61 sends a closing signal to the grounding cutoff switch 65, thereby establishing an electrical connection between the heat-generating resistor 20 and the cylinder head 50. As a result, the glow plug circuit 70 is closed, whereby the heat-generating resistor 20 generates heat.

[0041] The ceramic member 11 has a temperature of about 300°C to 800°C as a result of combustion; however, the electrical conductivity of the support body 111 at this temperature is insufficient for detection of ion current. Thus, in detecting ion current, in order to raise the temperature of the ceramic member 11 to such a level as to impart sufficient electrical conductivity for detection of ion current to the support body 111; for example, to about 1,200°C, and to maintain the temperature at such a level, the ion current detection control unit 61 performs processing for applying electricity to the glow plug 10 (heat-generating resistor 20) for heating the ceramic member 11. The ion current detection control unit 61 applies electricity to the glow plug 10 by, for example, PWM control, thereby maintaining the temperature of the ceramic member 11 at 1,200°C. Upon completion of application of voltage to the glow plug 10, the ion current detection control unit 61 sends an opening signal to the grounding cutoff switch 65 to cut off the electrical connection between the heat-generating resistor 20 and the cylinder head 50. In the present embodiment, the grounding cutoff switch 65 is normally closed. The ion current detection control unit 61 may perform the process of opening the glow plug circuit 70 upon reception of, for example, an end signal indicative of completion of application of voltage to the glow plug 10 from the glow plug control unit 71, or a circuit-opening permission signal indicative of permission of opening the glow plug circuit 70. After the internal combustion engine is sufficiently warmed up, generally, assisting ignition by the glow plug 10 is unnecessary; under this condition, the ion current detection control unit 61 can receive a circuit-opening permission signal from the glow plug control unit 71. The grounding cutoff switch 65 may be normally opened such that, upon reception of a circuit closing signal from the glow plug control unit 71, the ion current detection control unit 61 sends a closing signal to the grounding cutoff switch 65, whereby the grounding cutoff switch 65 closes the glow plug circuit 70. For example, in an environmental condition which does not require frequent activation of the glow plug 10, by means of the grounding cutoff switch 65 being normally opened, sticking or the like of the grounding cutoff switch 65 can be prevented or restrained.

[0042] After opening the grounding cutoff switch 65, the ion current detection control unit 61 sends a closing signal to the ion current detection switch 66 to apply current for detecting ion current to the ion current detection circuit 60, thereby starting detection of ion current. When combustion of fuel starts as a result of assistance in ignition by the glow plug 10 or compressive spontaneous ignition, a large amount of ions are generated within the combustion chamber 51. In this state, upon application of an ion current detection voltage between the ion detection electrode 30 and the cylinder head 50, the ion detection electrode 30 captures negative ions, whereas the cylinder head 50 captures positive ions. As a result, a current path R1 is formed between the ion detection electrode 30 and the cylinder head 50. As a result of formation of the current path R1, there is formed a current circuit which connects the external connection terminal 601, the ion detection electrode 30, the current path R1, and the external connection terminal 602. Consequently, current corresponding to the amount of ions generated within the combustion chamber 51 flows through the ion current detection resistance 63, thereby generating an electrical potential difference between the opposite ends of the ion current detection resistance 63. The ion current detection voltmeter 62 measures the electrical potential difference generated between the opposite ends of the ion current detection resistance 63, and the ion current detection control unit 61 obtains the measured electrical potential difference.

[0043] The advantages of the glow plug 10 according to the present embodiment and the ion current detection system 80 according to the first mode will next be described in detail with reference to FIGS. 5 and 6. In FIG. 5, major component members related to the description are denoted by detailed reference numerals, whereas other configurational features are denoted by comprehensive reference numerals. In a conventional glow plug 910 shown in FIG. 5, a grounding terminal portion 921 of a heat-generating resistor 920 is grounded to the body 54 through the cylinder head 50. That is, in the conventional glow plug circuit, even when the glow plug circuit is opened by the glow plug control unit 71, the heat-generating resistor 920 and the body 54 are electrically connected to each other at all times. As a result, when an ion current detection circuit 900 applies voltage to an ion detection electrode 930, a current path R2 is formed between the ion detection electrode 930 and the heat-generating resistor 920 to thereby generate leak current. That is, since, in a temperature range of the activated glow plug 910, electrical conductivity of a ceramic member is enhanced, current could flow between the grounded heat-generating resistor 920 and the ion detection electrode 930.

[0044] As a result of generation of ions within the combustion chamber 51, upon application of voltage to the ion detection electrode 930 by the ion current detection circuit 900, a current path R3 is formed, and the ion current detection circuit 900 detects current corresponding to the amount of generated ions.

[0045] Generally, for example, at a temperature of the ceramic member of 1,200°C, ion current which flows through the current path R3 has a peak value of tens of μA. Meanwhile, leak current which flows through the current path R2 between the ion detection electrode 930 and the heat-generating resistor 920 is about 6 mA. Since leak current assumes about a two-digit greater value, detecting ion current has not been easy.

[0046] Specifically, a current waveform detected by the ion current detection circuit 900 is represented by a waveform A shown in FIG. 6. Since the waveform of ion current appears in the form of a fine waveform superposed on the waveform of leak current, detecting ion current has not been easy. Particularly, in the case where the latter analysis of current waveform is not performed, difficulty is encountered even in identifying ion current in some cases. Also, accurately extracting ion current has not been easy.

[0047] By contrast, in the glow plug 10 according to the present embodiment, the first end portion 201 of the heat-generating resistor 20 which is the ground side end portion is not electrically grounded to the cylinder head 50 and is connected to the glow plug circuit 70 through the first heat-generating-element terminal portion 21 at the proximal end portion 12b. Also, the grounding cutoff switch 65 is disposed in the grounding line 703 which electrically connects the glow plug circuit 70 and the body 54 (cylinder head 50), for electrically disconnecting/connecting the glow plug circuit 70 and the body 54; i.e., the heat-generating resistor 20 and the cylinder head 50, from/to each other. As a result, in a state in which the heat-generating resistor 20 and the cylinder head 50 are electrically disconnected from each other by opening the grounding cutoff switch 65, performing detection of ion current allows the detection of the waveform of ion current represented by a waveform B in FIG. 6.

[0048] Since the waveform B does not involve superposition of ion current and leak current, the emergence of ion current can be identified without need to perform the latter analysis of current waveform, and ion current can be accurately detected (extracted).

[0049] As mentioned above, in the glow plug 10 according to the present embodiment, the first end portion 201 of the heat-generating resistor 20 is connected to the first heat-generating-element terminal portion 21 and is not electrically connected to the cylinder head 50, thereby being electrically insulated from the cylinder head 50. Therefore, in detecting ion current, there can be prevented the formation of a current path between the ion detection electrode 30 and the heat-generating resistor 20, which results from the electrical connection of the heat-generating resistor 20 to the cylinder head 50.

[0050] Also, according to the ion current detection system 80 according to the first mode which uses the glow plug 10 according to the present embodiment, the grounding cutoff switch 65 is disposed in the grounding line 703 which electrically connects the heat-generating resistor 20 and the cylinder head 50, for enabling the heat-generating resistor 20 and the cylinder head 50 to be electrically disconnected from each other. In a vehicle, since grounding is implemented by body earth, the internal combustion engine is also grounded to the body 54. Therefore, electrically disconnecting the heat-generating resistor 20 and the cylinder head 50 from each other means the electrical disconnection of the heat-generating resistor 20 not only from the internal combustion engine but also from the body 54 and thus means that the heat-generating resistor 20 and the cylinder head 50 are electrically disconnected from each other in any electrical path.

[0051] Therefore, the ion current detection system 80 according to the first mode which uses the glow plug 10 according to the present embodiment can accurately detect ion current and thus can accurately detect the amount of ions generated as a result of combustion within the combustion chamber 51. As a result, on the basis of the accurate amount of ions, the condition of combustion within a combustion chamber can be grasped or estimated, thereby improving the combustion efficiency of the internal combustion engine, improving the condition of combustion in the internal combustion engine, and implementing highly accurate control of components of exhaust gas emitted from the internal combustion engine.

[0052] Furthermore, according to the ion current detection system 80 according to the first mode, since the glow plug circuit 70 and the ion current detection circuit 60 can be electrically insulated from each other merely through employment of the grounding cutoff switch 65 in the grounding line 703, voltage can be applied to the glow plug 10 by means of the vehicle power supply 56 being used as a common power supply without need to provide independent power supplies for the glow plug circuit 70 and the ion current detection circuit 60, respectively. Also, in the ion current detection circuit 60, rather than providing the ion current detection power supply 64, a booster may be provided so as to boost the voltage from the vehicle power supply 56 and apply the boosted voltage to the ion detection electrode 30.

Configuration of ion current detection system 80B according to second mode:

[0053] FIG. 7 shows the ion current detection system 80B according to the second mode which uses the glow plug 10 according to the present embodiment. The ion current detection system 80B according to the second mode, together with an internal combustion engine, is mounted for use in a vehicle. In the ion current detection system 80 according to the first mode, the ion current detection circuit 60 includes the grounding cutoff switch 65, and the grounding cutoff switch 65 is opened for preventing the formation of the current path R2 between the ion detection electrode 30 and the heat-generating resistor 20. By contrast, in the ion current detection system 80B according to the second mode, the glow plug circuit 70B is electrically independent of the ion current detection circuit 60, thereby implementing the above-mentioned accurate detection of ion current. In the following description, configurational features similar to those of the ion current detection system 80 according to the first mode are denoted by the same reference numerals, and repeated description thereof is omitted. The description will be centered on different configurational features.

[0054] In the glow plug 10 according to the second embodiment used in the ion current detection system 80B according to the second mode as mentioned above, the first end portion 201 of the heat-generating resistor 20 is connected to an external circuit through the first heat-generating-element terminal portion 21 and is not electrically connected to the cylinder head 50 to thereby be electrically insulated. Also, the glow plug circuit 70B in the ion current detection system 80B according to the second mode has a dedicated DC power supply 73 provided therein. In the glow plug circuit 70B, the first end portion 201 of the heat-generating resistor 20 is connected to the negative pole of the dedicated power supply 73 through the first heat-generating-element terminal portion 21 and the external connection terminal 701, whereas the second end portion 202 is connected to the positive pole of the dedicated power supply 73 through the second heat-generating-element terminal portion 22 and the external connection terminal 702. Thus, in the glow plug circuit 70B, a path for electrically connecting the heat-generating resistor 20 and the cylinder head 50 is not formed; therefore, the heat-generating resistor 20 and the cylinder head 50 are electrically insulated from each other at all times.

[0055] Meanwhile, the ion current detection circuit 60 is configured similarly to that in the ion current detection system 80 according to the first mode except that the grounding cutoff switch 65 is not provided.

[0056] Therefore, in the ion current detection system 80B according to the second mode, also, in detecting ion current, there can be prevented the formation of a current path between the ion detection electrode 30 and the heat-generating resistor 20, which results from the electrical connection of the heat-generating resistor 20 to the cylinder head 50. As a result, the ion current detection system 80B can accurately detect ion current and thus can accurately detect the amount of ions generated as a result of combustion within the combustion chamber 51.

[0057] Also, in the ion current detection system 80B according to the second mode, since the glow plug circuit 70B is electrically insulated from the ion current detection circuit 60, ion current can be accurately detected without need to perform changeover by use of the grounding cutoff switch 65. In the ion current detection system 80B according to the second mode, also, in order to raise the temperature of the ceramic member 11 to such a level as to impart sufficient electrical conductivity for detection of ion current to the support body 111; for example, to about 1,200°C, and to maintain the temperature at such a level, processing can be performed for applying electricity to the glow plug 10 (heat-generating resistor 20) for heating the ceramic member 11.

Modifications:

[0058] (1) In the above embodiment, the first and second heat-generating-element terminal portions 21 and 22 for applying electricity to the heat-generating resistor 20, and the ion detection terminal portion 31 for applying voltage for ion detection to the ion detection electrode 30 are provided at the proximal end portion 12b of the housing 12. However, in place of these terminal portions, lead wires may be provided. Also, a connector for connection to an external circuit may be provided at the ends of the lead wires.

[0059] (2) The description of the above embodiment does not specify whether or not the ion current detection circuit 60 has a switch for electrically disconnecting the ion current detection power supply 64 and the ion detection electrode 30 from each other. However, desirably, the switch is provided in the ion current detection system 80 according to the first mode. This is because, after the grounding cutoff switch 65 is opened, ion current can be accurately measured through detection of ion current. Meanwhile, in the ion current detection system 80B according to the second mode, since the ion current detection circuit 60 and the glow plug circuit 70B are electrically insulated from each other at all times, ion current may be detected at all times without provision of the switch.

[0060] (3) The above embodiment is described while referring to a lead storage battery as a DC power supply. However, other types of batteries such as a nickel-hydrogen battery and a lithium-ion battery can be used. The ion current detection system 80 according to the first mode separately employs the vehicle power supply 56 and the ion current detection power supply 64. However, the ion current detection process may be performed by use of only the vehicle power supply 56. In this case, a booster may be provided in order to obtain voltage required for detection of ion current.

[0061] (4) The above description of the embodiment does not refer to the planar disposition of the first and second heat-generating-element terminal portions 21 and 22 and the ion detection terminal portion 31. These three terminal portions may be disposed, for example, in a row or as follows: the first and second heat-generating-element terminal portions 21 and 22 are disposed in parallel, while the ion detection terminal portion 31 is disposed at any position. A connector to be connected to the three terminal portions for establishing electrical connection to an external circuit may be implemented in the form of: a unitary connector having connection portions corresponding to the three terminal portions; a unitary connector having connection portions corresponding to the first and second heat-generating-element terminal portions 21 and 22, and an independent connector to be connected to the ion detection terminal portion 31; or independent connectors to be connected to the terminal portions, respectively.

[0062] (5) The above embodiment is described while referring to the ion current detection control unit 61 and the glow plug control unit 71 which are provided separately. However, for example, a single vehicle control unit may execute the functions which these control units execute.

[0063] (6) The above embodiment is described while referring to the glow plug 10 in which the first and second heat-generating-element terminal portions 21 and 22 for applying electricity to the heat-generating resistor 20, and the ion detection terminal portion 31 for applying an ion detection voltage to the ion detection electrode 30 are disposed at the proximal end portion 12b. However, the advantages of the above embodiment are yielded on condition that, in detecting ion current, the heat-generating resistor 20 is not electrically connected to the cylinder head 50. Thus, for example, the following configuration may be employed: in the conventional glow plug in which the ion detection terminal portion 31 and the second heat-generating-element terminal portion 22 are disposed at the proximal end portion 12b and in which the first heat-generating-element terminal portion is connected to the housing 12 in contact with the cylinder head 50, a limited region for contact with the first heat-generating-element terminal portion is defined on the housing 12, and the cylinder head 50 is configured such that a region of the cylinder head 50 corresponding to the limited region can be electrically connected to or disconnected from the remaining region of the cylinder head 50.

[0064] The present invention has been described with reference to the above embodiment and modifications. However, the embodiment and modifications are meant to help understand the invention, but are not meant to limit the invention. The present invention may be modified or improved without departing from the gist and the scope of the invention and encompasses equivalents of such modifications and improvements. For example, in order to solve, partially or entirely, the above-mentioned problem or yield, partially or entirely, the above-mentioned effects, technical features of the embodiment and modifications corresponding to technical features of the modes described in the section "Summary of the Invention" can be replaced or combined as appropriate. Also, the technical feature(s) may be eliminated as appropriate unless the present specification mentions that the technical feature(s) is mandatory.

[Description of Reference Numerals]

[0065]

10:	glow plug
11:	ceramic member
11a:	distal end portion
111:	support body
12:	housing
12b:	proximal end portion
121:	threaded portion
122:	tool engagement portion
123:	annular ring
20:	heat-generating resistor
21:	first heat-generating-element terminal portion
22:	second heat-generating-element terminal portion
30:	ion detection electrode
31:	ion detection terminal portion
50:	cylinder head
51:	combustion chamber
54:	body
56:	vehicle power supply
60:	ion current detection circuit
61:	ion current detection control unit
62:	ion current detection voltmeter
63:	ion current detection resistance
64:	ion current detection power supply
65:	grounding cutoff switch
66:	ion current detection switch
70:	glow plug circuit
70B:	glow plug circuit
71:	glow plug control unit
72:	activation switch
73:	dedicated power supply
80:	ion current detection system
80B:	ion current detection system
201:	first end portion
202:	second end portion
211:	first internal conductor path
212:	electrical conduction terminal
221:	second internal conductor path
222:	electrical conduction terminal
301:	first end portion
302:	second end portion
311:	third internal conductor path
312:	electrical conduction terminal
501:	glow plug attachment portion
502:	threaded portion
601:	external connection terminal
602:	external connection terminal
701:	external connection terminal

702: external connection terminal
703: grounding line
704: battery wiring line
900: ion current detection circuit
910: glow plug
920: heat-generating resistor
921: grounding terminal portion
930: ion detection electrode
R1: current path
R2: current path
R3: current path

Claims

1. An ignition assist device (10) for an internal combustion engine (50), comprising:

   a housing (12);
   a ceramic member (11) disposed in the housing and having a distal end portion (11a) exposed from the housing; and
   a heat-generating element (20) and an ion detection electrode (30) which are embedded in the ceramic member (11) in such a manner as to be electrically insulated from each other;
   the ignition assist device further comprising:

      an ion detection terminal portion (31) disposed at such positions as to not come into contact with the internal combustion engine (50) and adapted to supply an ion detection voltage to the ion detection electrode (30); and
      two heat-generating-element terminal portions (21,22) for supplying electricity to the heat-generating element (20).

2. An ignition assist device (10) according to claim 1, further comprising:

   an ion detection conductor path (311) whose one end is electrically connected to one end (302) of the ion detection electrode (30) and whose other end is electrically connected to the ion detection terminal portion (31);
   a first heat-generating-element conductor path (211) whose one end is electrically connected to one (201) of two end portions of the heat-generating element (20) and whose other end is electrically connected to one (21) of the two heat-generating-element terminal portions; and
   a second heat-generating-element conductor path (221) whose one end is electrically connected to the other one (202) of the two terminal portions of the heat-generating element (20) and whose other end is electrically connected to the other one (22) of the two heat-generating-element terminal portions.

3. An ignition assist device according to claim 1 or 2, wherein
   the ignition assist device (10) has a proximal end portion (12b) located opposite the distal end portion (11a), and
   the ion detection terminal portion (31) and the two heat-generating-element terminal portions (21,22) are disposed at the proximal end portion (12b).

4. An ignition assist device (10) according to claim 3, wherein the proximal end portion (12b) is that portion of the ignition assist device which is exposed from the internal combustion engine (50) when the ignition assist device (10) is attached to the internal combustion engine (50).

5. An ion current detection system (80, 80B) for detecting current flowing as a result of generation of ions in a combustion chamber of an internal combustion engine (50), comprising:

   an ignition assist device (10) attached to the internal combustion engine (50) and comprising

      an ion detection electrode (30) and a heat-generating element (20) which are embedded in a ceramic member (11) in such a manner as to be electrically insulated from each other,
      an ion detection terminal portion (31) for applying an ion detection voltage to the ion detection electrode (30), and
      two heat-generating-element terminal portions (21,22) disposed at such positions as to not come into contact with the internal combustion engine and adapted to supply electricity to the heat-generating element (20);

   an ion current detection circuit (60) comprising

      a first terminal (601) electrically connected to the ion detection terminal portion (31) and
      a second terminal (602) electrically connected to the internal combustion engine (50); and

   a heat-generating-element circuit (70, 70B) comprising

      a first terminal (701) electrically connected to one (21) of the two heat-generating-element terminal portions and
      a second terminal (702) electrically connected to the other one (22) of the two heat-generating-element terminal portions.

6. An ion current detection system (80B) according to claim 5, wherein the ion current detection circuit (60) and the heat-generating-element circuit (70B) have respective power supplies independent of each other and are electrically independent of each other.

7. An ion current detection system (80) according to claim 5, further comprising a switching element (65) for electrically connecting a second terminal (702) of the heat-generating-element circuit (70) and the internal combustion engine (50) to each other or electrically disconnecting the second terminal (702) of the heat-generating-element circuit (70) and the internal combustion engine (50) from each other, wherein
at least in detection of ion current by the ion current detection circuit (60), the switching element (65) electrically disconnects the internal combustion engine (50) and the second terminal (702) of the heat-generating-element circuit (70) from each other.

8. An ion current detection system (80, 80B) according to any one of claims 5 to 7, wherein
the ignition assist device (10) has a distal end portion (11a) located toward the combustion chamber of the internal combustion engine and a proximal end portion (12b) located opposite the distal end portion (11a), and
the ion detection terminal portion (31) and the two heat-generating-element terminal portions (21,22) are disposed at the proximal end portion (12b).

9. An ion current detection system (80, 80B) according to claim 8, wherein the proximal end portion (12b) is that portion of the ignition assist device (10) which is exposed from the internal combustion engine (50) when the ignition assist device (10) is attached to the internal combustion engine (50).

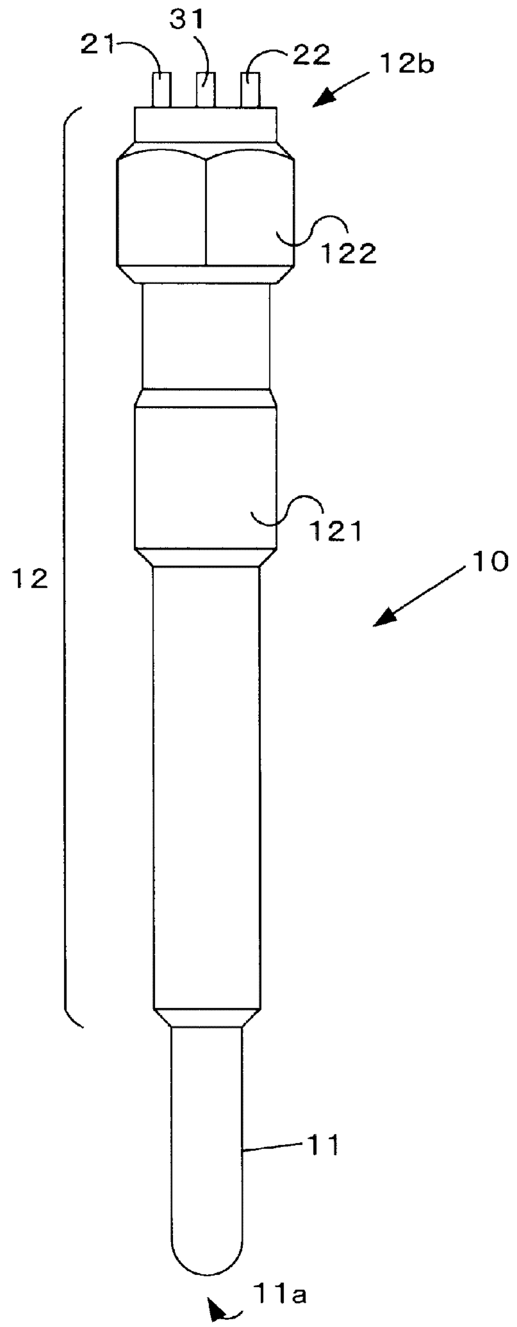

FIG. 1

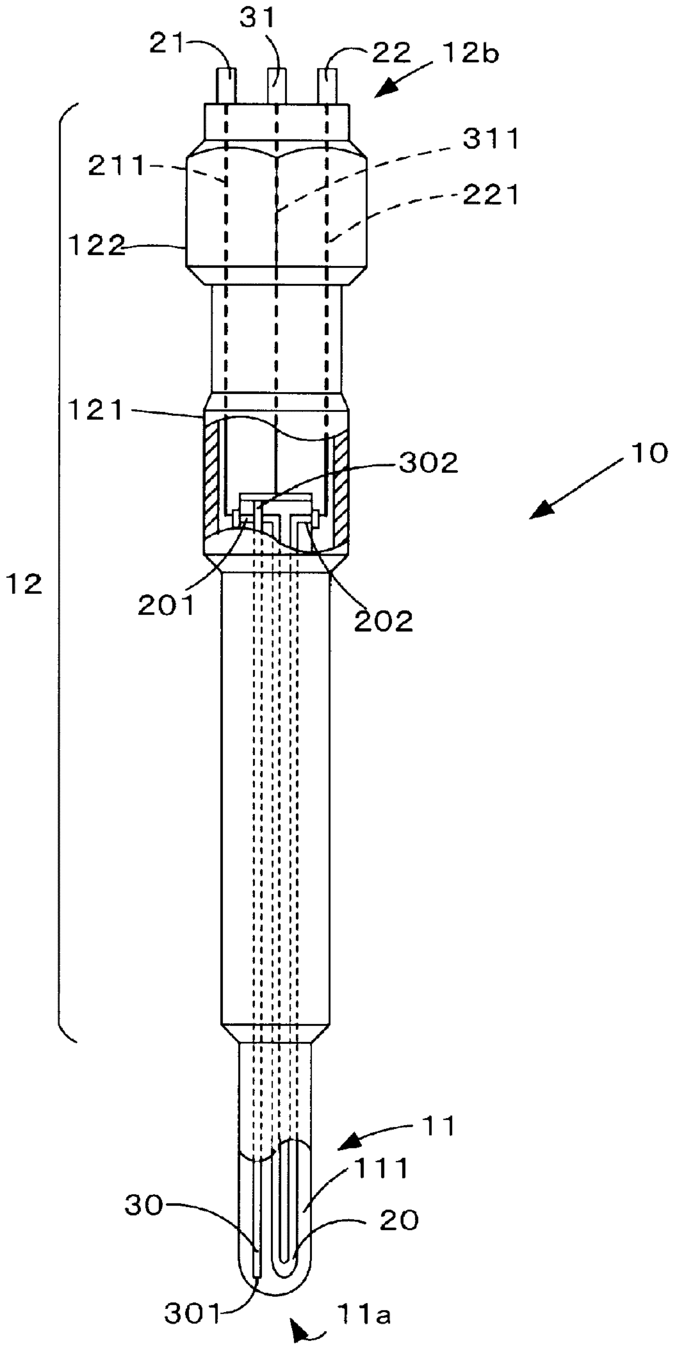
31
21
22
12b
311
211
221
122
121
302
10
12
201
202
11
111
30
20
301
11a

FIG. 2

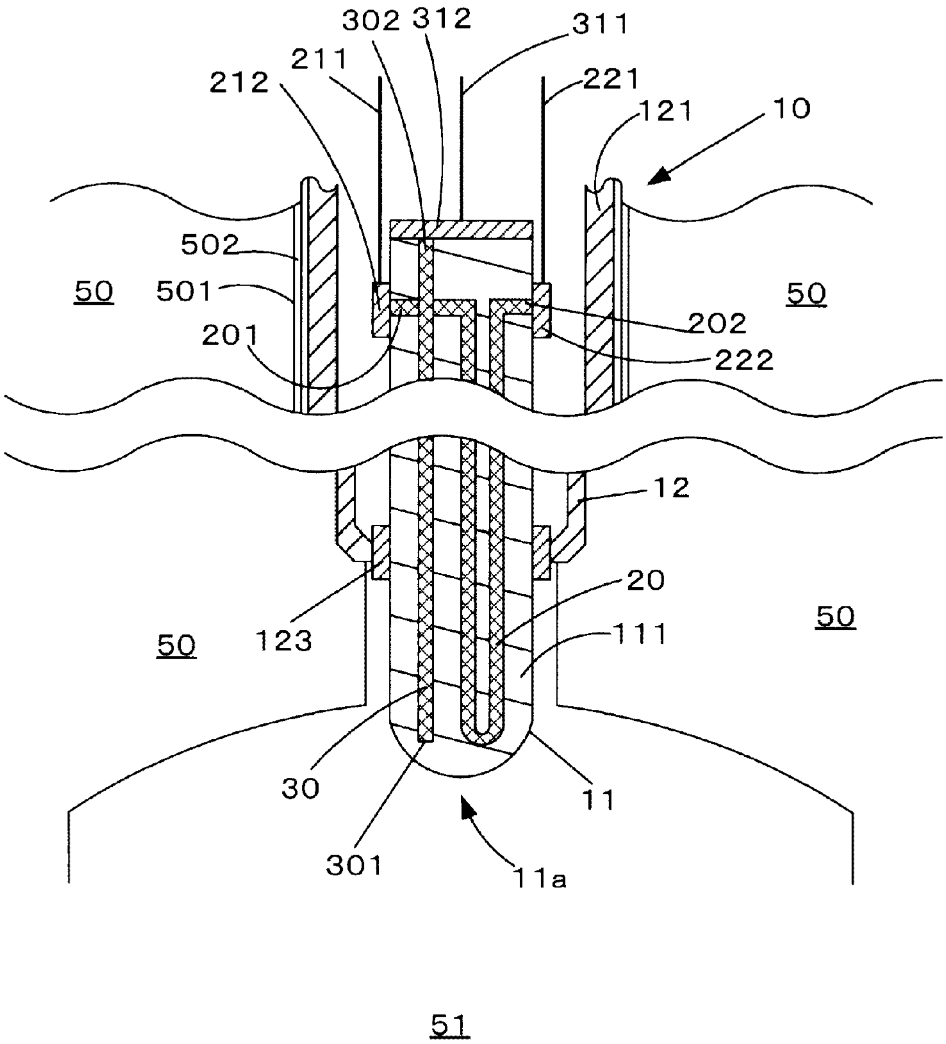
302
312
311
211
212
221
121
10
502
50
501
50
202
201
222
12
20
50
123
111
50
30
11
301
11a
51

FIG. 3

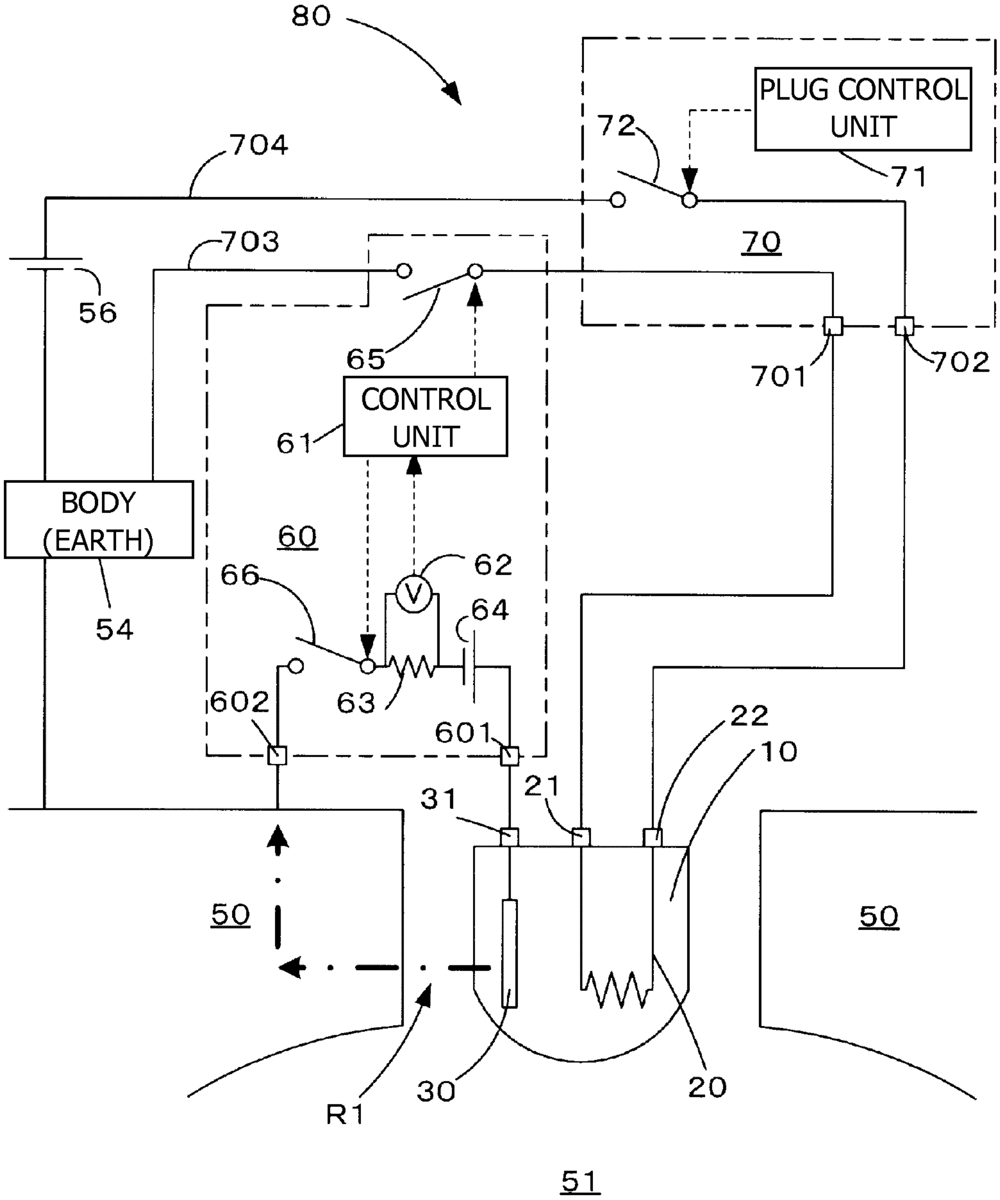
80
704
703
56
PLUG CONTROL UNIT
72
71
70
701
702
65
CONTROL UNIT
61
BODY (EARTH)
54
60
62
66
64
63
602
601
31
21
22
10
50
50
30
20
R1
51

FIG. 4

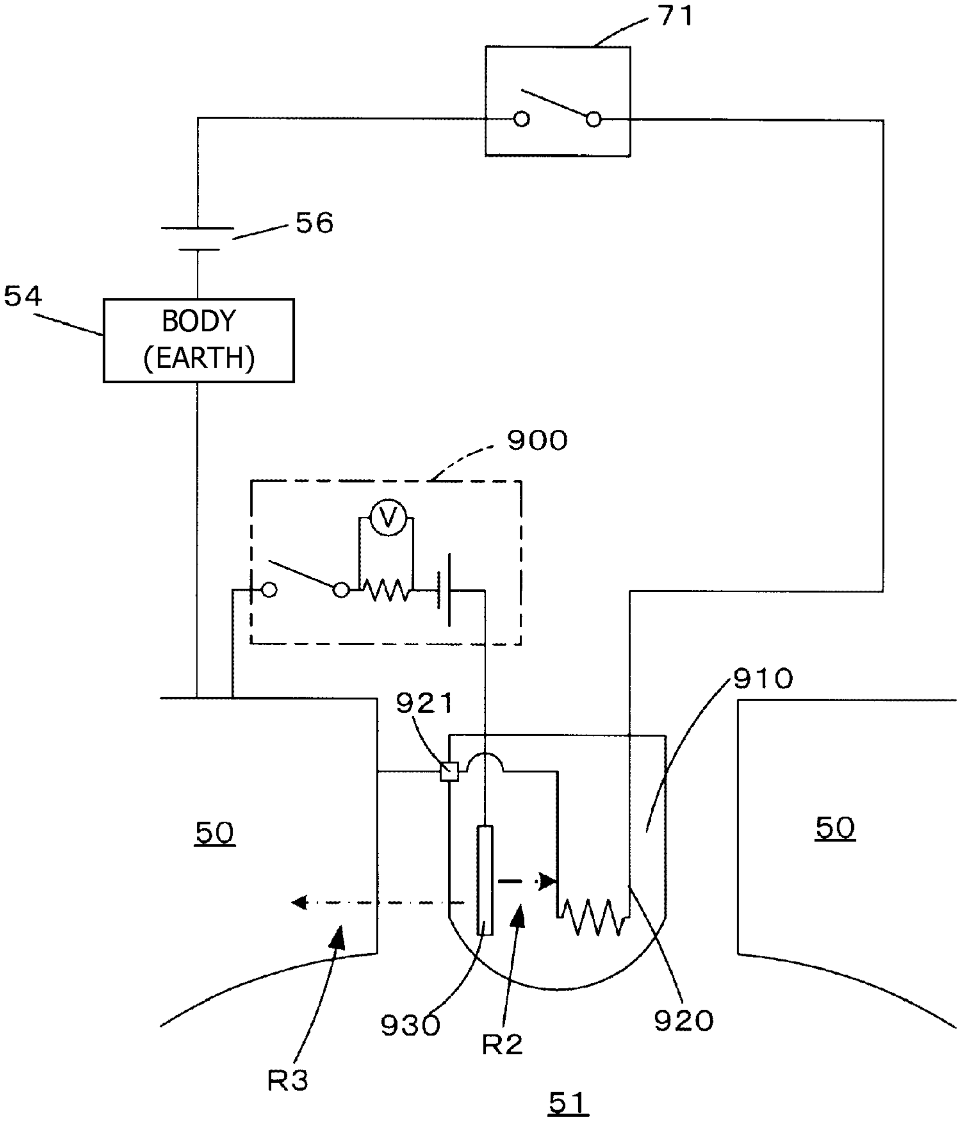

FIG. 5

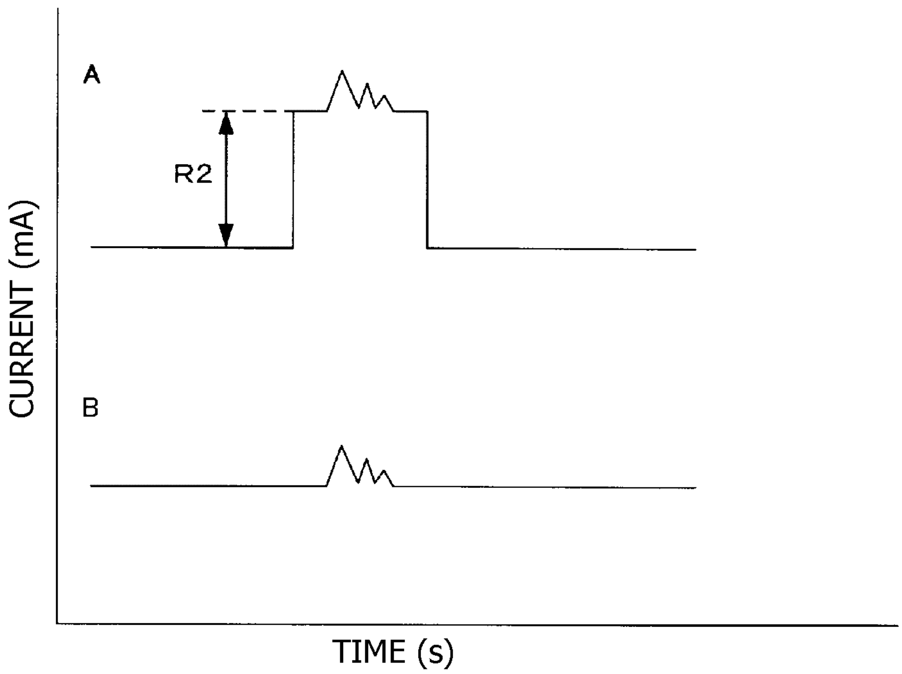

FIG. 6

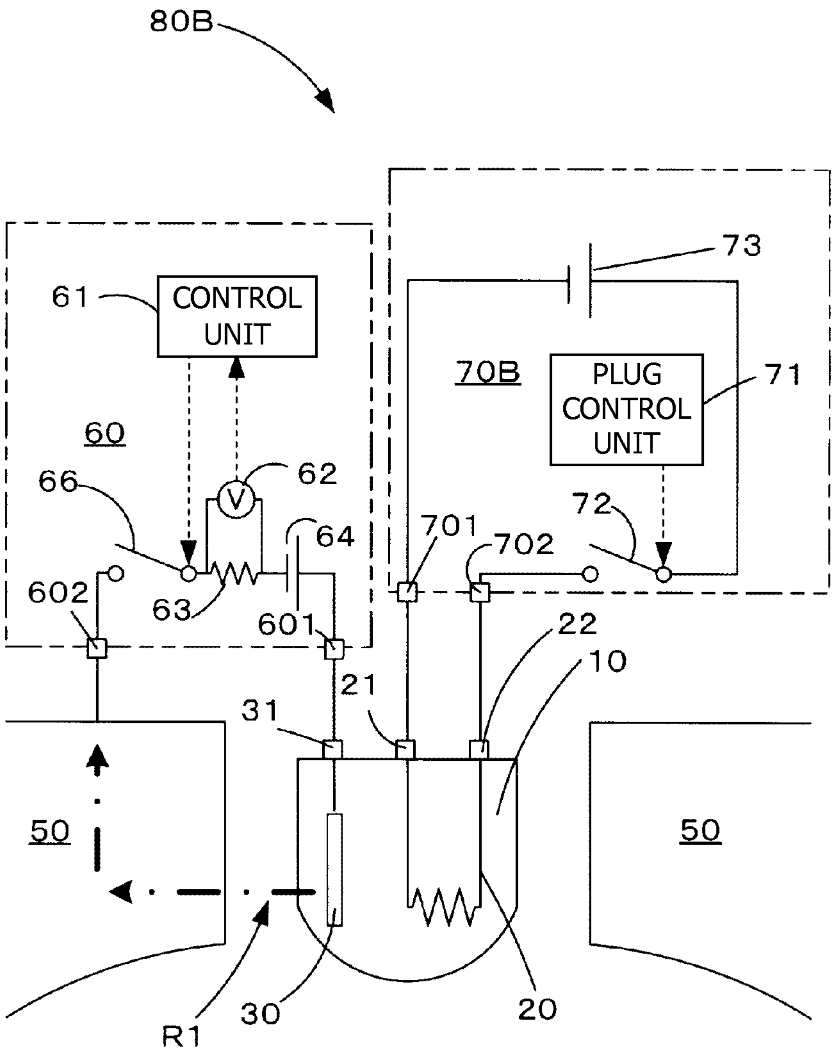
80B
61
CONTROL UNIT
60
62
66
64
602
63
601
73
70B
PLUG CONTROL UNIT
71
72
701
702
22
10
21
31
50
50
R1
30
20
51

FIG. 7

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EUROPEAN SEARCH REPORT

Application Number
EP 15 20 2745

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
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