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(54) ION CURRENT MEASUREMENT APPARATUS

IONENSTROMMESSVORRICHTUNG

APPAREIL DE MESURE DE COURANT IONIQUE

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Description

[0001] The present invention relates to ion current measurement apparatus.

[0002] A glow plug is a heater which is used as an auxiliary heat source of a compression-ignition-type internal combustion engine (e.g., a diesel engine or the like). A function of measuring ion current originating from ions generated in a combustion chamber may be added to such a glow plug. For example, EP-A2-1136697 discloses such a glow plug in which ion current is measured by measuring current through the heating element in the glow plug and estimating the resistivity of the substrate forming the front of the glow plug from knowledge of the variation of substrate resistivity with temperature and the temperature obtained by measuring the heater resistivity. Measurement of the value of the ion current (hereinafter also referred to as an "ion current value") allows estimation of the combustion state of fuel within the combustion chamber. There has been known a glow plug having a structure in which a conductor different from a heating element is embedded in a ceramic substrate in order to realize measurement of the ion current value. In the case of a glow plug having the above-described structure, when a voltage is applied between the conductor and the ground potential (engine block), an ion current flows to the conductor through the substrate (see, for example, Japanese Patent No. 3605965).

[0003] In the case of the above-described prior art technique, since the substrate is formed of ceramic, the electrical resistance of the substrate strongly depends on the temperature of the substrate. Thus, the measured ion current value strongly depends on the temperature of the substrate. Therefore, due to a change in the temperature of the substrate, the accuracy in detecting the ion current value may deteriorate. Such a problem is not limited to glow plugs having an ion current measurement function and is common among all ion current measurement apparatuses having a function of measuring the ion current value. In view of the above-described prior art technique, an object of the present invention is to mitigate the influence, on the accuracy in detecting the ion current value, of a change in the temperature of a detection section which detects the ion current value.

[0004] The present invention, provides an ion current measurement apparatus as defined in claim 1and which includes a control section and a detection section. In preferred embodiments the detection section is in a glow plug.

[0005] Therefore, even when the electrical resistance (hereinafter referred to as the "second substrate resistance") of the substrate between the second conductor and the above-mentioned space changes, the influence of the change on the detection accuracy of the ion current value can be reduced. This is because the first and second substrate resistances have a strong correlation therebetween. As a result, even when the temperature of the detection section changes, the influence of the change on the detection accuracy of the ion current can be reduced.

[0006] The first conductor may be a heating element which generates heat when electricity is supplied thereto. thus, the detection section can function as a heater.

[0007] The present invention will be further described by way of example with reference to the accompanying drawings, in which:-

FIG. 1 is a schematic diagram of an ion current measurement apparatus.
FIG. 2 is a partially sectioned view of a glow plug.
FIG. 3 is a sectional view of a forward end of the glow plug and its vicinity.
FIG. 4 is a flowchart showing ion current measurement processing.
FIG. 5 is a graph showing a change in a measured current value with time.
FIG. 6 is a graph approximately showing the relation between a first resistance of a substrate and the highest surface temperature of the substrate.
FIG. 7 is a flowchart showing ion current measurement processing (second embodiment).

[0008] A first embodiment will be described. FIG. 1 schematically shows the configuration of an ion current measurement apparatus 100. The ion current measurement apparatus 100 is mounted on a diesel engine vehicle and measures the value of ion current originating from ions generated in a combustion chamber of a diesel engine. Further, the ion current measurement apparatus 100 heats the interior of the combustion chamber. This heating is performed so as to assist the ignition of fuel injected from an injector 459.

[0009] The ion current measurement apparatus 100 includes a glow plug 1 and a control section 50. The glow plug 1 is a ceramic glow plug. As shown in FIG. 1, the glow plug 1 is attached to a cylinder block 45 by screwing an external thread portion of a housing 4 into the cylinder block 45. As a result, the glow plug 1 is attached in a state in which a forward end portion of the glow plug 1 is exposed to a combustion chamber of the cylinder block 45.

[0010] The control section 50 includes an ECU 52, a glow relay 53, a battery 54, and a glow relay 531. The glow relay 53 is disposed between the positive terminal of the battery 54 and an external lead wire 233 of the glow plug 1.

[0011] The negative terminal of the battery 54 is connected to the cylinder block 45 through the glow relay 531. When the glow relay 531 is on, the negative terminal of the battery 54 electrically communicates with the cylinder block 45. Since the potential of the cylinder block 45 is the ground potential, when the glow relay 531 is on, the negative terminal of the battery 54 is grounded.

[0012] The ECU 52 supplies the electrical power of the battery 54 to the glow plug 1 through the external lead wire 233 by turning on the glow relay 53 and the glow relay 531. By this supply of the electrical power, the ECU 52 causes the glow plug 1 to generate heat. The ECU 52 controls the heat generation of the glow plug 1 by controlling the ratio between the on time and off time of the glow relay 53. The glow relay 531 is always maintained in its on state during a period during which heating is performed, and is turned off when heating is stopped.

[0013] The control section 50 further includes a DC power supply 51, a relay 55, a resistor 521, and a potentiometer 522. The relay 55 is disposed between the resistor 521 and an external lead wire 333 of the glow plug 1. The relay 55 allows and prohibits the supply of electricity from the DC power supply 51 to the glow plug 1 through switching operation.

[0014] The negative terminal of the DC power supply 51 is connected to the cylinder block 45, whereby the negative terminal of the DC power supply 51 is grounded. The resistor 521 is disposed on the positive terminal side of the DC power supply 51. The potentiometer 522 measures a voltage (drop voltage) by which the voltage of the DC power supply 51 drops at the resistor 521. The ECU 52 measures the ion current value by using these circuit configurations and utilizing the glow plug 1 as a detection section.

[0015] FIG. 2 is a partially sectioned view of the glow plug 1. FIG. 3 is a sectional view of a distal end of the glow plug 1 and its vicinity, and shows the state in which the glow plug 1 is attached to the cylinder block 45. Below, the glow plug 1 will be described with reference to FIGS. 2 and 3.

[0016] As shown in FIG. 2, the glow plug 1 includes the housing 4, a heater 10, a terminal portion 23, a terminal portion 31, an internal lead wire 33, an internal lead wire 231, a connection terminal 232, the external lead wire 233, a connection terminal 332, the external lead wire 333, and a rubber bush 421. These members are assembled along the axial line O of the glow plug 1. Notably, in the present specification, the side of the glow plug 1 where the heater 10 is located will be referred to as the "forward end side," and the side opposite thereto will be referred to as the "rear end side."

[0017] As shown in FIG. 2, the housing 4 includes an outer tube 41, a protection tube 42, and a metallic shell 47. The protection tube 42 is an approximately cylindrical member extending along the axial line O and has openings on the forward end side and rear end side thereof. A forward-end-side opening portion of the protection tube 42 is attached to the rear end of the metallic shell 47. The rubber bush 421 is inserted into a rear-end-side opening portion of the protection tube 42. The rubber bush 421 is a circular columnar member made of rubber. The rubber bush 421 inserted into the protection tube 42 seals the space located forward of the rubber bush 421. The outer tube 41 is disposed on the forward end side of the protection tube 42. The metallic shell 47 has an external thread portion 43. The external thread portion 43 is used to attach the glow plug 1 to the cylinder block 45 of the engine.

[0018] As shown in FIG. 3, the heater 10 has a generally rod-shaped member which has a hemispherical forward end portion and extends along the axial line O. The heater 10 is fixed within the housing 4 via the outer tube 41. The outer tube 41 is a ring-shaped member made of metal. The heater 10 has an electro-heating element 2, an electrode 3, a substrate 11, and a pair of lead wires 21 and 22. The electro-heating element 2, the electrode 3, and the lead wires 21 and 22 are embedded in the substrate 11 and are held. The substrate 11 is formed of a ceramic which contains Si_3N_4 (silicon nitride) as a main component.

[0019] As shown in FIG. 2, the external lead wires 233 and 333 extend through the rubber bush 421 and reach the interior of the glow plug 1. The external lead wire 233 is connected to the terminal portion 23 through the connection terminal 232 and the internal lead wire 231. The terminal portion 23 is disposed on the outer circumferential surface of the substrate 11 with a gap formed between the terminal portion 23 and the inner circumferential surface of the housing 4. As will be described later, the terminal portion 23 electrically communicates with the housing 4 through the heater 10. The housing 4 is fixed to the cylinder block 45 as described above, whereby the housing 4 electrically communicates with the cylinder block 45 which is the ground potential. As described above, the cylinder block 45 is connected to the negative terminal of the battery 54. Therefore, when the glow relays 53 and 531 are turned on, a closed circuit is formed.

[0020] As shown in FIG. 3, the lead wire 21 is connected to the terminal portion 23. The lead wire 21 extends through the interior of the substrate 11 and is connected to one end of the electro-heating element 2 having a U-like shape. The other end of the electro-heating element 2 is connected to the outer tube 41 through the lead wire 22. Therefore, when the glow relays 53 and 531 are turned on, the voltage of the battery 54 is applied to the electro-heating element 2, and a current flows through the electro-heating element 2 embedded in the substrate 11. The electro-heating element 2 is formed of a ceramic which is smaller in electrical resistance than the substrate 11. When the voltage of the battery 54 is applied to the electro-heating element 2, a portion of the electro-heating element 2 near the forward end of the heater 10 generates heat.

[0021] Next, a circuit for the above-described measurement of the ion current value will be described. As shown in FIG. 2, the external lead wire 333 is connected to the terminal portion 31 disposed at the rear end of the substrate 11 through the connection terminal 332 and the internal lead wire 33. As shown in FIG. 3, the electrode 3 is connected, at one end thereof, to the terminal portion 31 and extends along the direction of the axial line O within the substrate 11. The other end of the electrode 3 is disposed near the forward end of the electro-heating element 2.

[0022] The electrode 3 is formed of an electrically conductive ceramic and is embedded in the substrate 11 such that the electrode 3 is separated from the electro-heating element 2. Therefore, when the relay 55 is turned on and the DC power supply 51 electrically communicates with the electrode 3, the potential of the electrode 3 becomes higher than the ground potential. When the potential of the electrode 3 rises, the potential of the substrate 11 also becomes higher than the ground potential. When the potential of the substrate 11 is high and ions exist in the combustion chamber, an ion current is produced. This ion current flows through the space between the substrate 11 and the cylinder block 45. Since the negative terminal of the DC power supply 51 is connected to the cylinder block 45, when an ion current is produced, a closed circuit is formed.

[0023] FIG. 4 is a flowchart showing ion current measurement processing. The ion current measurement processing is repeatedly executed by the ECU 52.

[0024] First, the ECU 52 obtains a drop voltage V_{521} at the resistor 521 through use of the potentiometer 522 (step S610). Since the drop voltage V_{521} varies due to the influence of the ion current, in step S610, the ECU 52 obtains the value of the drop voltage V_{521} over at least a time corresponding to one cycle of the engine.

[0025] Subsequently, the ECU 52 converts the obtained drop voltage V_{521} to a current value I by dividing the drop voltage V521 by the resistance of the resistor 521 (step S620). FIG. 5 is a graph exemplifies I(t) which shows a time course variation in the current value I obtained as a result of the conversion in step S620.

[0026] Next, the ECU 52 calculates a first substrate resistance R_{11} (step S630). The first substrate resistance R_{11} refers to the electrical resistance of the substrate 11 between the electro-heating element 2 and the electrode 3. The substrate 11 is formed of ceramic and has an electrical resistance on the basis of which the substrate 11 is generally classified as an insulator. However, since the electrical resistance of the substrate 11 is naturally finite, when a high voltage is applied to the electrode 3, a slight current flows through the substrate 11. This current flows toward conductors embedded in the substrate 11 and conductors in contact with the substrate 11, and finally flows to the cylinder block 45, which is the ground potential. The conductors disposed in the substrate 11 are the electro-heating element 2, the lead wire 21, and the lead wire 22. The conductors in contact with the substrate 11 include ions produced within the combustion chamber, in addition to the terminal portion 23, the terminal portion 31, and the outer tube 41.

[0027] Since the above-mentioned ions are produced as a result of combustion of fuel within the combustion chamber, the ion current value varies within a time corresponding to one cycle of the engine. In contrast, the currents flowing through other paths hardly vary in such a short period of time. Therefore, the current value obtained as a result of the conversion in step S620 can be divided into a portion corresponding to the ion current and a portion corresponding to the current flowing through the other paths. Specifically, as shown in FIG. 5, the minimum value Imin of the current value which is obtained as a result of the conversion in step S620 and which varies with time is the portion corresponding to the current flowing through the other paths, and a value obtained by subtracting the minimum value Imin from the current value is the portion corresponding to the ion current. The value obtained by subtracting the minimum value Imin from the current value (I(t) - Imin) will be referred to as a "current value Iion(t)."

[0028] The greater part of the current flowing through the other paths flows from the vicinity of the forward end of the electrode 3 to the vicinity of the forward end of the electro-heating element 2. This is because a portion of the substrate 11 having a higher temperature has a smaller electrical resistance as will be described later. Since the electro-heating element 2 generates heat in the vicinity of the forward end thereof as described above, a portion of the substrate 11 near the forward end of the electro-heating element 2 has a higher temperature as compared with other portions.

[0029] In view of the above, the current flowing to the conductors other than the electrode 3 is ignored in the calculation of the first substrate resistance R_{11}. Further, since the electrical resistance of the electro-heating element 2 is smaller than the first substrate resistance R_{11}, the electrical resistance of the electro-heating element 2 is ignored in the calculation of the first substrate resistance R_{11}. Namely, in the present embodiment, the electro-heating element 2 is treated as a conductor.

[0030] In the case where the above-described premise is employed, the first substrate resistance R_{11} is calculated by the following expression (3). In the following expressions (1) to (3), V_{11} represents the potential difference between the electro-heating element 2 and the electrode 3 and V_0 represents the voltage of the DC power supply 51.

$$R_{11} = V_{11}/Imin \cdots (1),$$

$$V_{11} = V_0 - V_{521} \cdots (2)$$

[0031] When the expression (2) is substituted into the expression (1), the following expression (3) is obtained.

$$R_{11} = (V_0 - V_{521})/Imin \cdots (3)$$

[0032] Since $V_{521} << V_0$ in the present embodiment, the following expression (4) is obtained from the expression (3).

$$R_{11} = V_0/Imin \cdots (4)$$

[0033] Subsequently, the ECU 52 judges whether or not the first substrate resistance R_{11} is equal to or less than a predetermined value (step S640). For explanation of this predetermined value, the relation between the first substrate resistance R_{11} and the highest surface temperature of the substrate 11 will be described. The highest surface temperature of the substrate 11 refers to the highest value among the surface temperatures of the substrate 11. The substrate 11 has different surface temperatures in different portions thereof, and normally, a portion near the forward end of the electro-heating element 2 has the highest surface temperature.

[0034] FIG. 6 is a graph approximately showing the relation between the first substrate resistance R_{11} and the highest surface temperature of the substrate 11. This graph is a semilogarithmic graph which shows the first substrate resistance R_{11} in logarithm scale. This relation was obtained in advance by an experiment in which the first substrate resistance R_{11} was actually measured while the highest surface temperature of the substrate 11 was changed, and is stored in the ECU 52.

[0035] As shown in FIG. 6, the higher the highest surface temperature of the substrate 11, the greater the degree to which the first substrate resistance R_{11} decreases. For example, when the highest surface temperature of the substrate 11 changes from 600°C to 1200°C as shown in FIG. 6, the first substrate resistance R_{11} becomes about one-thousandth. Since the substrate 11 has such a characteristic, the highest surface temperature of the substrate 11 has a large influence on the measurement of the ion current value. This is because the substrate 11 acts as a resistor even in a closed circuit formed as a result of generation of the ion current. The resistance of the substrate 11 serving as a resistance in this closed circuit will be referred to as a second substrate resistance R_{12}.

[0036] The relation between the second substrate resistance R_{12} and the current value Iion(t) can be expressed by the following expression (5).

$$Iion(t) = V_0/(R_{12}+Rion(t)) \cdots (5)$$

[0037] In the expression (5), Rion(t) represents ion resistance Rion(t). The ion resistance Rion(t) is the electrical resistance in the combustion chamber and a variable which varies with the amount of ions generated in the combustion chamber.

[0038] Meanwhile, the highest surface temperature of the substrate 11 is a parameter controlled in accordance with the operating state of the engine. For example, in the present embodiment, when the engine is started, the highest surface temperature of the substrate 11 is controlled to a target temperature of 1200°C. After that, the target temperature is changed to a temperature lower than 1200°C or heating is stopped. Like the first substrate resistance R_{11}, the second substrate resistance R_{12} depends on the highest surface temperature of the substrate 11. Therefore, as can be understood from the expression (5), the current value Iion (t) depends on the highest surface temperature of the substrate 11.

[0039] However, in the case where the second substrate resistance R_{12} << the ion resistance Rion(t), the expression (5) can be simplified to obtain the following expression (6).

$$Iion(t) = V_0/Rion(t) \cdots (6)$$

[0040] Namely, in the case where the second substrate resistance R_{12} << the ion resistance Rion(t), the current value Iion(t) hardly depends on the second substrate resistance R_{12} and hardly depends on the highest surface temperature of the substrate 11.

[0041] In the present embodiment, in the case where the highest surface temperature of the substrate 11 is 1200°C or higher, the expression (6) stands even at the time when the ion resistance Rion(t) is the minimum. The "time when the ion resistance Rion(t) is the minimum" is the time when the electrical resistance within the combustion chamber becomes the smallest within one cycle of the engine.

[0042] In view of the above, in the present embodiment, it is considered that correction of the ion current value is unnecessary when the highest surface temperature is equal to or higher than 1200°C and correction of the ion current value is necessary when the highest surface temperature is lower than 1200°C. The predetermined value of the first substrate resistance R_{11} in step S640 is the first substrate resistance R_{11} at the time when the highest surface temperature is 1200°C (a resistance A in FIG. 6; in the following description, denoted as R_{11}@1200°C).

[0043] Therefore, it is also considered that, in step S640, the ECU 52 judges whether or not the highest surface temperature of the substrate 11 is equal to or higher than 1200°C.

[0044] In the case where the first substrate resistance R_{11} is equal to or less than the predetermined value (step S640, YES), the ECU 52 obtains the current value Iion(t) as the ion current value (step S660).

[0045] Meanwhile, in the case where the first substrate resistance R_{11} is greater than the predetermined value (step 640, NO), the ECU 52 corrects the current value Iion(t) (step S650) and obtains the corrected current value as the ion current value (step S660). When the corrected current value is represented by Ic(t), this correction is expressed by the following expression (7).

$$Ic(t) = Iion(t)\times\{(R_{12}+Rion(t))/(R_{12}@1200°C+Rion(t))\} \quad \cdots (7)$$

[0046] In the expression (7), R_{12}@1200°C represents the second substrate resistance R_{12} at the time when the highest surface temperature of the substrate 11 is 1200°C. Like R_{11}@1200°C, R_{12}@1200°C is very small value as compared with the smallest value of Rion(t). Therefore, the expression (7) can be simplified to obtain the following expression (8).

$$Ic(t) = Iion(t)\times\{(R_{12}+Rion(t))/Rion(t)\} \cdots (8)$$

[0047] Further, the following expression (10) can be obtained by substituting the following expression (9) into the expression (8). The expression (9) can be obtained by modifying the expression (5).

$$Rion(t) = (V_0/Iion(t))-R_{12} \cdots (9)$$

$$Ic(t) = Iion(t)/(1-Iion(t)\times R_{12}/V_0) \cdots (10)$$

[0048] In the present embodiment, the second substrate resistance R_{12} is calculated by the following expression (11).

$$R_{12} = R_{11}\times R_{12}@1200°C/R_{11}@1200°C \cdots (11)$$

[0049] The corrected current Ic(t) is calculated by the expressions (10) and (11). The value of R_{12}@1200°C/R_{11}@1200°C was obtained in advance by an experiment and is stored in the ECU 52.

[0050] After step S660, the ECU 52 executes steps S670 to S690 for controlling the heating of the combustion chamber. First, the ECU 52 determines a target temperature (step S670). The target temperature refers to a target value of the highest surface temperature of the substrate 11. The target temperature is determined on the basis of the input value from the water temperature sensor 525, the input value from the engine speed sensor 526, and other values relating to the engine (e.g., the temperature of intake gas).

[0051] Subsequently, the ECU 52 determines a target resistance (step S680). The target resistance refers to the first substrate resistance R_{11} corresponding to the target temperature determined in step S670. This determination is made on the basis of the relation shown in FIG. 6.

[0052] Finally, the ECU 52 controls the energization of the heater 10 (step S690). Specifically, the ECU 52 controls the ratio between the on time and off time of the glow relay 53 such that the first substrate resistance R_{11} approaches the target resistance. After that, the ECU 52 ends the ion current measurement processing.

[0053] According to the above-described embodiment, at least the following effects (a), (b), and (c) can be obtained.
(a) Even when the highest surface temperature of the substrate 11 changes, the influence on the obtained value of the ion current value can be reduced. Conceivably, this effect is obtained mainly for the following reasons (a-1), (a-2), and (a-3).

[0054] (a-1) As described above, the second substrate resistance R_{12} strongly depends on the highest surface temperature of the substrate 11 as in the case of the first substrate resistance R_{11}. Therefore, the value of ion current which actually flows strongly depends on the highest surface temperature of the substrate 11. However, even when the highest surface temperature of the substrate 11 changes, its influence can be cancelled out, because the measured ion current value is corrected in the present embodiment.

[0055] (a-2) As shown by the above-described expression (11), a variation of the second substrate resistance R_{12}

can be estimated by measuring the first substrate resistance R_{11}, and the accuracy of this estimation is high. Therefore, the above-described effect can be obtained. This will be described in detail below.

[0056] Since the electrical resistance of the substrate 11 decreases greatly when its temperature increases, the electrical resistance of a portion of the substrate 11 between the electro-heating element 2 and the electrode 3, which portion has the highest temperature, becomes the dominant factor of the first substrate resistance R_{11}. The portion of the substrate 11 between the electro-heating element 2 and the electrode 3, which portion has the highest temperature, is located near the forward end of the electro-heating element 2.

[0057] Similarly, the electrical resistance of a portion of the substrate 11 between the electrode 3 and the surface of the substrate 11, which portion has the highest temperature, becomes the dominant factor of the second substrate resistance R_{12}. The portion of the substrate 11 between the electrode 3 and the surface of the substrate 11, which portion has the highest temperature, is also located near the forward end of the electro-heating element 2.

[0058] Since the above-mentioned two portions are close to each other as described above, the values of the above-mentioned two highest temperatures are close to each other. As a result, the first substrate resistance R_{11} and the second substrate resistance R_{12} have a strong correlation therebetween. Therefore, the first substrate resistance R_{11} is an excellent parameter for estimating the variation of the second substrate resistance R_{12}.

[0059] (a-3) Since the first substrate resistance R_{11} and the second substrate resistance R_{12} are parameters which strongly reflect the state of a local portion as described above, they are less likely to be affected by a variation in the production of the glow plug and disturbances. The disturbances refer to the cooling water temperature of the engine, the temperature of engine oil, the temperature within the combustion chamber, etc.

[0060]

(b) The obtainment of the first substrate resistance R_{11} can be realized easily by the above-described simple circuit.
(c) In the case where the first substrate resistance R_{11} is equal to or smaller than the predetermined value, correction of the ion current value is unnecessary. Therefore, the processing load can be lightened.

[0061] A second embodiment that does not form part of the invention will be described. Since the hardware configuration of the second embodiment is the same as that of the first embodiment, the description of the hardware configuration will not be repeated.

[0062] FIG. 7 is a flowchart showing the ion current measurement processing in the second embodiment. Since steps S610 to S630 are the same as those of the first embodiment, their description will not be repeated.

[0063] After the calculation of the first substrate resistance R_{11} (step S630), the ECU 52 controls the ratio between the on time and off time of the glow relay 53 such that the first substrate resistance R_{11} approaches a predetermined resistance (step S700). The predetermined resistance is a fixed value determined in advance. This fixed value will be described later.

[0064] Subsequently, the ECU 52 judges whether or not the first substrate resistance R_{11} falls within a predetermined range (step S710). The predetermined range is determined by adding errors to the above-mentioned predetermined resistance.

[0065] In the case where the first substrate resistance R_{11} falls within the predetermined range (step S710, YES), the ECU 52 obtains the current value Iion(t) as the ion current value (step S720), and ends the ion current measurement processing.

[0066] Meanwhile in the case where first substrate resistance R_{11} falls outside the predetermined range (step S710, NO), the ECU 52 ends the ion current measurement processing without obtaining the ion current value.

[0067] As a result of execution of this energization control, the highest surface temperature of the glow plug 1 is maintained constant. Therefore, it is preferred that the processing be executed in the case where the engine can be operated without any problem even when the highest surface temperature of the glow plug 1 is maintained constant. For example, there may be employed a method of executing the processing only when the highest surface temperature of the glow plug 1 is maintained at 1200°C. In this case, the predetermined resistance in step S700 is a resistance corresponding to 1200°C.

[0068] A conceivable alternative method is executing the ion current measurement processing when heating is not requested. Even in the case where the highest surface temperature of the glow plug 1 is low and the ion current value is affected by the second substrate resistance R_{12}, correction can be avoided through use of the method of the second embodiment. This is because, when the measurement is performed under the condition that the highest surface temperature of the glow plug 1 falls within the predetermined range as described above, the influence of the second substrate resistance R_{12} on the ion current value is approximately constant, and the behavior of the ion current can be monitored without any problem. In the case of this method, the highest surface temperature is preferably set such that the engine can be operated without any problem. In this case, the predetermined resistance in step S700 is a resistance corresponding to that highest surface temperature.

[0069] As described above, the ion current measurement processing of the second embodiment can accurately estimate the state of combustion within the combustion chamber without correcting the ion current value. Notably, the method in which the highest surface temperature of the glow plug 1 is maintained at 1200°C as described above can accurately measure the ion current value as having been described in the first embodiment.

[0070] The present invention is not limited to the above described embodiments, examples, and modifications and may be embodied in various other forms without departing from the scope of the invention as defined by the appended claims. For example, the following are exemplified.

[0071] In the embodiment, the glow plug 1 and the control section 50 are contained in the ion current measurement apparatus 100. However, the control section 50 may considered as an ion current measurement apparatus, and the ion current measurement apparatus 100 may be considered as an ion current measurement system.

[0072] The material of the substrate may be changed to other ceramics. For example, the material may be titanium diboride or a mixture of silicon nitride and titanium diboride. Alternatively, the material may be alumina, sialon, or the like.

[0073] A circuit for obtaining the first substrate resistance may be added. For example, the circuit may be configured to apply a voltage between the pair of external lead wires and measure the value of current. Since this configuration allows accurate grasping of the voltage applied between the electro-heating element and the electrode, the accuracy in measuring the first substrate resistance improves.

[0074] The highest surface temperature may be estimated from the relation shown in FIG. 6 and the calculated first substrate resistance.

[Description of Reference Numerals]

[0075]

1: glow plug
2: electro-heating element
3: electrode
4: housing
10: heater
11: substrate
21: lead wire
22: lead wire
23: terminal portion
31: terminal portion
33: internal lead wire
41: outer tube
42: protection tube
43: external thread portion
45: cylinder block
50: control section
51: DC power supply
52: ECU
53: glow relay
54: battery
55: relay
100: ion current measurement apparatus
231: internal lead wire
232: connection terminal
233: external lead wire
333: external lead wire
421: rubber bush
521: resistor
522: potentiometer
525: water temperature sensor
526: engine speed sensor
531: glow relay

Claims

1. A ion current measurement apparatus (100) comprising a detection section (1) and a control section (50), the detection section (1) including first and second conductors (2, 3) and a substrate (11) which is formed of ceramic and in which the first and second conductors (2, 3) are separately embedded and held, one end of the second conductor (3) being disposed near the forward end of the first conductor (2), the detection section (1) being adapted for attachment to an internal combustion engine such that the substrate (11) is exposed to a combustion chamber of the internal combustion engine in which ions are generated as a result of combustion of fuel;
the control section (50) comprising:

    a measurement section (52, S610, S620) adapted to measure a value of current (Iion) flowing through the second conductor (3) as an ion current originating from the generated ions,
    an obtainment section (S630) adapted to obtain a first substrate electrical resistance (R_{11}) of the substrate (11) between the first conductor (2) and the second conductor (3) based on a potential difference between the first conductor (2) and the second conductor (3) and an electrical current flowing between the first conductor (2) and the second conductor (3); and
    a correction section (S640, S650) adapted to judge (S640) whether the first substrate resistance (R_{11}) is greater than a predetermined value, and in the case where the first substrate resistance (R_{11}) is greater than the predetermined value a second substrate resistance (R_{12}) is calculated based on the first substrate resistance (R_{11}), the second substrate resistance (R_{12}) being the electrical resistance of the substrate(11) between the second conductor (3) and the combustion chamber of the internal combustion engine in which ions are generated as a result of combustion of fuel, and to correct the current value (Iion), measured by the measurement section (S610, S620), based on the second substrate resistance (R_{12}).

2. An ion current measurement apparatus (100) according to claim 1, wherein the first conductor (2) is a heating element which generates heat when electricity is supplied thereto.

Patentansprüche

1. Ionenstrommessvorrichtung (100), umfassend einen Erfassungsabschnitt (1) und einen Steuerabschnitt (50); wobei der Erfassungsabschnitt (1) erste und zweite Leiter (2, 3) und ein Substrat (11) umfasst, das aus Keramik gebildet ist und in dem die ersten und zweiten Leiter (2, 3) separat eingebettet und gehalten werden, wobei ein Ende des zweiten Leiters (3) in der Nähe des vorderen Endes des ersten Leiters (2) angeordnet ist, wobei der der Erfassungsabschnitt (1) für die Befestigung an einem Verbrennungsmotor eingerichtet ist, sodass das Substrat (11) einer Verbrennungskammer des Verbrennungsmotors ausgesetzt ist, worin Ionen infolge der Verbrennung von Kraftstoff erzeugt werden;
wobei der Steuerabschnitt (50) Folgendes umfasst:

    einen Messabschnitt (52, S610, S620), der dazu eingerichtet ist, einen Stromwert (Iion) zu messen, der als ein Ionenstrom, der von den erzeugten Ionen stammt, durch den zweiten Leiter (3) fließt,
    einen Erlangungsabschnitt (S630), der dazu eingerichtet ist, einen ersten elektrischen Substrat-Widerstand (Rn) des Substrats (11) zwischen dem ersten Leiter (2) und dem zweiten Leiter (3) beruhend auf einem potentiellen Unterschied zwischen dem ersten Leiter (2) und dem zweiten Leiter (3) und einem elektrischen Strom, der zwischen dem ersten Leiter (2) und dem zweiten Leiter (3) fließt, zu erlangen; und
    einen Korrekturabschnitt (S640, S650), der dazu eingerichtet ist, zu beurteilen (S640), ob der erste Substratwiderstand (Rn) größer ist als ein festgelegter Wert, und in dem Fall, in dem der erste Substratwiderstand (R_{11}) größer ist als der festgelegte Wert, wird ein zweiter Substratwiderstand (R_{12}) beruhend auf dem ersten Substratwiderstand (R_{11}) berechnet, wobei der zweite Substratwiderstand (R_{12}) der elektrische Widerstand des Substrats (11) zwischen dem zweiten Leiter (3) und der Verbrennungskammer des Verbrennungsmotors ist, worin Ionen infolge der Verbrennung von Kraftstoff erzeugt werden, und der dazu eingerichtet, den vom Messabschnitt (S610, S620) gemessenen Stromwert (Iion) beruhend auf dem zweiten Substratwiderstand (R_{12}) zu korrigieren.

2. Ionenstrommessvorrichtung (100) nach Anspruch 1, wobei der erste Leiter (2) ein Heizelement ist, das Wärme erzeugt, wenn ihm Elektrizität zugeführt wird.

Revendications

1. Appareil de mesure de courant ionique (100) comprenant une section de détection (1) et une section de commande (50),
la section détection (1) comprenant des premier et deuxième conducteurs (2, 3) et un substrat (11) qui est formé de céramique et dans lequel les premier et deuxième conducteurs (2,3) sont incorporés séparément et maintenus, une extrémité du deuxième conducteur (3) étant disposée près de l'extrémité avant du premier conducteur (2), la section de détection (1) étant conçue pour être attachée à un moteur de combustion interne de manière que le substrat (11) est exposé à une chambre de combustion du moteur à combustion interne dans laquelle des ions sont générés suite à la combustion de carburant ;
la section de commande (50) comprenant :

    une section de mesure (52, S610, S620) conçue pour mesurer une valeur de courant (lion) circulant à travers le deuxième conducteur (3) en tant que courant ionique provenant des ions générés,
    une section d'obtention (S630) conçue pour obtenir une première résistance électrique de substrat (R_{11}) du substrat (11) entre le premier conducteur (2) et le deuxième conducteur (3) en fonction d'une différence de potentiel entre le premier conducteur (2) et le deuxième conducteur (3) et une courant électrique circulant entre le premier conducteur (2) et le deuxième conducteur (3) ; et
    une section de correction (S640, S650) conçue pour juger (S640) si la première résistance de substrat (R_{11}) est plus grande qu'une valeur prédéterminée et au cas où la première résistance de substrat (R_{11}) est plus grande que la valeur prédéterminée, une deuxième résistance de substrat (R_{12}) est calculée en fonction de la première résistance de substrat (R_{11}), la deuxième résistance de substrat (R_{12}) étant la résistance électrique du substrat (11) entre le deuxième conducteur (3) et la chambre de combustion du moteur à combustion interne dans lequel des ions sont générés suite à la combustion de carburant, et pour corriger la valeur de courant (lion), mesurée par la section de mesure (S610, S620), en fonction de la deuxième résistance de substrat (R_{12}).

2. Appareil de mesure de courant ionique (100) selon la revendication 1, dans laquelle le premier conducteur (2) est un élément chauffant qui génère de la chaleur lorsque celui-ci est alimenté en électricité.

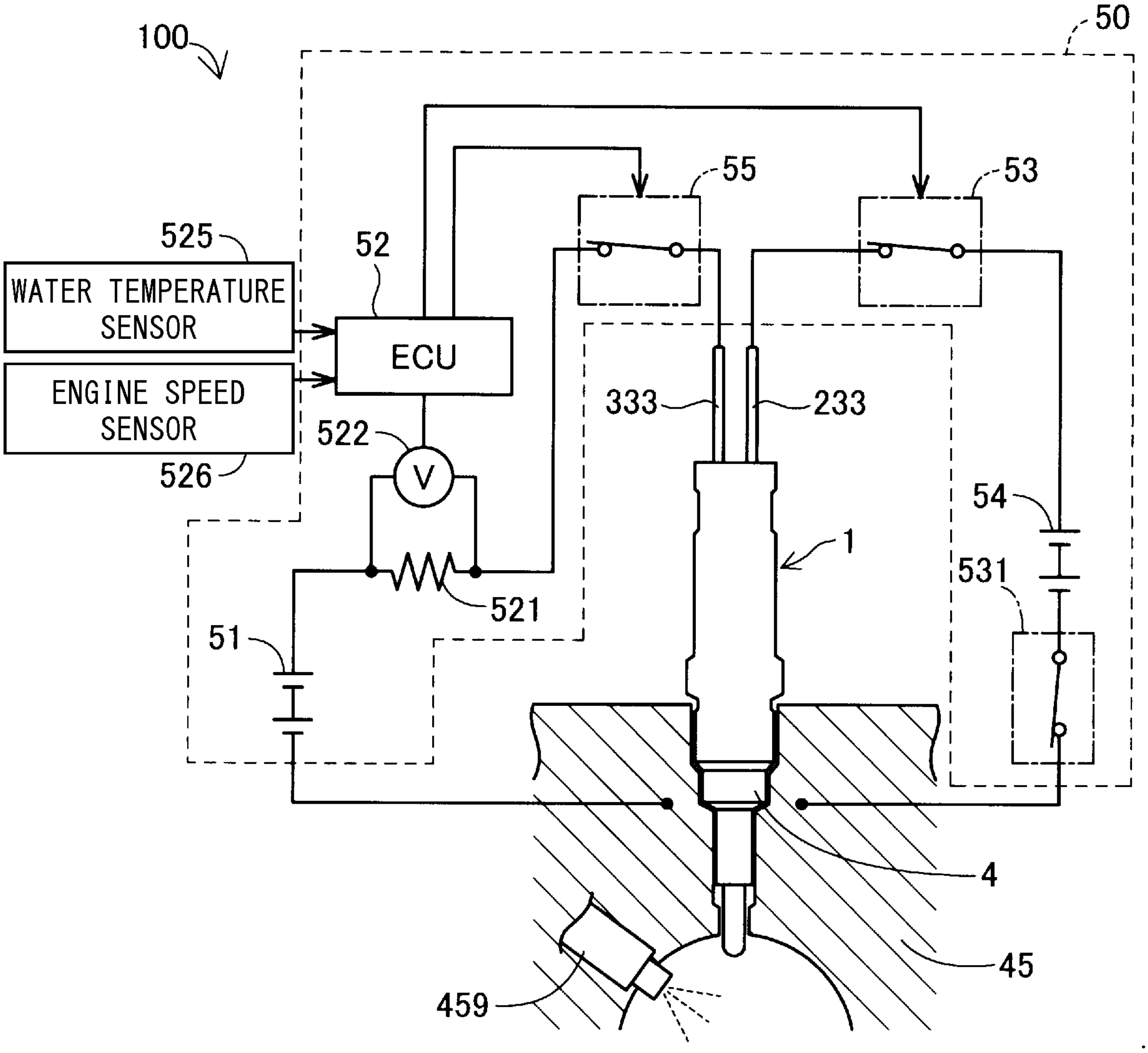
100
50
55
53
525
52
WATER TEMPERATURE SENSOR
ECU
ENGINE SPEED SENSOR
333
233
522
V
526
54
1
531
521
51
4
45
459

FIG. 1

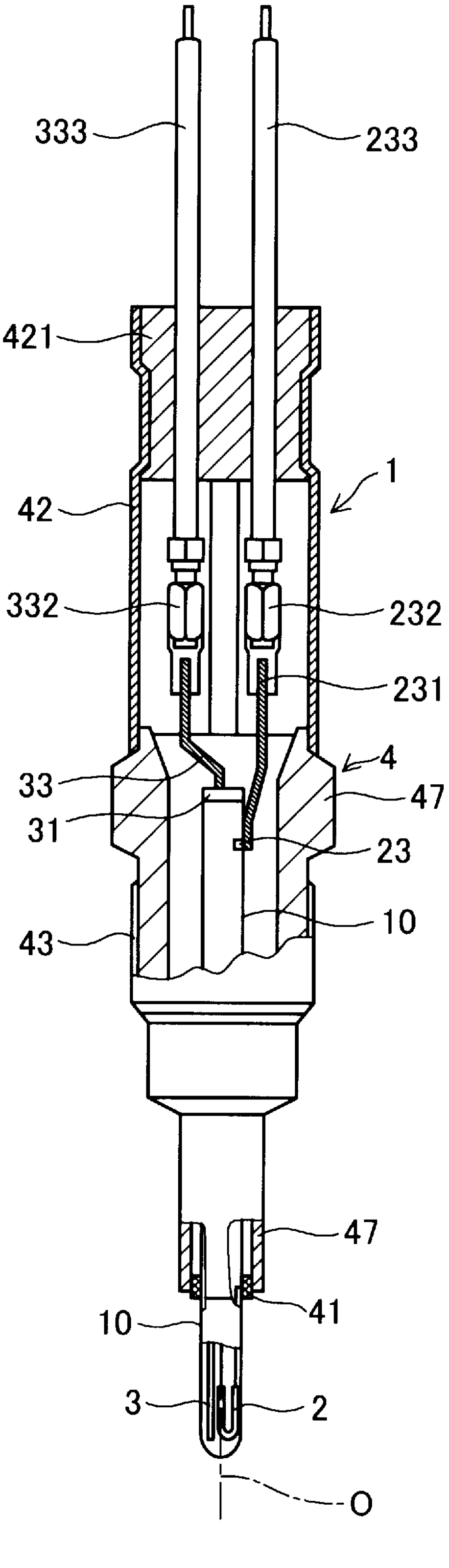

FIG. 2

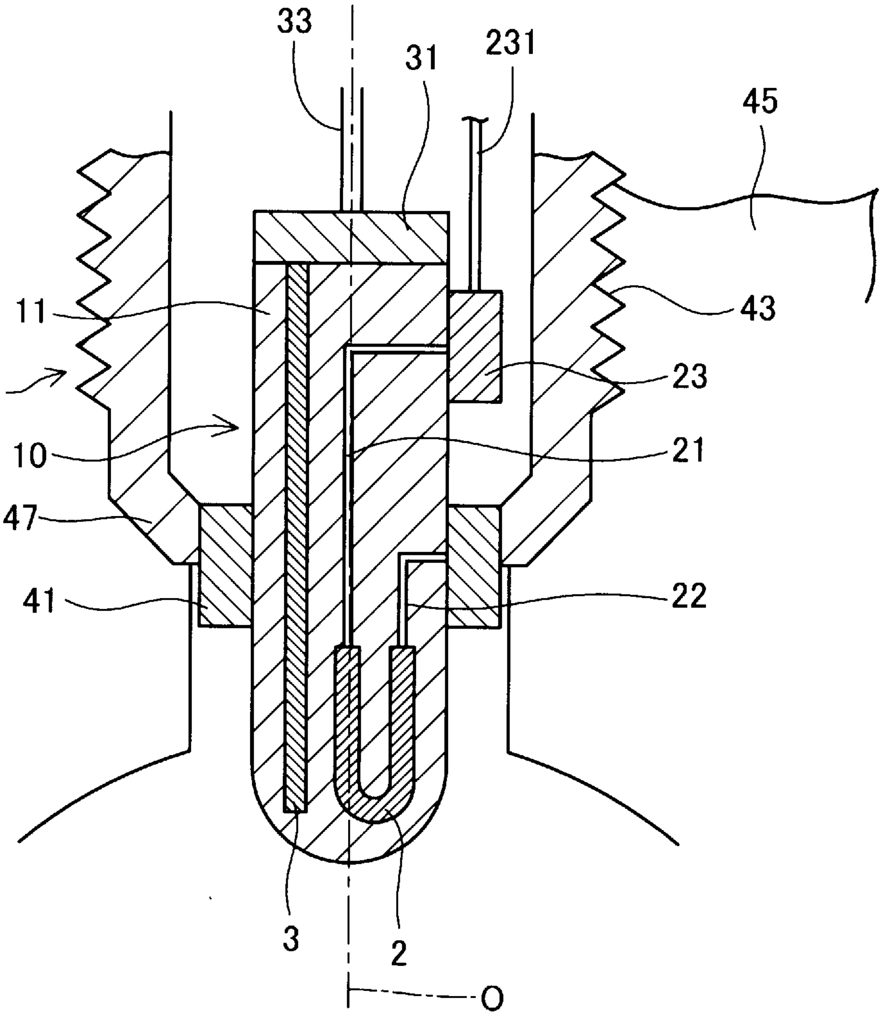

FIG. 3

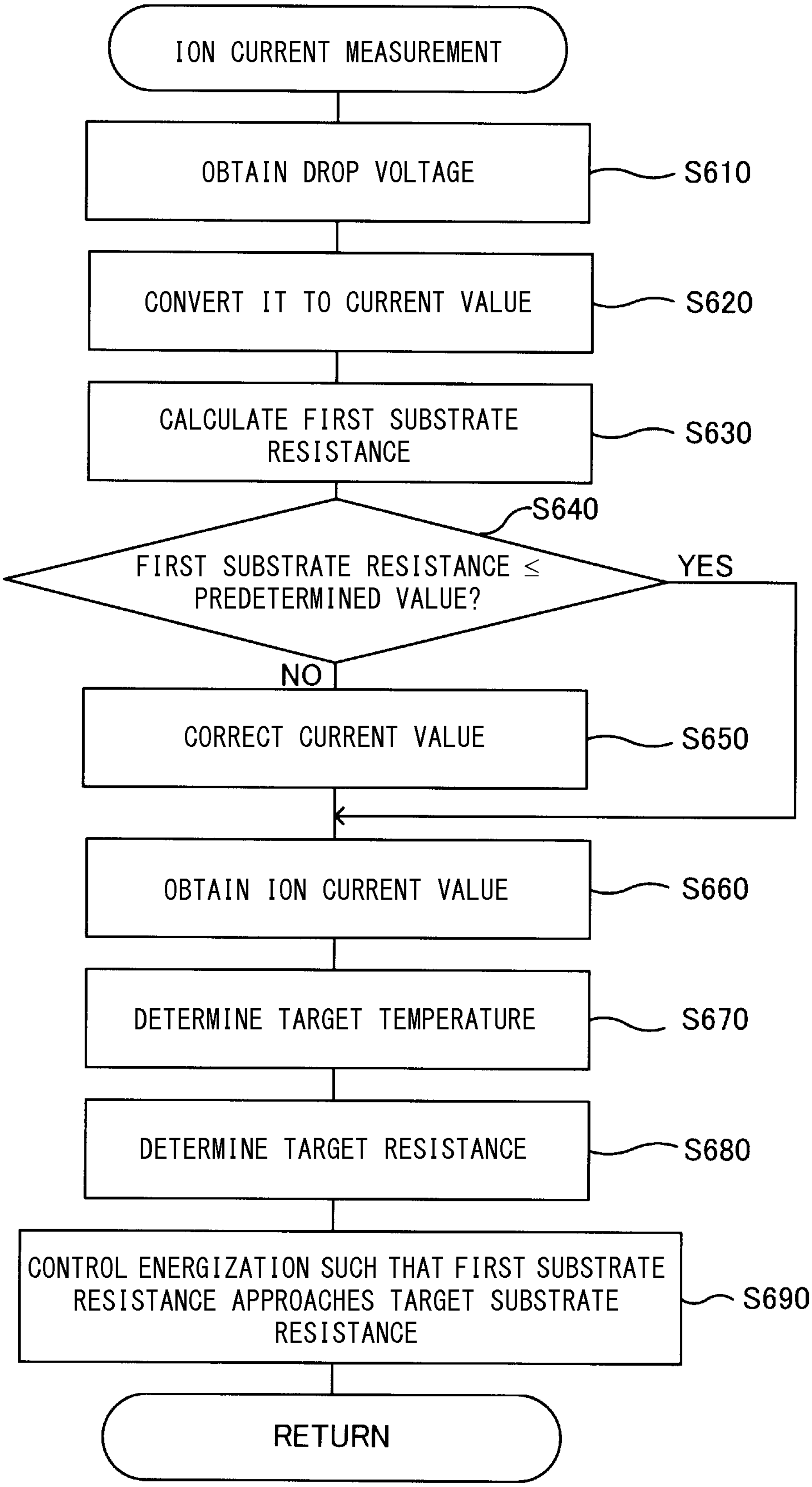
ION CURRENT MEASUREMENT
OBTAIN DROP VOLTAGE
S610
CONVERT IT TO CURRENT VALUE
S620
CALCULATE FIRST SUBSTRATE RESISTANCE
S630
S640
FIRST SUBSTRATE RESISTANCE ≤ PREDETERMINED VALUE?
YES
NO
CORRECT CURRENT VALUE
S650
OBTAIN ION CURRENT VALUE
S660
DETERMINE TARGET TEMPERATURE
S670
DETERMINE TARGET RESISTANCE
S680
CONTROL ENERGIZATION SUCH THAT FIRST SUBSTRATE RESISTANCE APPROACHES TARGET SUBSTRATE RESISTANCE
S690
RETURN

FIG. 4

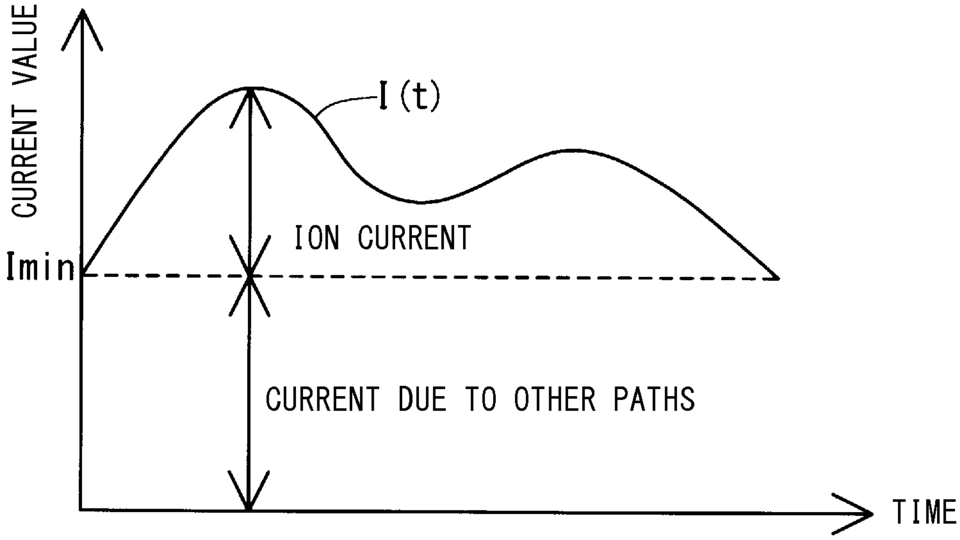
CURRENT VALUE
I (t)
ION CURRENT
Imin
CURRENT DUE TO OTHER PATHS
TIME

FIG. 5

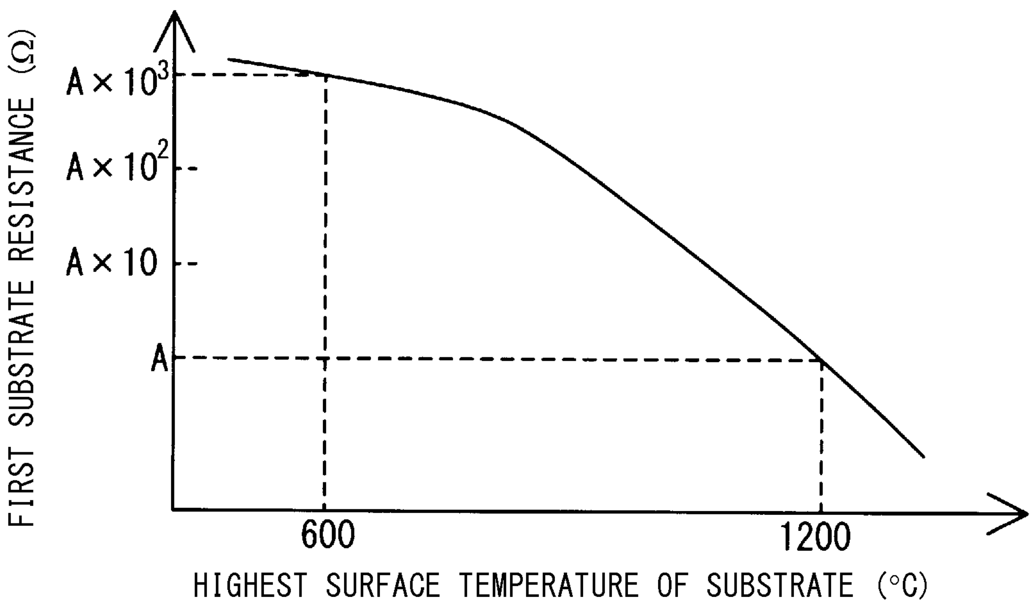
FIRST SUBSTRATE RESISTANCE (Ω)
A×10³
A×10²
A×10
A
600
1200
HIGHEST SURFACE TEMPERATURE OF SUBSTRATE (°C)

FIG. 6

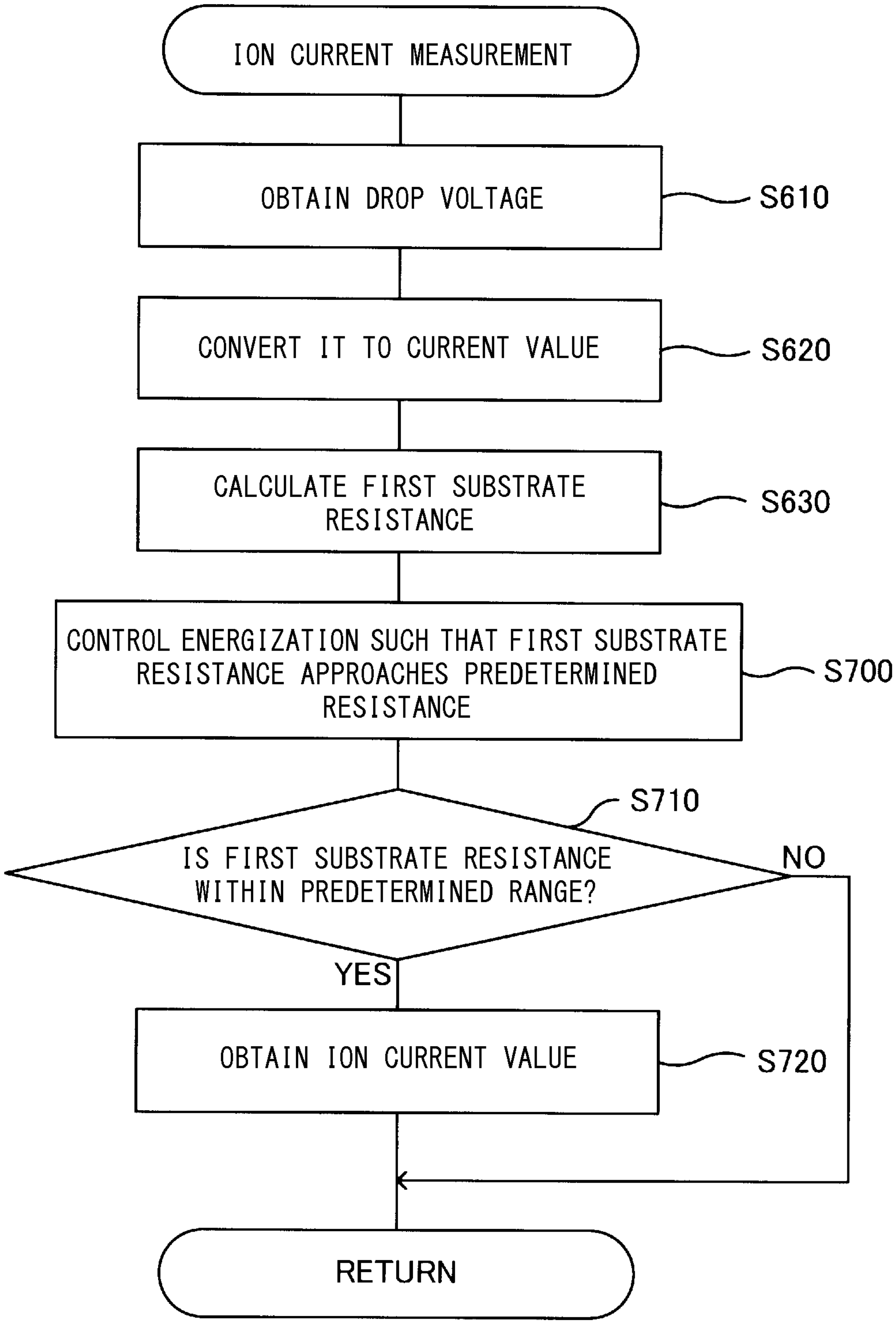
ION CURRENT MEASUREMENT
OBTAIN DROP VOLTAGE
S610
CONVERT IT TO CURRENT VALUE
S620
CALCULATE FIRST SUBSTRATE RESISTANCE
S630
CONTROL ENERGIZATION SUCH THAT FIRST SUBSTRATE RESISTANCE APPROACHES PREDETERMINED RESISTANCE
S700
S710
IS FIRST SUBSTRATE RESISTANCE WITHIN PREDETERMINED RANGE?
NO
YES
OBTAIN ION CURRENT VALUE
S720
RETURN

FIG. 7

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- EP 1136697 A2 **[0002]**
- JP 3605965 B **[0002]**