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(71) Applicant: **NGK Spark Plug Company Limited**
**Nagoya**
**Aichi 467-8525 (JP)**

(72) Inventors:
- **YATSUYA, Yosuke**
**Nagoya-shi**
**Aichi 467-8525 (JP)**
- **SAKURAI, Toshiyuki**
**Nagoya-shi**
**Aichi 467-8525 (JP)**
- **NARITA, Saori**
**Nagoya-shi**
**Aichi 467-8525 (JP)**
- **SEGAWA, Masayuki**
**Nagoya-shi**
**Aichi 467-8525 (JP)**
- **IKAI, Yoshihito**
**Nagoya-shi**
**Aichi 467-8525 (JP)**
- **MITSUOKA, Takeshi**
**Nagoya-shi**
**Aichi 467-8525 (JP)**

(74) Representative: **Grünecker, Kinkeldey, Stockmair & Schwanhäusser**
**Leopoldstrasse 4**
**80802 München (DE)**

# (54) GLOWPLUG, PRODUCTION METHOD THEREOF AND HEATING DEVICE

(57) A glow plug (1) includes a cylindrical tube (7) which has a closed front end portion, a heating coil (9) which is inserted into the inside of the tube (7), and a seal portion (11) which is formed on a rear-end-side opening of the tube (7) and seals the inside of the tube (7). The heating coil (9) is made of a metal material containing W or Mo as a main component, and the tube (7) is made of an alloy containing 0.5 mass% or more and 5.0 mass% or less of Al and 20 mass% or more and 40 mass% or less of Cr. By allowing the tube (7) to contain a predetermined quantity or more of Al or Cr, the oxidation resistance of the tube (7) can be enhanced and, at the same time, an oxygen partial pressure inside the tube (7) is lowered and hence, the oxidation of the heating coil (9) can be suppressed. As a result, durability of both the heating coil (9) and the tube (7) can be enhanced and hence, a glow plug can realize the heat generation at a higher temperature over a long period.

FIG.2A

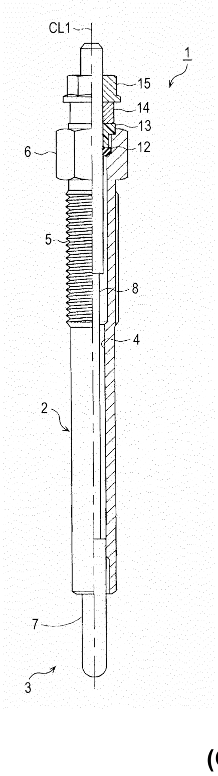


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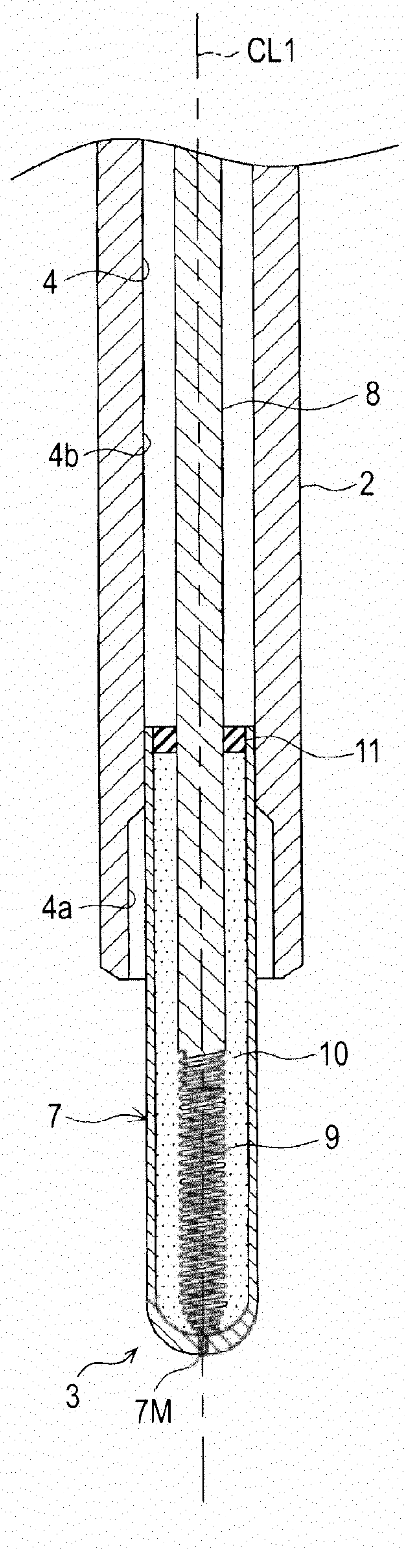
FIG.2B



**Description**

TECHNICAL FIELD

**[0001]** The present invention relates to a glow plug used for preheating of a diesel engine and the like, and a heating device.

BACKGROUND ART

**[0002]** As a glow plug used for preheating or the like a diesel engine in general, there has been known a glow plug which has the sheath heater structure. The sheath heater structure is formed by sealing a heating resistor made of an alloy containing chromium (Cr), aluminum (Al) or the like in addition to iron (Fe) and nickel (Ni) which are main components, together with insulation powder, in the inside of a tube which is made of an alloy containing iron (Fe) and nickel (Ni) as main components and is formed in a cylindrical shape with a closed front end.

**[0003]** Recently, to realize the further reduction of emission or the like, there has been a demand for the further elevation of a temperature in the inside of a combustion chamber. To satisfy this demand, heat may be generated by a glow plug at a higher temperature (for example, setting a temperature of a surface of a tube to 1150°C or more). However, since the temperature difference between a temperature of a surface of the tube and a temperature of the heating resistor is approximately 300°C, to heat the glow plug at a higher temperature, it is necessary to heat the heating resistor at an extremely high temperature (for example, 1450°C or more). However, a melting point of a conventionally-used alloy containing Fe and Ni as main components is around 1500°C. Accordingly, when the heating resistor is heated up to the above-mentioned extremely high temperature, there is a possibility of giving rise to a drawback such as melting of the heating resistor.

**[0004]** In view of the above, to realize the enhancement of heat resistance, a heating resistor may be made of tungsten (W) or molybdenum (Mo) which has a high melting point (see patent document 1 and the like, for example).

Prior art document

Patent document

**[0005]**

Patent document 1: JP-A-58-158425

SUMMARY OF THE INVENTION

Problems that the Invention is to Solve

**[0006]** However, W and Mo have a property that these components are extremely likely to be oxidized and hence, W or Mo reacts with oxygen present inside the tube thus giving rise to a possibility that the heating resistor is rapidly degraded.

**[0007]** Further, to realize the heat generation of the glow plug at a higher temperature, it is necessary to enhance durability of the tube per se besides durability of heating resistor. However, Fe and Ni are likely to be oxidized under high temperature and hence, there exists a possibility that the tube made of an alloy which does not sufficiently contain Al or Cr while containing Fe and Ni as main components cannot have sufficient durability.

**[0008]** The present invention has been made under such circumstances, and it is an object of the present invention to provide a glow plug which has a heating resistor made of a metal material which contains W or Mo as a main component, wherein durability of both the heating resistor and a tube can be enhanced so that the heat generation at a higher temperature can be realized over a long period, a manufacturing method of the glow plug, and a heating device provided with the glow plug.

Means for Solving the Problems

**[0009]** Hereinafter, the respective constitutions suitable for achieving the above-mentioned object are explained in accordance with paragraphs. The manner of operation and advantageous effects peculiar to the corresponding constitutions are described when necessary.

Constitution 1

**[0010]** A heating device having this constitution includes:

a glow plug which has a heating resistor thus constituting a heating part; and
a energization control device which is configured to adjust electric power to be supplied to the heating resistor, and is capable of controlling the heat generation of the heating resistor by adjusting the electric power to be supplied, wherein
the energization control device supplies the electric power to the heating resistor such that a temperature of the heating part is elevated to 1000°C from a normal temperature within 3 seconds,
the glow plug includes;

a cylindrical tube which has a closed front end portion and constitutes the heating part in a state where the heating resistor is inserted into the inside of the tube; and
a seal portion which is provided at a rear-end-side opening of the tube and brings the inside of the tube into a sealed state,

the heating resistor is made of a metal material containing W or Mo as a main component, and
the tube is made of an alloy containing 0.5 mass% or more and 5.0 mass% or less of Al and 20 mass% or more and 40 mass% or less of Cr.

**[0011]** Here, "heating part" means the tube into which the heating resistor is inserted. However, a portion of a surface of the tube where a temperature becomes the highest due to the energization of the heating resistor may be employed as a portion corresponding to "heating part".

**[0012]** According to the above-mentioned constitution 1, the heating resistor is made of the metal material which contains W or Mo having a high melting point as a main component and hence, the heating resistor having excellent heat resistance can be realized.

**[0013]** On the other hand, as described previously, there exists a possibility that oxidation resistance is lowered due to the use of W or Mo. According to the above-mentioned constitution 1, however, the tube contains 0.5 mass% or more of Al and 20 mass% or more of Cr. Accordingly, at the time of heat generation, Al or Cr which is more likely to be oxidized than W or Mo functions as an oxygen getter element and hence, an oxide film made of $Al_2O_3$ or $Cr_2O_3$ is formed on an inner peripheral surface of the tube. Since the inside of the tube is in a sealed state, an oxygen partial pressure inside the tube can be effectively lowered. As a result, the oxidation of the heating resistor containing W or Mo as a main component can be more surely prevented.

**[0014]** Further, by allowing the tube to contain a predetermined quantity or more of Al or Cr, an oxide film made of $Al_2O_3$ or $Cr_2O_3$ can be formed on an outer surface of the tube over a broad range. The intrusion of oxygen into the inside of the tube can be more surely suppressed due to the oxide film and hence, the oxidation resistance of the tube can be enhanced. Further, the content of Al or Cr is set sufficiently large and hence, even when peeling-off or cracks occur in the oxide film due to thermal stress caused by the repetition of a thermal cycle, the oxide film can be formed again more surely and over a longer period.

**[0015]** As described above, according to the above-mentioned constitution 1, by allowing the tube to contain a predetermined quantity or more of Al or Cr, the oxidation of the heating resistor made of W, Mo or the like can be effectively prevented, the heating resistor can sufficiently exhibit the excellent heat resistance which W or Mo possesses, and the tube can maintain the excellent oxidation resistance for a long period. As a result, durability of both the heating resistor and the tube can be remarkably enhanced whereby the glow plug can realize the heat generation at a higher temperature over a long period.

**[0016]** Further, according to the above-mentioned constitution 1, the energization control device supplies the electric power to the heating resistor such that the temperature of the surface of the tube (heating part) is elevated to 1000°C from the normal temperature within 3 seconds. By heating the tube rapidly in this manner, thermal stress applied to the tube can be increased. Accordingly, an oxide film made of $Al_2O_3$ or $Cr_2O_3$ formed on the inner peripheral surface of the tube can be easily broken and hence, a non-oxidized metal surface is likely to be exposed from the oxide film on the inner peripheral surface of the tube. Due to the new oxidation of Al or Cr contained in the metal surface, an oxygen partial pressure inside the tube can be further reduced thus preventing the oxidation of the heating resistor made of W or the like extremely effectively.

**[0017]** When an Al content in the tube exceeds 5.0 mass% or a Cr content in the tube exceeds 40 mass%, there exists a possibility that workability of the tube is lowered. Accordingly, it is preferable to set the Al content to 5.0 mass% or less and the Cr content to 40 mass% or less.

Constitution 2

**[0018]** The heating device having this constitution is, in the above-mentioned constitution 1, characterized in that an average value of normal-temperature resistance at a portion of the heating resistor between a front end of the heating resistor and a position 6 mm away from the front end toward a rear end of the heating resistor along a center axis of the tube is set larger than an average value of the normal-temperature resistance of the whole heating resistor.

**[0019]** Here, "an average value of normal-temperature resistance at a portion of the heating resistor between a front end of the heating resistor and a position 6 mm away from the front end toward a rear end of the heating resistor along a center axis of the tube" means a value obtained by dividing the normal-temperature resistance at the portion of the heating resistor between the front end of the heating resistor and the position 6 mm away from the front end toward the rear end of the heating resistor along the center axis of the tube (front-end-side heating body) by a length of the front-end-side heating body along the center axis of the tube (that is, the normal-temperature resistance of the front-end-side heating body per unit length along the center axis of the tube). Further, "average value of the normal-temperature resistance of the whole heating resistor" means a value obtained by dividing the normal-temperature resistance of the whole heating resistor by a length of the heating resistor along the center axis of the tube (that is, normal-temperature resistance of the heating resistor per unit length along the center axis of the tube) (same definition being applicable hereinafter).

**[0020]** In a state where a glow plug is assembled to an internal combustion engine, in general, a portion of the tube between a front end and a position approximately 4 mm away from the front end toward a rear end (hereinafter referred to as "exposed portion") is arranged in the inside of the combustion chamber by projecting into a combustion chamber from an inner wall of the combustion chamber. Accordingly, the temperature of the exposed portion is likely to become higher at the time of heat generation compared to other portions of the tube around which constitutional parts of the internal combustion engine are positioned. Further, the temperature of the exposed portion is more rapidly elevated compared to other portions of the tube, and the exposed portion is also rapidly cooled and hence, the exposed portion is likely to be subjected to a sudden temperature change. Accordingly, at the time of supplying electric power to the heating resistor, by particularly elevating the temperature of the exposed portion, the temperature of the tube can be elevated higher, and it is possible to cause a rapid temperature change in the tube. By setting the temperature of the tube higher or by causing the rapid temperature change in the tube, thermal stress which occurs in the tube can be further increased and hence, an oxide film made of $Al_2O_3$ or $Cr_2O_3$ formed on an inner peripheral surface of the tube can be more easily broken. As a result, an oxidation prevention effect of the heating resistor by the above-mentioned constitution 1 can be further enhanced.

**[0021]** In view of the above-mentioned point, according to the above-mentioned constitution 2, the average value of the normal-temperature resistance at the portion of the heating resistor between the front end of the heating resistor and the position 6 mm away from the front end toward the rear end of the heating resistor along the center axis of the tube (front-end-side heating body) is set larger than the average value of the normal-temperature resistance of the whole heating resistor. By setting the average value of the normal-temperature resistance of the front-end-side heating body larger than the average value of the normal-temperature resistance of the whole heating resistor, the temperature of a portion of the tube at the position approximately 2 mm away from the front end toward the rear end (that is, a center portion of the exposed portion and an area around the center portion) can be positively elevated. Accordingly, due to the above-mentioned constitution 2, the temperature of the tube can be elevated higher, and it is also possible to cause a rapid temperature change in the tube. As a result, thermal stress which is generated in the tube can be further increased leading to the further enhancement of an oxidation prevention effect of the heating resistor.

**[0022]** Further, to rapidly elevate the temperature in the combustion chamber, it is desirable to particularly elevate the temperature of the exposed portion. Accordingly, the above-mentioned constitution 2 has significance also in this respect.

Constitution 3

**[0023]** The heating device having this constitution is, in the above-mentioned constitution 1 or 2, characterized in that the heating resistor is formed into a coil shape, a wire diameter of the heating resistor is 0.2 mm or more, and an average pitch of a portion of the heating resistor between the front end of the heating resistor and the position 6 mm away from the front end toward the rear end of the heating resistor along the center axis of the tube is set smaller than an average pitch of a portion of the heating resistor positioned on a more rear end side than the position 6 mm away from the front end toward the rear end of the heating resistor along the center axis of the tube by 0.9 mm or more.

**[0024]** Here, "average pitch" means, in a cross section which includes the center axis (coil axis) of the heating resistor, an average of a distance (pitch) between the centers of cross sections of neighboring heating resistors along the center axis (coil axis) (the same definition being applicable hereinafter).

**[0025]** According to the above-mentioned constitution 3, the average pitch at the portion of the heating resistor between the front end and the position 6 mm away from the front end toward the rear end (front-end-side heating body) is set smaller than the average pitch at the portion of the heating resistor positioned on the more rear end side than the portion of the heating resistor 6 mm away from the front end (rear-end-side heating body) by 0.9 mm or more. Accordingly, without making the front-end-side heating body excessively thin (by maintaining a wire diameter of the heating resistor to 0. 2 mm or more), the average value of the normal-temperature resistance of the front-end-side heating body can be set sufficiently large compared to the average value of the normal-temperature resistance of the whole heating resistor. That is, according to the above-mentioned constitution 3, it is possible to further rapidly elevate the temperature of the exposed portion while sufficiently maintaining mechanical strength of the heating resistor. As a result, an oxidation prevention effect of the heating resistor can be further enhanced.

**[0026]** Further, it is unnecessary to make the front-end-side heating body excessively thin and hence, the heating resistor can be manufactured relatively easily thus preventing lowering of productivity more reliably.

Constitution 4

**[0027]** The heating device having this constitution is, in any one of the above-mentioned constitutions 1 to 3, characterized in that the glow plug includes insulation powder which is filled in the tube and around the periphery of the heating resistor, and

the insulation powder is powder which contains magnesium oxide (MgO) as a main component.

**[0028]** According to the above-mentioned constitution 4, since MgO which exhibits excellent thermal conductivity is used as the insulation powder, the thermal conductivity from the heating resistor to the tube can be enhanced. As a result, it is possible to make the glow plug (heating part) generate heat at a higher temperature without excessively elevating a temperature of the heating resistor.

**[0029]** Further, since the temperature of the tube (heating part) can be set higher, thermal stress applied to the tube can be further increased whereby an oxide film made of $Al_2O_3$ or $Cr_2O_3$ formed on the inner peripheral surface of the tube can be more easily broken. Accordingly, an unoxidized metal surface is more likely to be exposed on the inner peripheral surface of the tube and hence, an oxygen partial pressure inside the tube can be lowered more effectively due to the oxidation of Al or Cr contained in the metal surface.

**[0030]** Further, while MgO is likely to form a composite oxide between MgO and $Al_2O_3$ or $Cr_2O_3$ formed on the inner peripheral surface of the tube, the composite oxide is extremely coarse compared to an oxide film made of $Al_2O_3$ or the like. Accordingly, Al or Cr contained in the tube and oxygen present inside the tube more easily react with each other and hence, an oxygen partial pressure inside the tube can be further lowered.

**[0031]** Due to a synergistic action of favorable heat conductivity which is property that MgO possesses and property of MgO that MgO easily forms a composite oxide with $Al_2O_3$ or the like, an oxygen partial pressure inside the tube can be reduced extremely effectively. As a result, durability of the heating resistor can be further enhanced whereby the heat generation at a higher temperature can be realized over a further prolonged period with respect to the glow plug.

Constitution 5

**[0032]** The heating device having this constitution is, in any one of the above-mentioned constitutions 1 to 4, characterized in that the seal portion is made of a material having oxygen permeability of $2.0\times10^{-9}$ ($cm^3\cdot cm/sec\cdot cm^2\cdot cmHg$) or less.

**[0033]** According to the above-mentioned constitution 5, the oxygen permeability of the seal portion is set to a sufficiently small value of $2.0\times10^{-9}$ or less. Accordingly, it is possible to effectively prevent the intrusion of oxygen into the inside of the tube without excessively increasing a thickness of the seal portion.

Constitution 6

**[0034]** The heating device having this constitution is, in any one of the above-mentioned constitutions 1 to 5, characterized in that a front end portion of the heating resistor is joined to a front end portion of the tube, and

the front end portion of the tube does not contain W, but contains Cr whose content is equal to or more than a content of Cr in the metal material.

**[0035]** The metal material used for forming the heating resistor may contain Cr or may not contain Cr.

**[0036]** There has been known a glow

plug where a front end portion of a heating resistor is joined to a front end portion of a tube. Here, as a technique for joining the heating resistor to the tube, there has been known a technique in which the heating resistor is inserted into the tube with the front end portion in an open state, and the front end portion of the tube and the front end portion of the heating resistor are welded to each other while closing the front end portion of the tube by arc welding or the like. When the heating resistor which contains W as a main component is joined to the front end portion of the tube using this technique, there exists a possibility that the front end portion of the tube may contain W. When the front end portion (particularly outer surface) of the tube contains W, W is rapidly oxidized so that there exists a possibility that the tube is broken.

**[0037]** In this respect, according to the above-mentioned constitution 6, the front end portion of the tube is formed such that the front end portion does not contain W, but contains Cr whose content is equal to or more than the content of Cr in the heating resistor (the heating resistor may not contain Cr). Accordingly, the occurrence of the above-mentioned drawback attributed to the containing of W can be prevented, and an oxide film made of $Cr_2O_3$ can be more surely formed on a surface of the front end portion of the tube due to contained Cr. As a result, it is possible to realize the sufficiently excellent durability at the front end portion of the tube thus preventing breaking of the tube more reliably.

**[0038]** In realizing the above-mentioned constitution 6 while joining the front end portion of the tube and the front end portion of the heating resistor by the above-mentioned technique, it is possible to name a technique where, for example, a metal piece which contains Cr while not containing W is welded to the front end portion of the heating resistor in advance, and the metal piece and the front end portion of the tube are welded to each other.

Constitution 7

**[0039]** A glow plug having this constitution includes:

a cylindrical tube with a closed front end portion;
a heating resistor which is inserted into the inside of the tube; and
a seal portion which is formed on a rear-end-side opening of the tube and seals the inside of the tube, wherein
the heating resistor is made of a metal material containing W or Mo as a main component, and
the tube is made of an alloy containing 0.5 mass% or more and 5.0 mass% or less of Al and 20 mass% or more and 40 mass% or less of Cr.

**[0040]** According to the above-mentioned constitution 7, basically, the manner of operation and advantageous effects substantially equal to the manner of operation and the advantageous effects of the above-mentioned constitution 1 can be acquired. That is, by allowing the tube to contain a predetermined quantity or more of Al or Cr, oxidation of the heating resistor made of W, Mo or the like can be effectively prevented whereby the heating resistor can sufficiently exhibit excellent heat resistance which W or Mo possesses, and the tube can maintain excellent oxidation resistance over a long period. As a result, durability of both the heating resistor and the tube can be remarkably enhanced whereby the heat generation of the glow plug at a higher temperature can be realized over a long period.

Constitution 8

**[0041]** The glow plug having this constitution is, in the above-mentioned constitution 7, characterized in that an average value of normal-temperature resistance at a portion of the heating resistor between a front end of the heating resistor and a position 6 mm away from the front end toward a rear end of the heating resistor along a center axis of the tube is set larger than an average value of the normal-temperature resistance of the whole heating resistor.

**[0042]** According to the above-mentioned constitution 8, basically, the manner of operation and advantageous effects substantially equal to the manner of operation and advantageous effects of the above-mentioned constitution 2 can be acquired.

Constitution 9

**[0043]** The glow plug having this constitution is, in the above-mentioned constitution 7 or 8, characterized in that the heating resistor is formed into a coil shape, a wire diameter of the heating resistor is 0.2 mm or more, and
an average pitch of a portion of the heating resistor between the front end of the heating resistor and the position 6 mm away from the front end toward the rear end of the heating resistor along the center axis of the tube is set smaller than an average pitch of a portion of the heating resistor positioned on a more rear end side than the position 6 mm away from the front end toward the rear end of the heating resistor along the center axis of the tube by 0.9 mm or more.

**[0044]** According to the above-mentioned constitution 9, basically, the manner of operation and advantageous effects substantially equal to the manner of operation and advantageous effects of the above-mentioned constitution 3 can be acquired.

Constitution 10

**[0045]** The glow plug having this constitution is, in any one of the above-mentioned constitutions 7 to 9, characterized in that the glow plug includes insulation powder which is filled in the tube and around the periphery of the heating resistor,

and
the insulation powder is powder which contains MgO as a main component.

**[0046]** According to the above-mentioned constitution 10, basically, the manner of operation and advantageous effects substantially equal to the manner of operation and the advantageous effects of the above-mentioned constitution 4 can be acquired.

Constitution 11

**[0047]** The glow plug having this constitution is, in any one of the above-mentioned constitutions 7 to 10, characterized in that the seal portion is made of a material having oxygen permeability of $2.0 \times 10^{-9}$ ($cm^3 \cdot cm/sec \cdot cm^2 \cdot cmHg$) or less.

**[0048]** According to the above-mentioned constitution 11, basically, the manner of operation and advantageous effects substantially equal to the manner of operation and the advantageous effects of the above-mentioned constitution 5 can be acquired.

Constitution 12

**[0049]** The glow plug having this constitution is, in any one of the above-mentioned constitutions 7 to 11, characterized in that a front end portion of the heating resistor is joined to a front end portion of the tube, and
the front end portion of the tube does not contain W, but contains Cr whose content is equal to or more than a content of Cr in the metal material.

**[0050]** According to the above-mentioned constitution 12, basically, the manner of operation and advantageous effects substantially equal to the manner of operation and the advantageous effects of the above-mentioned constitution 6 can be acquired.

Constitution 13

**[0051]** A method of manufacturing a glow plug according to this constitution, which includes: a cylindrical tube with a closed front end portion; a heating resistor which is inserted into the inside of the tube; and a seal portion which is formed on a rear-end-side opening of the tube and seals the inside of the tube, the method of manufacturing a glow plug including the steps of:

arranging the heating resistor made of a metal material containing W or Mo as a main component in the tube which is made of an alloy containing 0.5 mass% or more and 5.0 mass% or less of Al and 20 mass% or more and 40 mass% or less of Cr;
sealing the inside of the tube by forming the seal portion on the rear-end-side opening of the tube; and
heating an outer surface of the tube after the sealing step.

**[0052]** According to the above-mentioned constitution 13, the outer surface of the tube is heated in the heating step after the sealing step and hence, it is possible to allow Al or Cr in the inside of the tube to positively react with oxygen present inside the tube prior to the material of the heating resistor. As a result, an oxygen partial pressure inside the tube can be further lowered while suppressing the oxidation of the heating resistor thus further enhancing durability of the heating resistor.

**[0053]** Here, when a heating temperature of the outer surface of the tube is excessively low or when a heating time is excessively short, there exists a possibility that oxidation of Al or Cr in the tube is not sufficiently promoted. Further, when the heating temperature is excessively high or when the heating time is excessively long, there also exists a possibility that the seal portion is broken. Accordingly, to prevent the breaking of the seal portion while promoting the oxidation of Al or Cr more surely, it is preferable to set the heating temperature to 700°C or more and 1300°C or less and the heating time to 1 second or more and 60 seconds or less. It is more preferable to set the heating temperature to 800°C or more and 1300°C or less and the heating time to 3 seconds or more and 30 seconds or less.

BRIEF DESCRIPTION OF THE DRAWINGS

**[0054]**

Fig. 1 is a block diagram showing the schematic constitution of a heating device;
Fig. 2(a) is a front view with a part broken away of a glow plug, and Fig. 2(b) is a partially enlarged cross-sectional view of a front end portion of the glow plug;
Fig. 3 is a partially enlarged cross-sectional view for explaining a method of joining a front end portion of a tube and

a front end portion of a heating coil;

Fig. 4 is a partially enlarged cross-sectional view showing the constitution of a heating coil and the like according to a second embodiment;

Fig. 5 is an enlarged view with a part broken away showing a glow plug and the like assembled in an internal combustion engine;

Fig. 6 is a partially enlarged cross-sectional view showing the constitution of a heating coil and the like according to a third embodiment;

Fig. 7(a) and Fig. 7(b) are partially enlarged cross-sectional views showing the constitution of samples; and

Fig. 8(a) and Fig. 8(b) are partially enlarged cross-sectional views showing the constitution of samples.

## MODE FOR CARRYING OUT THE INVENTION

**[0055]** Hereinafter, embodiments of the present invention are explained in conjunction with drawings.

[First embodiment]

**[0056]** Fig. 1 is a block diagram showing the schematic constitution of a heating device 21 according to the present invention.

**[0057]** The heating device 21 includes a glow plug 1 and a glow control unit (GCU) 31 which constitutes an energization control device for controlling the electric power to the glow plug 1. Although only one glow plug 1 is shown in Fig. 1, a plurality of cylinders are provided to an actual engine, and the glow plug 1 and a switch 33 described later are provided corresponding to each cylinder.

**[0058]** The GCU 31 is operated with electric power supplied from a battery VA, and includes a microcomputer 32 having a CPU, a ROM, a RAM and the like, and the switch 33 which turns on or off the electric power supply to the glow plug 1 from the battery VA.

**[0059]** The energization control executed by the GCU 31 for controlling the electric power to the glow plug 1 is performed in accordance with a PWM control, and the switch 33 is configured to turn on or off the electric power to the glow plug 1 in accordance with an instruction from the microcomputer 32.

**[0060]** Further, in this embodiment, to measure a resistance value of the glow plug 1, the switch 33 is configured to operate an FET (field effect transistor) having a current detection function via an NPN-type transistor or the like. In addition to such a constitution, the microcomputer 32 is connected to a power supply terminal of the glow plug 1 via a voltage dividing resistor (not shown in the drawing) so that a voltage obtained by dividing a voltage applied to the glow plug 1 (voltage outputted from the GCU 31) is inputted to the microcomputer 32. The microcomputer 32 can calculate a voltage applied to the glow plug 1 based on a voltage inputted to the microcomputer 32. Further, the microcomputer 32 obtains a resistance value of the glow plug 1 based on the applied voltage and an electric current which is measured by the switch 33 and flows in the glow plug 1.

**[0061]** Further, the microcomputer 32 according to this embodiment is configured to perform pre-glow energization for rapidly elevating a temperature of the glow plug 1 when an engine key is turned to an ON position and after-glow energization for maintaining a temperature of the glow plug 1 at a predetermined temperature for a predetermined time after the pre-glow power supply.

**[0062]** In this embodiment, in the pre-glow energization, electric power is supplied to the glow plug 1 such that a temperature of a surface of a tube 7 of the glow plug 1 (described later) is elevated to 1000°C from a normal temperature within 3 seconds thus rapidly elevating a temperature of the glow plug 1 to a predetermined target temperature.

**[0063]** In this pre-glow energization, by making a curve showing the relationship between electric power supplied to the glow plug 1 and a lapsed time agree with a preset reference curve, the temperature of the glow plug 1 is rapidly elevated to the target temperature without depending on properties of the glow plug 1. To be more specific, using a relational formula or a table indicative of the above-mentioned preset reference curve, electric power to be supplied at respective points of time corresponding to times lapsed from starting the electric power is obtained. A voltage to be applied to the glow plug 1 is obtained based on the relationship between an electric current which flows in the glow plug 1 and a value of electric power to be supplied at such points of time, and the voltage to be applied to the glow plug 1 is controlled in accordance with a PWM control. Accordingly, the electric power is supplied so as to draw the same curve as the reference curve, and the glow plug 1 generates heat corresponding to a cumulative amount of electric power supplied until respective points of time in the course of temperature elevation. Accordingly, when the supply of electric power along the above-mentioned reference curve is completed, the glow plug 1 reaches the target temperature at a time set in accordance with the reference curve.

**[0064]** Further, in the after-glow energization, the supply of electric power to the glow plug 1 is adjusted such that a surface temperature of the tube 7 becomes an extremely high temperature of 1150°C or more during a relatively long period (for example, approximately 180 seconds).

**[0065]** In this after-glow energization, the power supply to the glow plug 1 is controlled such that a resistance value of the glow plug 1 agrees with a resistance value (target resistance value) when the temperature of the glow plug 1 is set to a target temperature. To be more specific, an effective voltage to be applied to the glow plug 1 is calculated based on the difference between a current resistance value of the glow plug 1 and a target resistance value of the glow plug 1 in accordance with a PI control, for example, and a duty ratio is set based on the effective voltage. Since a temperature of the surface of the tube 7 is maintained at a high temperature of 1150°C or more, the reduction of emission or the like can be realized at the time of after-glow energization.

**[0066]** Next, the constitution of the glow plug 1 to which the energization control is applied by the above-mentioned GCU 31 is explained in detail. As shown in Fig. 2 (a), 2(b), the glow plug 1 includes a main fitting 2 having a cylindrical shape and a sheath heater 3 mounted on the main fitting 2.

**[0067]** The main fitting 2 has an axial hole 4 which penetrates the main fitting 2 in an axis CL1 direction and, on an outer peripheral surface of the main fitting 2, a threaded portion 5 for mounting the glow plug 1 on a diesel engine or the like, and a tool engaging portion 6 having a hexagonal cross section for engagement with a tool such as a torque wrench are formed.

**[0068]** The sheath heater 3 is formed as an integral body constituted of the tube 7 and an intermediate shaft 8 arranged in the axis CL1 direction.

**[0069]** The tube 7 is a cylindrical tube which is made of a metal material which contains iron (Fe) or nickel (Ni) as a main component and has a closed front end portion. Further, in the inside of the tube 7, a heating coil 9 made of a predetermined metal material (corresponding to "heating resistor" of the present invention) is arranged. A front end portion of the heating coil 9 is joined to the front end portion of the tube 7 (the metal material for forming the tube 7 and the metal material for forming the heating coil 9 are described in detail later).

**[0070]** The tube 7 is configured such that the front end portion of the tube 7 is closed when the heating coil 9 is joined to the tube 7, while the front end portion of the tube 7 is in an opened state before the heating coil 9 is joined to the tube 7. In this embodiment, a metal piece MP (see Fig. 3) described later is welded to the front end portion of the heating coil 9 in advance and, thereafter, the metal piece MP is arranged at a front end opening of the tube 7, and the metal piece MP or the like is melted by arc welding or the like and hence, the front end portion of the tube 7 is closed, and also the front end portion of the heating coil 9 is joined to the front end portion of the tube 7. Accordingly, a melted portion 7M is formed on the front end portion of the tube 7.

**[0071]** In this embodiment, the metal piece MP is made of the same metal material as the metal material for forming the tube 7. Further, although the tube 7 into which the heating coil 9 is inserted corresponds to "heating portion" according to the present invention, a portion of a surface of the tube 7 which acquires the highest temperature due to the supply of electric power (in this embodiment, a portion of the tube 7 positioned 2 mm away from a front end toward a rear end side of the tube 7) may correspond to "heating portion".

**[0072]** Further, insulation powder 10 is filled in the tube 7 and around the heating coil 9. Accordingly, although the heating coil 9 is made electrically conductive with the tube 7 at the front end thereof, an outer peripheral surface of the heating coil 9 and an inner peripheral surface of the tube 7 are brought into an insulation state due to the presence of the insulation powder 10 therebetween.

**[0073]** Further, a rear end of the tube 7 is sealed by an annular seal portion 11 between the tube 7 and the intermediate shaft 8 thus bringing the inside of the tube 7 into a sealed state.

**[0074]** A large-diameter portion 4a is formed on a front end portion of the shaft hole 4, and a small-diameter portion 4b is formed on a rear end side of the large-diameter portion 4a. By press-fitting the tube 7 into the small-diameter portion 4b of the shaft hole 4, the tube 7 is held in a state where the tube 7 projects from a front end portion of the main fitting 2.

**[0075]** A front end of the intermediate shaft 8 is inserted into the tube 7 and is electrically connected with a rear end of the heating coil 9. The intermediate shaft 8 is also inserted into the shaft hole 4 formed in the main fitting 2. A rear end of the intermediate shaft 8 projects from a rear end of the main fitting 2, and an O ring 12 made of rubber or the like, an insulation bushing 13 made of a resin or the like, a pusher ring 14 for preventing the removal of the insulation bushing 13, and a nut 15 for connecting a power supply cable are fitted on the intermediate shaft 8 in this order at the rear end portion of the main fitting 2.

**[0076]** Next, composition of the metal material for forming the heating coil 9, the composition of the metal material for forming the tube 7 and the like are explained.

**[0077]** In this embodiment, the heating coil 9 is made of a metal material which contains tungsten (W) or molybdenum (Mo) as a main component [in this embodiment, pure metal of W or Mo (pure metal may contain unavoidable impurities)].

**[0078]** Further, the tube 7 is made of a metal material which contains Ni or Fe as a main component, and contains 0.5 mass% or more and 5.0 mass% or less of aluminum (Al) and 20 mass% or more and 40 mass% or less of chromium (Cr). In this embodiment, a Cr content in the tube 7 is set larger than a Cr content in the heating coil 9, and the tube 7 does not contain W.

**[0079]** The insulation powder 10 is formed of powder which contains magnesium oxide (MgO) as a main component.

**[0080]** Further, the seal portion 11 is made of an elastic material having oxygen permeability of $2.0 \times 10^{-9}$

($cm^3 \cdot cm/sec \cdot cm^2 \cdot cmHg$) or less [for example, ethylene propylene rubber (EPDM rubber), fluoro-rubber or the like]. A thickness of the seal portion 11 along the axis CL1 direction is set relatively small (for example, 10 mm or less).

**[0081]** Further, the melted portion 7M (the front end portion of the tube 7) is formed by melting of the tube 7 and the metal piece MP which are made of the same material and hence, the melted portion 7M does not contain W at least in an outer surface thereof. Further, the melting portion 7M contains Cr whose content is equal to or more than the content of Cr in a metal material which forms the heating coil 9 (the heating coil 9 according to this embodiment does not contain Cr).

**[0082]** Next, a manufacturing method of the above-mentioned glow plug 1 is explained. Parts which are not specified are formed using a conventionally known method.

**[0083]** Firstly, a resistance heating wire which contains W or Mo as a main component is formed into a coil shape thus manufacturing the heating coil 9. The cylindrical tube 7 whose front end is not closed is manufactured using a metal material which contains Ni or Fe as a main component, and contains 0.5 mass% to 5.0 mass% of Al and 20 mass% to 40 mass% of Cr.

**[0084]** Next, as shown in Fig. 3, the metal piece MP made of the same metal material as the metal material for forming the tube 7 is joined to the front end portion of the heating coil 9 and, thereafter, in an arrangement step, a front end of the intermediate shaft 8 and the heating coil 9 which is integrally formed with the intermediate shaft 8 are arranged in the inside of the cylindrical tube 7. Then, the metal piece MP is arranged at the front end opening of the tube 7 and, thereafter, the metal piece MP and the tube 7 are melted by arc welding or the like thus closing the front end portion of the tube 7 and also joining the front end portion of the tube 7 and the front end portion of the heating coil 9 to each other.

**[0085]** Thereafter, the insulation powder 10 is filled in the inside of the tube 7, and the seal portion 11 is arranged between the rear end opening of the tube 7 and the intermediate shaft 8 in a sealing step thus sealing the inside of the tube 7. Accordingly, the tube 7 is integrally formed with the intermediate shaft 8 thus completing the sheath heater 3. After sealing the inside of the tube 7, swaging may be applied to the front end portion of the tube 7 thus narrowing a diameter of the front end portion of the tube 7. Packing density of the insulation powder 10 can be further increased by applying swaging.

**[0086]** Finally, the sheath heater 3 formed in the above-mentioned manner is fixed to the shaft hole 4 formed in the main fitting 2 by press-fitting, and the above-mentioned O ring 12, insulation bushing 13 and the like are fitted on the intermediate shaft 8 at the rear end portion of the main fitting 2. Accordingly, the above-mentioned glow plug 1 is acquired.

**[0087]** In the acquired glow plug 1, preheating for heating the outer surface of the tube 7 may be performed. In preheating, the glow plug 1 is heated by an electric furnace or a high-frequency heating device for 1 second to 30 seconds until a temperature of the outer surface of a portion of the tube 7 where the heating coil 9 is positioned (for example, a range from the front end of the tube 7 to a position 1 mm away from the front end of the tube 7 toward a rear end side in the axis CL1 direction) becomes 800°C to 1300°C.

**[0088]** As has been described in detail heretofore, according to this embodiment, the heating coil 9 is made of the metal material which contains W or Mo having a high melting point as the main component and hence, the heating coil 9 having excellent heat resistance can be realized.

**[0089]** On the other hand, there exists a possibility that oxidation resistance is lowered due to the use of W or Mo. According to this embodiment, however, the tube 7 contains 0.5 mass% or more of Al and 20 mass% or more of Cr. Accordingly, at the time of heat generation, Al or Cr which is more likely to be oxidized than W or Mo functions as an oxygen getter element and hence, an oxide film made of $Al_2O_3$ or $Cr_2O_3$ is formed on an inner peripheral surface of the tube 7. Since the inside of the tube 7 is in a sealed state, an oxygen partial pressure inside the tube 7 can be effectively lowered. As a result, the oxidation of the heating coil 9 containing W or Mo as a main component can be more surely prevented.

**[0090]** Further, by allowing the tube 7 to contain a predetermined quantity or more of Al or Cr, an oxide film made of $Al_2O_3$ or $Cr_2O_3$ can be formed on an outer surface of the tube 7 over a broad range. The intrusion of oxygen into the inside of the tube 7 can be more surely suppressed due to the oxide film and hence, the oxidation resistance of the tube 7 can be enhanced. Further, the content of Al or Cr is set sufficiently large and hence, even when peeling-off or cracks occur in the oxide film due to thermal stress caused by the repetition of a thermal cycle, the oxide film can be formed again more surely over a longer period.

**[0091]** As described above, according to this embodiment, by allowing the tube 7 to contain a predetermined quantity or more of Al or Cr, the oxidation of the heating coil 9 made of W, Mo or the like can be effectively prevented and hence, the heating coil 9 can sufficiently exhibit the excellent heat resistance which W or Mo possesses, and the tube 7 also can maintain the excellent oxidation resistance for a long period. As a result, durability of both the heating coil 9 and the tube 7 can be remarkably enhanced whereby the glow plug 1 can realize the heat generation at a higher temperature over a long period.

**[0092]** Further, the GCU 31 supplies electric power to the heating coil 9 such that the temperature of the surface (heating part) of the tube 7 is elevated from the normal temperature to 1000°C within 3 seconds and hence, thermal stress applied to the tube 7 can be increased. Accordingly, an oxide film made of $Al_2O_3$ or $Cr_2O_3$ formed on the inner peripheral surface of the tube 7 can be easily broken and hence, a non-oxidized metal surface is likely to be exposed from the oxide film on the inner peripheral surface of the tube 7. Due to the new oxidation of Al or Cr contained in the metal surface, an oxygen partial pressure inside the tube 7 can be further reduced thus preventing the oxidation of the heating coil 9 made of W or the like extremely effectively.

**[0093]** Particularly, in this embodiment, in the after-glow energization, a surface temperature (heating part) of the tube 7 becomes an extremely high temperature of 1150°C or more, and this condition makes the heat generation over a long period difficult. However, due to a synergistic action of the above-mentioned manner of operations and advantageous effects, the heat generation even at such a high temperature can be realized over a long period. In other words, the present invention particularly exhibits the significance when the temperature of the surface (heating part) of the tube 7 becomes an extremely high temperature of 1150°C or more in the after-glow energization which is performed for a relatively long period.

**[0094]** Further, since MgO which exhibits excellent thermal conductivity is used as the insulation powder 10, the thermal conductivity from the heating coil 9 to the tube 7 can be enhanced. As a result, it is possible to make the glow plug 1 (tube 7) generate heat at a higher temperature without excessively elevating a temperature of the heating coil 9.

**[0095]** Further, since the temperature of the tube 7 can be set higher, thermal stress applied to the tube 7 can be further increased whereby an oxide film made of $Al_2O_3$ or $Cr_2O_3$ formed on the inner peripheral surface of the tube 7 can be more easily broken. Accordingly, an unoxidized Al or Cr is more likely to be exposed on the inner peripheral surface of the tube 7 and hence, an oxygen partial pressure inside the tube 7 can be lowered more effectively.

**[0096]** Further, while MgO is likely to form a composite oxide between MgO and $Al_2O_3$ or $Cr_2O_3$ formed on the inner peripheral surface of the tube 7, the composite oxide is extremely coarse compared to an oxide film made of $Al_2O_3$ or the like. Accordingly, Al or Cr contained in the tube 7 and oxygen inside the tube 7 are more likely to react with each other and hence, an oxygen partial pressure inside the tube 7 can be further lowered.

**[0097]** That is, with the use of the metal material which contains MgO as a main component as the insulation powder 10, favorable heat conductivity which is property that MgO possesses and property of MgO that Mgo is likely to form a composite oxide with $Al_2O_3$ or the like synergistically act together and hence, an oxygen partial pressure inside the tube 7 can be reduced extremely effectively. As a result, durability of the heating coil 9 can be further enhanced and hence, the glow plug 1 can generate heat at a higher temperature over a further prolonged period with respect to the glow plug 1.

**[0098]** Also the oxygen permeability of the material which forms the seal portion 11 is set to a sufficiently small value of $2.0\times10^{-9}$ or less and hence, it is possible to effectively prevent the intrusion of oxygen into the inside of the tube 7 without excessively increasing a thickness of the seal portion 11.

**[0099]** The melted portion 7M (the front end portion of the tube 7) is formed such that the melted portion 7M does not contain W at least on the outer surface thereof, and contains Cr whose content is equal to or more than a content of Cr in the metal material which forms the heating coil 9. Accordingly, the oxidation of the melted portion 7M attributed to the containing of W can be prevented, and an oxide film made of $Cr_2O_3$ can be more surely formed on the surface of the front end portion of the tube 7. As a result, it is possible to realize the sufficiently excellent durability at the front end portion of the tube 7 thus preventing breaking of the tube 7 more reliably.

**[0100]** Further, as the material for forming the heating coil 9, in general, there has been known a material which contains Cr. In this embodiment, the heating coil 9 is made of pure metal of W or Mo. Accordingly, it is possible to prevent the occurrence of a state where an oxide film of Cr is formed on a surface of the heating coil 9 so that contents of the heating coil 9 change resulting in lowering of a resistance value of the heating coil 9. As a result, durability of the heating coil 9 can be further enhanced.

**[0101]** By performing the preheating at the time of manufacturing the glow plug, it is possible to allow Al or Cr in the inside of the tube 7 to positively react with oxygen present inside the tube 7 prior to the material of the heating coil 9. As a result, an oxygen partial pressure inside the tube 7 can be further lowered while suppressing the oxidation of the heating coil 9 thus further enhancing durability of the heating coil 9.

[Second embodiment]

**[0102]** Next, the second embodiment is explained by focusing on the difference between the above-mentioned first embodiment and the second embodiment. In the second embodiment, as shown in Fig. 4, a wire diameter of a front-end-side coil 49A of a heating coil 49 which is positioned between a front end and a position 6 mm away from the front end toward a rear end of the heating coil 49 along a center axis CL2 of a tube 47 (agreeing with the axis CL1 in this embodiment) is set smaller than a wire diameter of a rear-end-side coil 49B of the heating coil 49 positioned at a more rear end side than the front-end-side coil 49A. To be more specific, a front end portion of the front-end-side coil 49A is formed such that the wire diameter of the front end portion of the front-end-side coil 49A is gradually decreased toward a front end side.

**[0103]** By setting the wire diameter of the front-end-side coil 49A smaller than the wire diameter of the rear-end-side coil 49B, an average value of normal-temperature resistance of the front-end-side coil 49A per unit length along the center axis CL2 of the tube 47 is set larger than an average value of normal-temperature resistance of the whole heating coil 49 per unit length along the center axis CL2. In this manner, by setting the average value of normal-temperature resistance of the front-end-side coil 49A larger than the average value of normal-temperature resistance of the whole heating coil 49, at the time of supplying electric power to the glow plug 1 (heating coil 49) from the battery VA, it is possible to positively elevate a temperature of a portion X of the tube 47 approximately 2 mm away from a front end of the tube 47 toward a rear end of the tube 47 and a temperature of an area in the vicinity of the portion X and hence, the portion X and the area in the vicinity of the portion X can acquire the highest temperature.

**[0104]** In a state where the glow plug 1 is mounted on an internal combustion engine EN, as shown in Fig. 5, generally, a portion 47E of the tube 47 positioned between the front end of the tube 47 and a position approximately 4 mm away from the front portion toward the rear end of the tube 47 (hereinafter referred to as "exposed portion") is arranged in the inside of a combustion chamber ER. Accordingly, it is safe to say that the portion X is positioned at the approximately center of the exposed portion 47E.

**[0105]** As has been described in detail heretofore, according to this second embodiment, a temperature of the exposed portion 47E of the tube 47 which is more likely to be elevated and is likely to be subjected to a steep temperature change can be positively elevated and hence, a temperature of the tube 47 can be elevated higher thus generating a steep temperature change in the tube 47. Accordingly, thermal stress which occurs in the tube 47 can be further increased and hence, it is possible to make an oxide film formed on an inner peripheral surface of the tube 47 more easily broken. As a result, an oxidation prevention effect of the heating coil 49 can be further enhanced.

[Third embodiment]

**[0106]** Next, the third embodiment is explained by focusing on the difference between the above-mentioned second embodiment and the third embodiment. In the second embodiment, the wire diameter of the front-end-side coil 49A is set smaller than the wire diameter of the rear-end-side coil 49B for setting the average value of normal-temperature resistance of the front-end-side coil 49A larger than the average value of normal-temperature resistance of the whole heating coil 49. On the other hand, in this third embodiment, as shown in Fig. 6 (heating coil being schematically shown in Fig. 6 to Fig. 8), an average pitch of a front-end-side coil 59A is set smaller than an average pitch of a rear-end-side coil 59B by 0.9 mm or more so as to make an average value of normal-temperature resistance of the front-end-side coil 59A sufficiently larger than an average value of normal-temperature resistance of a whole heating coil 59 (in the third embodiment, the average value of normal-temperature resistance of the front-end-side coil 59A being set twice or more larger than the average value of normal-temperature resistance of the whole heating coil 59) . Further, in this third embodiment, a wire diameter of the heating coil 59 is set to 0.2 mm or more, and the heating coil 59 is configured to have an approximately fixed wire diameter from a front end to a rear end thereof.

**[0107]** As described above, according to the third embodiment, a temperature of the exposed portion of the tube 57 can be positively elevated and hence, the further steep temperature elevation of the tube 57 or the like can be realized. Accordingly, it is possible to make an oxide film formed on an inner peripheral surface of the tube 57 more easily broken thus further enhancing an oxidation prevention effect of the heating coil 59.

**[0108]** Further, in the third embodiment, the front-end-side coil 59A can secure a sufficient diameter and hence, the heating coil 59 can sufficiently maintain a mechanical strength.

**[0109]** Still further, it is unnecessary to excessively narrow a diameter of the front-end-side coil 59A and hence, the heating coil 59 can be manufactured relatively easily thus surely preventing the lowering of productivity.

**[0110]** Next, to confirm the manner of operation and advantageous effects brought about by the above-mentioned embodiment, samples of glow plugs are prepared, wherein each heating coil is made of Fe-26Cr-7.5Al (PYROMAX), W or Mo and each tube is made of a metal material which contains Fe or Ni as a main component and varies in a content of Al or Cr, and a durability evaluation test is carried out with respect to the respective samples. To summarize the durability evaluation test, it goes as follows. That is, with respect to each sample, the number of cycles until the breaking of the heating coil occurs (breaking cycle) is measured by setting the following series of operations as 1 cycle. Electric power is supplied to each sample for 60 seconds such that a temperature of a surface (heating part) of the tube is elevated from a normal temperature to 1000°C within 2 seconds or within 10 seconds, and the tube surface temperature is saturated at 1150°C or 1200°C and, thereafter, the tube surface is cooled by air for 180 seconds. Here, the samples whose breaking cycle becomes 10000 cycles or more when the tube surface temperature is saturated at 1150°C are considered to have the excellent durability and the evaluation "good" is given to the samples, while the samples whose breaking cycle becomes less than 10000 cycles when the tube surface temperature is saturated at 1150°C are considered to have the inferior durability and the evaluation "bad" is given to the samples. Further, when the tube surface temperature is saturated at 1200°C (that is, under a condition where the heating coil is more liable to be broken), the samples whose breaking cycle becomes 5000 cycles or more are given the evaluation "good", while the samples whose breaking cycle becomes less than 5000 cycles are given the evaluation "bad". With respect to the samples whose tube is broken are given "*" in a determination column of following Tables 1 to 3.

**[0111]** Table 1 shows a result of the test with respect to samples where the heating coil is made of Fe-26Cr-7. 5 Al.

Table 2 shows a result of the test with respect to the samples where the heating coil is made of W. Table 3 shows a result of the test with respect to the samples where the heating coil is made of Mo. To elevate the tube surface temperature from a normal temperature to 1000°C within 2 seconds, electric power is supplied to the sample at 11 V for 2 seconds. To elevate the tube surface temperature from a normal temperature to 1000°C within 10 seconds, electric power is supplied to the sample at 4.5 V for 5 seconds and, thereafter, electric power is supplied to the sample at 7.5 V for 5 seconds. Further, to saturate the tube surface temperature at 1150°C, electric power is supplied to the sample at 6.5 V for 60 seconds, while to saturate the tube surface temperature at 1200°C, electric power is supplied to the sample at 7.5 V for 60 seconds. In all samples, the seal portion is made of fluoro-rubber, and the tube composition is specified by quantitative analysis in accordance with EPMA. With respect to the samples where the heating coil is made of Fe-26Cr-7.5 Al, only a test where the tube surface, temperature is elevated from a normal temperature to 1000°C within 2 seconds is carried out.

**[0112]**

[Table 1]

Heating coil: Fe-26Cr-7.5Al

| | 2 seconds to elevate temperature to 1000°C from normal temperature | | | |
|---|---|---|---|---|
| | Saturated at 1150°C | | Saturated at 1200°C | |
| Tube composition | Breaking cycle | Determination | Breaking cycle | Determination |
| Fe-25Cr-21Ni(SUS310s) | 2734 | bad | 38 | bad |
| Ni-15Cr-8Fe-0.5Mn-0.2Si (Inconel 600) | 1499 | bad | 21 | bad |
| Ni-23Cr-14Fe-1.4Al-0.5Mn-0.2Si (Inconel 601) | 2433 | bad | 42 | bad |
| Ni-23Cr-14Fe-0.5Al-0.5Mn-0.2Si | 2854 | bad | 11 | bad |
| Ni-23Cr-14Fe-0.3Al-0.5Mn-0.2Si | 2333 | bad | 18 | bad |
| Ni-18Cr-14Fe-1.4Al-0.5Mn-0.2Si | 2834 | bad | 29 | bad |
| Ni-20Cr-14Fe-1.4Al-0.5Mn-0.2Si | 2289 | bad | 22 | bad |
| Ni-26Cr-11Fe-2.4Al-0.2C -0.2Ti-0.1Zr-0.1Y(Alloy602) | 2984 | bad | 31 | bad |

**[0113]**

[Table 2]

Heating coil: W

| | 2 seconds to elevate temperature to 1000°C from normal temperature | | | | 10 seconds to elevate temperature to 1000°C from normal temperature | | | |
|---|---|---|---|---|---|---|---|---|
| | Saturated at 1150°C | | Saturated at 1200°C | | Saturated at 1150°C | | Saturated at 1200°C | |
| Tube composition | Breaking cycle | Determination | Break-ing cycle | Determination | Breaking cycle | Determination | Breaking cycle | Determination |
| Fe-25Cr-21Ni (SUS310s) | 3809 | bad | 1058 | bad | 3320 | bad | 935 | bad |
| Ni-15Cr-8Fe-0.5Mn-0.2Si (Inconel 600) | 1699 | bad(*) | 890 | bad(*) | 1544 | bad(*) | 854 | bad(*) |
| Ni-18Cr-14Fe-1.4Al-0.5Mn-0.2Si | 8992 | bad | 4199 | bad | 7145 | bad | 3998 | bad |
| Ni-23Cr-14Fe-0.3Al-0.5Mn-0.2Si | 8635 | bad | 3294 | bad | 7899 | bad | 2990 | bad |
| Ni-20Cr-14Fe-1.4Al-0.5Mn-0.2Si | 10290 | good | 5145 | good | 10092 | good | 5020 | good |
| Ni-23Cr-14Fe-0.5Al-0.5Mn-0.2Si | 10881 | good | 5208 | good | 10722 | good | 5109 | good |
| Ni-23Cr-14Fe-1.4Al-0.5Mn-0.2Si (Inconel 601) | 12504 | good | 5824 | good | 11190 | good | 5689 | good |
| Ni-26Cr-11Fe-2.4Al-0.2C-0.2Ti-0.1Zr-0.1Y (Alloy602) | 14796 | good | 9730 | good | 12993 | good | 6994 | good |

**[0114]**

[Table 3]

Heating coil: Mo

| | 2 seconds to elevate temperature to 1000°C from normal temperature | | | | 10 seconds to elevate temperature to 1000°C from normal temperature | | | |
|---|---|---|---|---|---|---|---|---|
| | Saturated at 1150°C | | Saturated at 1200°C | | Saturated at 1150°C | | Saturated at 1200°C | |
| Tube composition | Breaking cycle | Determination | Break-ing cycle | Determination | Breaking cycle | Determination | Breaking cycle | Determination |
| Fe-25Cr-21Ni (SUS310s) | 3395 | bad | 998 | bad | 3091 | bad | 899 | bad |
| Ni-15Cr-8Fe-0.5Mn-0.2Si (Inconel 600) | 1398 | bad(*) | 789 | bad(*) | 1099 | bad(*) | 892 | bad(*) |
| Ni-18Cr-14Fe-1.4Al-0.5Mn-0.2Si | 9023 | bad | 4281 | bad | 7023 | bad | 4082 | bad |
| Ni-23Cr-14Fe-0.3Al-0.5Mn-0.2Si | 8902 | bad | 3191 | bad | 7596 | bad | 2790 | bad |
| Ni-20Cr-14Fe-1.4Al-0.5Mn-0.2Si | 10562 | good | 5299 | good | 10190 | good | 5108 | good |
| Ni-23Cr-14Fe-0.5Al-0.5Mn-0.2Si | 11931 | good | 5188 | good | 11827 | good | 5083 | good |
| Ni-23Cr-14Fe-1.4Al-0.5Mn-0.2Si (Inconel 601) | 13299 | good | 5901 | good | 12119 | good | 5298 | good |
| Ni-26Cr-11Fe-2.4Al-0.2C-0.2Ti-0.1Zr-0.1Y (Alloy602) | 15110 | good | 9204 | good | 12893 | good | 7092 | good |

**[0115]** As shown in Table 1, it is found that, with respect to the samples where the heating coil is made of Fe-26Cr-7.5Al (PYROMAX), the breaking occurs in the heating coil at an early stage irrespective of the composition of the tube and, particularly, the heating coil is melted when a temperature of the heating coil is elevated to 1200°C. It is thought that a melting point of the metal material which forms the heating coil is relatively low, that is, approximately 1500°C and hence, when the tube surface temperature is elevated to a high temperature of 1150°C or more, the heating coil is heated to a temperature around a melting point of the heating coil per se.

**[0116]** Further, as shown in Table 2 and Table 3, it is also found that, even in a case where the heating coil is made of W or Mo having a high melting point, when a Al content or a Cr content in the tube is relatively small, the durability of the heating coil becomes insufficient. It is thought that this result is brought about by a phenomenon that the oxidative exhaustion of the heating coil rapidly progresses under a high temperature due to the property of W and Mo that W and Mo are relatively easily oxidized.

**[0117]** Further, it is confirmed that, with respect to the sample where the tube is made of Ni-15Cr-8Fe-0.5Mn-0.2Si (Inconel (registered trademark) 600), the breaking occurs in the tube. It is thought that the tube does not contain Al and a Cr content in the tube is relatively small and hence, an oxide film which is formed by oxidation of Al or Cr is not sufficiently formed on the tube surface whereby the oxidation resistance of the tube becomes insufficient.

**[0118]** To the contrary, it is found that the sample where the heating coil is made of W or Mo, an Al content in the tube is set to 0.5 mass% or more, and a Cr content in the tube is set to 20 mass% or more exhibits the excellent durability. It is thought that Al and Cr contained in the tube are oxidized prior to W or Mo in the heating coil and hence, an oxygen partial pressure in the tube can be lowered thus leading to the suppression of oxidation of the heating coil, and that an oxide film made of Al or Cr is sufficiently formed on an outer surface of the tube and hence, the tube can realize the excellent oxidation resistance which enables the tube to withstand a high temperature of 1150°C or more over a long period.

**[0119]** Further, it is confirmed that, particularly, the larger an Al content or a Cr content in the tube, the more excellent durability the tube can realize.

**[0120]** Based on the above-mentioned results of the test, it is reasonable to say that, to enhance the durability of both the heating coil and the tube thus allowing the glow plug to generate heat at a higher temperature over a long period, it is preferable to form the heating coil using a metal material which contains W or Mo as a main component, and to set an Al content in the tube to 0.5 mass% or more and a Cr content in the tube to 20 mass% or more. Further, to realize the further enhancement of the durability, it is also desirable to further increase the Al content to 1.4 mass% or more or 2.4 mass% or more and the Cr content to 23 mass% or more or 26 mass% or more. However, when the Al content exceeds 5.0 mass% or the Cr content exceeds 40 mass%, there exists a possibility that the workability is deteriorated. Accordingly, it is desirable to set the Al content to 5.0 mass% or less and the Cr content to 40 mass% or less.

**[0121]** Next, a plurality of samples of glow plugs are prepared, wherein the heating coil is made of W or Mo and the tube is made of Ni-26Cr-11Fe-2.4Al-0.2C-0.2Ti-0.1Zr-0.1Y (Alloy 602). Then, with respect to each sample, the breaking cycle until the breaking of the heating coil occurs is measured by setting the series of following operations as 1 cycle. Electric power is supplied to each sample such that a temperature of a tube surface is elevated from a normal temperature to 1000°C while changing a temperature elevation time with respect to each sample and, after the tube surface temperature reaches 1200°C, the tube surface temperature is maintained for 60 seconds and, thereafter, the tube surface is cooled by air for 180 seconds. Table 4 shows a result of the test of samples where the heating coil is made of W, and Table 5 shows a result of the test of samples where the heating coil is made of Mo. In all samples, a seal portion is made of fluoro-rubber.

**[0122]**

[Table 4]

| Heating coil: W | | |
|---|---|---|
| 1000°C arrival time (s) | Applied voltage | Breaking cycle |
| 2 | 11V2s-7.5V60s-off180s | 9730 |
| 3 | 11V1s-7.5V60s-off180s | 8592 |
| 5 | 7.5V65s-off180s | 7349 |
| 10 | 4.5V5s7.5V65s-off180s | 6994 |
| 30 | 2V10s-3V10s-4.5V5s -7.5V65s-off180s | 7049 |

**[0123]**

[Table 5]

| Heating coil: Mo | | |
|---|---|---|
| 1000°C arrival time (s) | Applied voltage | Breaking cycle |
| 2 | 11V2s-7.5V60s-off180s | 9204 |
| 3 | 11V1s-7.5V60s-off180s | 8762 |
| 5 | 7.5V65s-off180s | 7199 |
| 10 | 4.5V5s7.5V65s-off180s | 7092 |
| 30 | 2V10s-3V10s-4.5V5s -7.5V65s-off180s | 6888 |

**[0124]** As shown in Table 4 and Table 5, it is found that when the temperature elevation time from a normal temperature to 1000°C exceeds 3 seconds, the breaking cycle becomes around 7000 cycles, while when the temperature elevation time from the normal temperature to 1000°C is within 3 seconds, the breaking cycle becomes 8500 cycles or more so that the glow plug can realize the further excellent durability. It is also confirmed that when the temperature elevation time from the normal temperature to 1000°C is within 2 seconds, the breaking cycle exceeds 9000 cycles so that the further enhancement of the durability is realized. It is thought that the shorter the temperature elevation time, the larger thermal stress applied to the tube becomes and hence, an oxide film formed on an inner wall of the tube is liable to be broken (that is, unoxidized Al or Cr is likely to be exposed on an inner surface of the tube) whereby the oxidation between oxygen present inside the tube and Al or Cr is further promoted thus further lowering an oxygen partial pressure inside the tube.

**[0125]** Based on the above-mentioned results of the test, it is reasonable to say that, in the glow plug where the heating coil is made of a metal material which contains W or Mo as a main component and the tube is made of a metal material which contains a predetermined quantity or more of Al or Cr for further enhancement of the durability, it is preferable to supply electric power such that the tube surface temperature is elevated from a normal temperature to 1000°C within 3 seconds, and it is more preferable to supply electric power such that the tube surface temperature is elevated from a normal temperature to 1000°C within 2 seconds.

**[0126]** Next, samples of the glow plug are prepared, wherein an insulation powder which is filled in the tube is made of Mgo, aluminum oxide ($Al_2O_3$), or silicon nitride ($Si_3O_4$). Then, with respect to each sample, the breaking cycle until the breaking of the heating coil occurs is measured by setting the series of following operations as 1 cycle. Electric power is supplied to each sample at 7.5V for 65 seconds (a temperature of a tube surface is elevated from a normal temperature to 1000°C with 5 minutes) and, thereafter, the tube surface is cooled by air for 180 seconds. Table 6 shows a result of the test. Here, in all samples, the heating coil is made of W, and the tube is made of Ni-23Cr-14Fe-1.4Al-0.5Mn-0.2Si [Inconel (registered trademark) 601], Alloy 602 or SUS310s. Further, the seal portion is made of fluoro-rubber and, after the sample is prepared, preheating is applied at 800°C for 30 seconds.

**[0127]**

[Table 6]

| Insulation powder | Tube composition | | |
|---|---|---|---|
| | Ni-23Cr-14Fe-1.4Al -0.5Mn-0.2Si (Inconel 601) | Ni-26Cr-11Fe-2.4Al -0.2C-0.2Ti-0.1Zr-0.1Y (Alloy602) | Fe-25Cr-21Ni (SUS310s) |
| MgO | 7177 | 8850 | 994 |
| $Al_2O_3$ | 5699 | 6166 | 689 |
| $Si_3N_4$ | 6722 | 6954 | 933 |
| Determination | good | good | bad |

**[0128]** As shown in Table 6, it is confirmed that, with respect to the sample where the tube is made of Inconel 601 or Alloy 602, all insulation powders exhibit the excellent durability. Particularly, it is found that the sample where the insulation powder is made of MgO exhibits more excellent durability than the samples where the insulation powder is made of $Al_2O_3$ or $Si_3O_4$ . It is thought that, while MgO is likely to form a composite oxide with an oxide of Al or Cr formed on the inner periphery of the tube, the composite oxide is extremely coarse and hence, Al or Cr contained in the tube and oxygen present inside the tube are more likely to react with each other whereby an oxygen partial pressure inside the tube can be further lowered, and since MgO possesses the excellent heat conductivity compared to $Al_2O_3$ or the like, a larger thermal stress is applied to the tube and, as a result, an oxide film formed on the inner periphery of the tube can be more easily broken whereby the oxidation between oxygen present inside the tube and Al or Cr contained in the tube is further promoted or the like.

**[0129]** Based on the above-mentioned results of the test, from a viewpoint of realizing the further enhancement of the durability, it is reasonable to say that a material which contains MgO is preferably used as a main component as the insulation powder.

**[0130]** Next, samples of the glow plug are prepared, wherein the seal portion is made of EPDM or fluoro-rubber. Then, with respect to each sample, the breaking cycle until the breaking of the heating coil occurs is measured by setting the series of following operations as 1 cycle. Electric power is supplied to each sample at 7.5 V for 65 seconds (a temperature of a tube surface is elevated from a normal temperature to 1000°C within 5 minutes) and, thereafter, the tube surface is cooled by air for 180 seconds. Table 7 shows a result of the test. Here, the heating coil is made of W, and the tube is made of Inconel 601 or Alloy 602. Further, a thickness of the seal portion along the axial direction is set to 10 mm.

**[0131]**

[Table 7]

| | | Tube material | |
|---|---|---|---|
| Seal material | Oxygen permeability ($cm^3$·cm/sec·$cm^2$·cmHg) | Ni-23Cr-14Fe-1.4Al-0.5Mn-0.2Si (Inconel 601) | Ni-26Cr-11Fe-2.4Al-0.2C-0.2Ti-0.1Zr-0.1Y (Alloy602) |
| EPDM | $2.0\times10^{-9}$ | 9985 | 12993 |
| Fluoro-rubber | $1.0\times10^{-9}$ | 11987 | 13984 |

**[0132]** As shown in Table 7, it is found that all samples exhibit the excellent durability and, particularly, the smaller the oxygen permeability of the seal portion, the more excellent durability the sample can acquire. It is thought that the intrusion of oxygen into the inside of the tube through the seal portion can be more suppressed.

**[0133]** Based on the above-mentioned results of the test, to further enhance the durability of the heating coil, it is reasonable to say that the oxygen permeability of the seal portion is preferably set to $2.0\times10^{-9}$ ($cm^3$·cm/sec·$cm^2$·cmHg) or less, and the oxygen permeability is more preferably set to $1.0\times10^{-9}$ ($cm^3$·cm/sec·$cm^2$·cmHg) or less.

**[0134]** Next, a plurality of samples of glow plugs are prepared, wherein the heating coil is made of W and the tube is made of Inconel 601 and, with respect to each sample, a front end portion of the tube (a portion of the tube ranging from the front end to a position 1 mm away from the front end) is inserted into an electric furnace thus preheating the tube at 700°C to 1400°C for 1 second to 60 seconds. Then, with respect to each sample to which the preheating is applied, the number of cycles until the breaking of the heating coil occurs (breaking cycle) is measured by setting the series of following operations as 1 cycle. Electric power is supplied to each sample for 60 seconds such that a temperature of a tube surface is elevated from a normal temperature to 1000°C within 2 seconds and, at the same time, the tube surface temperature is saturated at 1200°C (that is, electric power is supplied at 11 V for 2 seconds and, thereafter, electric power is supplied at 7.5 V for 60 seconds) and, thereafter, the tube surface is cooled by air for 180 seconds. Table 8 shows a result of the test. Here, the seal portion is made of fluoro-rubber. Further, in Table 8, as the reference, the breaking cycle with respect to a sample to which the preheating is not applied is also shown together with the preheated samples.

**[0135]**

[Table 8]

| Preheating temperature (°C) | Preheating time (s) | Breaking cycle | Determination |
|---|---|---|---|
| - | - | 5824 | Good |
| 700 | 1 | 6744 | Good |
| | 30 | 7290 | Good |
| | 60 | 7582 | Good |
| 800 | 1 | 7889 | Good |
| | 3 | 9234 | Very good |
| | 10 | 9487 | Very good |
| | 30 | 9904 | Very good |
| | 60 | 418 | Bad |
| 1300 | 1 | 8654 | Good |
| | 3 | 9730 | Very good |
| | 10 | 9779 | Very good |
| | 30 | 9425 | Very good |
| | 60 | 599 | Bad |

(continued)

| Preheating temperature (°C) | Preheating time (s) | Breaking cycle | Determination |
|---|---|---|---|
| 1400 | 3 | 875 | Bad |

**[0136]** As shown in Table 8, it is found that the durability is extremely lowered with respect to the samples to which the preheating is applied at 800°C or more for 60 seconds and the samples to which the preheating is applied at 1400°C. It is thought that this lowering of durability is brought about by melting of the seal portion due to heating of the sample for a long time or by the reduction of a thickness of the tube due to heating of the sample at an extremely high temperature.
**[0137]** To the contrary, it is found that the sample to which the preheating is applied at a temperature of 700°C to 1300°C over 1 second to 30 seconds and the sample to which the preheating is applied at a temperature of 700°C for 60 seconds exhibit the further excellent durability compared to the sample to which the preheating is not applied. It is thought that, by heating the tube, Al and Cr contained in the tube positively react with oxygen inside the tube prior to the heating coil whereby an oxygen partial pressure inside the tube can be lowered while suppressing the oxidation of the heating coil as a result.
**[0138]** Further, particularly, with respect to the sample to which the preheating is applied at a temperature of 800°C to 1300°C over 3 seconds to 30 seconds, the breaking cycle exceeds 9000 cycles so that it is confirmed that the sample possesses the extremely excellent durability.
**[0139]** Based on the above-mentioned result of the test, it is reasonable to say that it is preferable to perform the preheating of the front end portion of the tube for realizing the further enhancement of the durability. Particularly, from a viewpoint of reliably enhancing the durability, it is more preferable to perform the preheating at a relatively low temperature of 700°C or less or to perform the preheating at a temperature exceeding 700°C and 1300°C or less over 1 second to 30 seconds, and it is further more preferable to perform the preheating at a temperature of 800°C or more and 1300°C or less over 3 seconds to 30 seconds.
**[0140]** Next, a plurality of samples of glow plugs where a wire diameter of the heating coil is changed to various values are prepared, and while measuring a temperature of a portion of a tube surface 2 mm away from a front end toward a rear end side (the center of the exposed portion) by a radiation pyrometer, electric power is supplied to each sample at 11 V for 2 seconds and, thereafter, electric power is supplied to each sample at 6 V for 180 seconds. Then, a time which elapses until the temperature of a portion of the tube 2 mm away from the front end toward the rear end side (measuring object portion) reaches 1000°C is measured (1000°C arrival time). Here, it is reasonable to say that, with respect to the sample where the temperature of the measuring object portion reaches 1000°C within 3 seconds, the temperature of the tube can be easily rapidly elevated and hence, unoxidized Al or Cr is likely to be exposed on an inner peripheral surface of the tube whereby the sample is preferable from a viewpoint of the enhancement of oxidation resistance of the heating coil. Table 9 shows the result of the test. In all samples, the heating coil is made of Mo, a pitch of the heating coil is set to a fixed value, an outer diameter of the heating coil is set to 2.5 mm, and the normal-temperature resistance of the whole heating coil is set to 300 mΩ. Further, to set the normal-temperature resistance of the whole heating coil equal among all samples, a length of the heating coil along an axis of the heating coil and the number of turns of the heating coil are changed corresponding to a wire diameter of the heating coil. In Table 9, the length of the heating coil and the number of turns of the heating coil with respect to each sample are shown together with the wire diameter and the 1000°C arrival time (s) for reference purposes.
**[0141]**

[Table 9]

| Wire diameter (mm) | Number of turns of coil | Length of coil (mm) | 1000°C arrival time (s) |
|---|---|---|---|
| 0.10 | 9 | 3.5 | 1.2 |
| 0.15 | 18 | 4.5 | 2.0 |
| 0.20 | 30 | 9 | 3.5 |
| 0.30 | 60 | 24 | 4.0 |

**[0142]** As shown in Table 9, it is found that, in the sample where the wire diameter of the heating coil is set to 0. 15 mm or less, the temperature of the measuring object portion reaches 1000°C within 3 seconds so that the rapid temperature elevation of the exposed portion can be easily acquired.
**[0143]** Next, a plurality of samples of glow plugs are prepared, wherein while a wire diameter of a portion of the heating coil positioned between a front end and a position 6 mm away from the front end toward a rear end of the heating coil along the center axis of the tube (front-end-side coil) is changed, a wire diameter of a portion of the heating coil which

is positioned at a more rear end side than the front-end-side coil (rear-end-side coil) is set to a fixed value (0.2 mm). A temperature of each sample is elevated under the above-mentioned energization condition (electric power is supplied at 11 V for 2 seconds and, thereafter, electric power is supplied at 6 V for 180 seconds). Then, a time which elapses before the temperature of the measuring object portion reaches 1000°C is measured. Table 10 shows the result of the test.

**[0144]** In all samples, the heating coil is made of Mo, an outer diameter of the heating coil is set to 2.5 mm, a length of the front-end-side coil is set to 6 mm, and a length of the rear-end-side coil is set to 18 mm. Further, in all samples, the heating coil is prepared by welding a portion corresponding to the front-end-side coil to a portion corresponding to the rear-end-side coil. Further, an average pitch of the front-end-side coil is changed in conformity with the wire diameter of the front-end-side coil so as to adjust normal-temperature resistance of the front-end-side coil to 150 mΩ. By also adjusting the normal-temperature resistance of the rear-end-side coil to 150 mΩ, the normal-temperature resistance of the whole heating coil is set to 300 mΩ, and an average value of the normal-temperature resistance of the whole heating coil is set to 12.5 mΩ/mm (=300 mΩ/24 mm).

**[0145]**

[Table 10]

| Front end side coil (length: 6 mm) | | Rear end side coil (length: 18 mm) | Average value of normal temperature resistance of whole heating coil (mΩ/mm) | 1000°C arrival time (s) |
|---|---|---|---|---|
| Wire diameter (mm) | Average value of normal temperature resistance (mΩ/mm) | Average value of normal temperature resistance (mΩ/mm) | | |
| 0.1 | 25.0 | 8.3 | 12.5 | 2 |
| 0.15 | 25.0 | 8.3 | 12.5 | 2 |
| 0.2 | 25.0 | 8.3 | 12.5 | 2 |

**[0146]** As shown in Table 10, in all samples, it is confirmed that the temperature of the measuring object portion reaches 1000°C within 3 seconds so that the rapid temperature elevation of the exposed portion can be easily acquired.

**[0147]** To form the heating coil such that the heating coil possesses sufficient mechanical strength, it is preferable to set a wire diameter of the heating coil to 2.0 mm or more. In view of the above, a plurality of samples of glow plugs where an average value of normal-temperature resistance of the front-end -side coil is changed are prepared by changing a pitch of the front-end -side coil while setting the wire diameter of the heating coil to 2.0 mm, and a temperature of each sample is elevated under the above-mentioned energization condition (electric power is supplied at 11 V for 2 seconds and, thereafter, electric power is supplied at 6 V for 180 seconds). Then, the evaluation "good" is given to the sample where the temperature of the measuring object portion reaches 1000°C within 3 seconds as the rapid temperature elevation of the exposed portion can be easily acquired, while the evaluation "fair" is given to the sample where the temperature of the measuring object portion does not reach 1000°C within 3 seconds as the temperature elevation of the exposed portion is slightly difficult. Table 11 shows the result of the test.

**[0148]** Further, with respect to the samples where a temperature of the measuring object portion reaches 1000°C within 3 seconds, the number of cycles until the breaking of the heating coil occurs (breaking cycle) is also measured by setting the series of following operations as 1 cycle. Electric power is supplied to the sample at 11 V for 2 seconds and, thereafter, electric power is supplied to the sample at 7.5 V for 180 seconds, and the electric power supply is stopped for 120 seconds. Table 11 also shows the measured breaking cycles in addition to the above-mentioned result of the test.

**[0149]** In all samples, the heating coil is made of Mo and an outer diameter of the heating coil is set to 2.5 mm. Further, as shown in Fig. 7(a) and Fig. 7(b), in all samples, a length of the front-end-side coil is set to 6 mm, and a length of the rear-end-side coil is set to 18 mm. Then, in all samples, the normal-temperature resistance of the whole heating coil is set to 300 mΩ by also changing the normal-temperature resistance of the rear-end-side coil by adjusting a pitch of the rear-end-side coil in conformity with the change of the normal-temperature resistance (pitch) of the front-end-side coil. Table 11 shows the normal-temperature resistance of the front-end-side coil, the normal-temperature resistance of the rear-end-side coil, an average pitch of the front-end-side coil, and an average pitch of the rear-end-side coil along with the above-mentioned result of the test. The average pitch of the front-end-side coil is calculated in such a manner that one turn (the frontmost end portion of the heating coil) adjacent to the front end of the tube is excluded from the front-end-side coil in calculation.

**[0150]**

[Table 11]

| Front end side coil (length: 6 mm) | | | Rear end side coil (length: 18 mm) | | | Difference in average pitch | Average value of normal temperature resistance of whole heating coil (mΩ/mm) | 1000°C arrival time (s) | Evaluation | Breaking cycle |
|---|---|---|---|---|---|---|---|---|---|---|
| Normal temperature resistance (mΩ) | Average value of normal temperature resistance (mΩ/mm) | Average pitch (mm) | Normal temperature resistance (mΩ) | Average value of normal temperature resistance (mΩ/mm) | Average pitch (mm) | | | | | |
| 60 | 10.0 | 0.79 | 240 | 13.3 | 0.75 | -0.04 | 12.5 | Not reached | Fair | Not made |
| 90 | 15.0 | 0.53 | 210 | 11.7 | 0.86 | 0.33 | 12.5 | 3 | Good | 8199 |
| 120 | 20.0 | 0.39 | 180 | 10.0 | 1.00 | 0.61 | 12.5 | 2.5 | Good | 8912 |
| 150 | 25.0 | 0.30 | 150 | 8.3 | 1.20 | 0.90 | 12.5 | 2 | Good | 9481 |
| 180 | 30.0 | 0.26 | 120 | 6.7 | 1.50 | 1.24 | 12.5 | 2 | Good | 10221 |
| 210 | 35.0 | 0.23 | 90 | 5.0 | 2.00 | 1.77 | 12.5 | 2 | Good | 9893 |

**[0151]** As shown in Table 11, in the sample where the average value of the normal-temperature resistance of the front-end-side coil is set larger than the average value of the normal-temperature resistance of the whole heating coil, the temperature of the measuring object portion reaches 1000°C within 3 seconds and hence, it is found that the rapid temperature elevation of the exposed portion can be easily acquired. Further, particularly, in the sample where the average pitch of the front-end-side coil is set smaller than the average pitch of the rear-end-side coil by 0.9 mm or more, the temperature of the measuring object portion reaches 1000°C within 2 seconds and hence, it is found that the exposed portion exhibits the further excellent rapid temperature elevation characteristic.

**[0152]** Further, it is reconfirmed that the shorter the 1000°C arrival time, the more the durability of the heating coil can be enhanced.

**[0153]** Next, samples of glow plugs where an average value of normal-temperature resistance of the whole heating coil is changed are prepared by changing a length L of the rear-end -side coil while setting both the normal-temperature resistance of the front-end-side coil and the normal-temperature resistance of the rear-end-side coil to 150 mΩ and setting the length of the front-end-side coil to 6.0 mm (that is, the average value of the normal-temperature resistance of the front-end-side coil to a fixed value (25 mΩ/mm)) as shown in Fig. 8 (a) and Fig. 8(b). Then, the temperature of each sample is elevated under the above-mentioned energization condition (electric power is supplied at 11 V for 2 seconds and, thereafter, electric power is supplied at 6 V for 180 seconds). The evaluation "good" is given to the sample where the temperature of the measuring object portion reaches 1000°C within 3 seconds, and the evaluation "fair" is given to the sample where the temperature of the measuring object portion does not reach 1000°C within 3 seconds. Table 12 shows the result of the test.

**[0154]** Further, with respect to the sample which receives the evaluation "good", the number of cycles until the breaking of the heating coil occurs (breaking cycle) is measured by setting the series of following operations as 1 cycle. Electric power is supplied to the sample at 11 V for 2 seconds and, thereafter, electric power is supplied to the sample at 7.5 V for 180 seconds, and the electric power supply is stopped for 120 seconds. Table 12 also shows the breaking cycles in addition to the above-mentioned result of the test.

**[0155]** In all samples, the heating coil is made of W and an outer diameter of the heating coil is set to 2.5 mm.

**[0156]**

[Table 12]

| Front end side coil (resistance: 150 mΩ) | | | Rear end side coil (resistance: 150 mΩ) | | | Difference in average pitch | Average value of normal temperature resistance of whole heating coil (mΩ/mm) | 1000°C arrival-time (s) | Evaluation | Breaking cycle |
|---|---|---|---|---|---|---|---|---|---|---|
| Length (mm) | Average value of normal temperature resistance (mΩ/mm) | Average pitch (mm) | Length (mm) | Average value of normal temperature resistance (mΩ/mm) | Average pitch (mm) | | | | | |
| 6 | 25.0 | 0.30 | 4 | 37.5 | 0.27 | -0.03 | 30.0 | not reached | Fair | not made |
| 6 | 25.0 | 0.30 | 6 | 25.0 | 0.40 | 0.10 | 25.0 | 3.5 | Fair | 7677 |
| 6 | 25.0 | 0.30 | 10 | 15.0 | 0.67 | 0.37 | 18.8 | 3 | good | 8821 |
| 6 | 25.0 | 0.30 | 18 | 8.3 | 1.20 | 0.90 | 12.5 | 2 | good | 9481 |
| 6 | 25.0 | 0.30 | 25 | 6.0 | 1.67 | 1.37 | 9.7 | 2 | good | 9928 |
| 6 | 25.0 | 0.30 | 40 | 3.8 | 2.67 | 2.37 | 6.5 | 2 | good | 10293 |

**[0157]** As shown in Table 12, it is reconfirmed that the rapid temperature elevation of the exposed portion can be easily acquired by setting the average value of the normal-temperature resistance of the front-end-side coil larger than the average value of the normal-temperature resistance of the whole heating coil. Further, it is also reconfirmed that the rapid temperature elevation characteristic of the exposed portion can be further enhanced by setting the average pitch of the front-end-side coil smaller than the average pitch of the rear-end-side coil by 0.9 mm or more.

**[0158]** From the above-mentioned result of the test, it is reasonable to say that, to positively elevate the temperature of the exposed portion of the tube which is likely to become high for acquiring the further enhancement of the oxidization resistance of the heating coil, it is preferable to set the average value of the normal-temperature resistance of the front-end-side coil larger than the average value of the normal-temperature resistance of the whole heating coil. Further, it is also reasonable to say that, to acquire the further enhancement of the oxidization resistance of the heating coil, it is preferable to set the average pitch of the front-end-side coil smaller than the average pitch of the rear-end-side coil by 0.9 mm or more.

**[0159]** The results of the test shown in Table 9 to Table 12 are obtained, as described above, by supplying electric power at 11 V for 2 seconds and, thereafter, by supplying electric power at 6 V for 180 seconds. Accordingly, even with respect to the sample on which the evaluation that the rapid temperature elevation of the exposed portion is slightly difficult under this energization condition is made, it is possible to set the surface temperature of the exposed portion to 1000°C or more within 3 seconds by changing the energization condition. Further, by changing the energization condition and the constitution of the heating coil, it is also possible to set a surface temperature of a portion of the tube other than the exposed portion to 1000°C or more within 3 seconds.

**[0160]** The present invention is not limited to the described content of the above-mentioned embodiments, and the present invention may be carried out as follows, for example. It is needless to say that other modifications and variations can be also considered besides modifications and variations exemplified hereinafter.

**[0161]** (a) In the above-mentioned embodiments, pure metal of W or Mo is exemplified as the metal material which forms the heating coil 9. However, the metal material which forms the heating coil 9 may be an alloy which contains W or Mo as a main component. Accordingly, the heating coil 9 may be made of a metal material which contains W or Mo as a main component, and also contains rhenium (Re), thorium oxide ($ThO_2$), Cr or the like. By containing several mass% or more and several tens mass% or less of Re, the heating coil 9 can sufficiently increase a resistance value thereof thus realizing a sufficient heat generating performance without excessively narrowing a diameter thereof (that is, while maintaining durability of the heating coil 9). Further, by containing several mass% of $ThO_2$, the heating coil 9 can suppress a grain growth under a high temperature thus further enhancing durability thereof.

**[0162]** (b) In the above-mentioned embodiments, the front end portion of the tube 7 and the front end portion of the heating coil 9 are joined to each other. However, the tube 7 and the heating coil 9 may be configured such that the front end portion of the tube 7 and the front end portion of the heating coil 9 are not joined to each other.

**[0163]** (c) In the above-mentioned embodiments, EPDM rubber and fluoro-rubber are exemplified as the material for forming the seal portion 11. However, the material for forming the seal portion 11 is not limited to such materials. Accordingly, the seal portion 11 may be made of silicon rubber having some thickness or the seal portion 11 may be made of a glass material when swaging is not applied to the tube 7.

**[0164]** (d) In the above-mentioned embodiments, the metal piece MP is made of the material having the same composition as the material for forming the tube 7. However, the composition of the metal piece MP is not limited to such composition. Here, to provide the front end portion of the tube 7 which does not contain W, it is preferable to use the metal piece MP which does not contain W. Further, as described in the above-mentioned embodiments, to enhance oxidation resistance of the front end portion of the tube 7 by providing the front end portion of the tube 7 which contains Cr, it is preferable to provide the metal piece MP which contains Cr.

**[0165]** (e) In the above-mentioned embodiments, the insulation powder 10 is made of the metal material which contains MgO as a main component. However, the insulation powder 10 may be made of a material which contains other metal (for example, $Al_2O_3$ or $Si_3N_4$) as a main component.

**[0166]** (f) A shape or the like of the glow plug 1 is not limited to the above-mentioned embodiments. For example, with respect to the tube 7, a small-diameter portion may be formed on the front end portion of the tube 7. Further, the shaft hole 4 formed in the main fitting 2 may be formed into a straight shape in the axial direction by eliminating the large-diameter portion 4a of the shaft hole 4, and the tube 7 may be press-fitted into the shaft hole 4.

**[0167]** (g) In the above-mentioned embodiments, the intermediate shaft 8 is directly joined to the rear end of the heating coil 9. However, between the heating coil 9 and the intermediate shaft 8, it may be possible to provide a coil (a so-called control coil) which is made of a metal material [for example, a metal material containing Co or Ni as a main component as represented by a cobalt (Co) -Ni-Fe-based alloy or the like] different from the metal material for forming the heating coil 9. In this case, during temperature elevation (at a relatively low temperature), a resistance value of the control coil is relatively low so that the temperature of the heating coil 9 can be rapidly elevated, while when the temperature is saturated, the resistance value of the control coil becomes relatively high so that a electric power supply quantity to the heating coil 9 is suppressed thus suppressing the excessive temperature elevation of the heating coil 9.

Explanation of symbols

**[0168]**

| | |
|---|---|
| 1: | glow plug |
| 7: | tube |
| 9: | heating coil (heating resistor) |
| 10: | insulation powder |
| 11: | seal portion |
| 21: | heating device |
| 31: | GCU (energization control device) |

## Claims

1. A heating device (21) comprising:

   a glow plug (1) which has a heating resistor (9) thus constituting a heating part; and
   a power supply control device (31) which is configured to adjust power to be supplied to the heating resistor (9), and is capable of controlling the heat generation of the heating resistor (9) by adjusting the power to be supplied, wherein
   the power supply control device (31) supplies electric power to the heating resistor (9) such that a temperature of the heating part is elevated to 1000°C from a normal temperature within 3 seconds,
   the glow plug (1) includes;

      a cylindrical tube (7) which has a closed front end portion and constitutes the heating part in a state where the heating resistor (9) is inserted into the inside of the tube (7); and
      a seal portion (11) which is provided at a rear-end-side opening of the tube (7) and brings the inside of the tube (7) into a sealed state,

   the heating resistor (9) is made of a metal material containing tungsten or molybdenum as a main component, and the tube (7) is made of an alloy containing 0.5 mass% or more and 5.0 mass% or less of aluminum and 20 mass% or more and 40 mass% or less of chromium.

2. The heating device (21) according to claim 1, wherein an average value of normal-temperature resistance at a portion of the heating resistor (9) between a front end of the heating resistor (9) and a position 6 mm away from the front end toward a rear end of the heating resistor (9) along a center axis of the tube (7) is set larger than an average value of the normal-temperature resistance of the whole heating resistor (9).

3. The heating device (21) according to claim 1 or 2, wherein the heating resistor (9) is formed into a coil shape, a wire diameter of the heating resistor (9) is 0.2 mm or more, and
   an average pitch of a portion of the heating resistor (9) between the front end of the heating resistor (9) and the position 6 mm away from the front end toward the rear end of the heating resistor (9) along the center axis of the tube (7) is set smaller than an average pitch of a portion of the heating resistor (9) positioned on a more rear end side than the position 6 mm away from the front end toward the rear end of the heating resistor (9) along the center axis of the tube (7) by 0.9 mm or more.

4. The heating device (21) according to any one of claims 1 to 3, wherein the glow plug (1) includes insulation powder (10) which is filled in the tube (7) and around the periphery of the heating resistor (9), and
   the insulation powder (10) is powder which contains magnesium oxide as a main component.

5. The heating device (21) according to any one of claims 1 to 4, wherein the seal portion (11) is made of a material having oxygen permeability of $2.0\times10^{-9}$ ($cm^3 \cdot cm/sec \cdot cm^2 \cdot cmHg$) or less.

6. The heating device (21) according to any one of claims 1 to 5, wherein a front end portion of the heating resistor (9) is joined to a front end portion of the tube (7), and
   the front end portion of the tube (7) does not contain tungsten, but contains chromium whose content is equal to or

more than a content of chromium in the metal material.

**7.** A glow plug (1) comprising:

a cylindrical tube (7) with a closed front end portion;
a heating resistor (9) which is inserted into the inside of the tube (7); and
a seal portion (11) which is formed on a rear-end-side opening of the tube (7) and seals the inside of the tube (7), wherein
the heating resistor (9) is made of a metal material containing tungsten or molybdenum as a main component, and the tube (7) is made of an alloy containing 0.5 mass% or more and 5.0 mass% or less of aluminum and 20 mass% or more and 40 mass% or less of chromium.

**8.** The glow plug (1) according to claim 7, wherein an average value of normal-temperature resistance at a portion of the heating resistor (9) between a front end of the heating resistor (9) and a position 6 mm away from the front end toward a rear end of the heating resistor (9) along a center axis of the tube (7) is set larger than an average value of the normal-temperature resistance of the whole heating resistor (9).

**9.** The glow plug (1) according to claim 7 or 8, wherein the heating resistor (9) is formed into a coil shape, a wire diameter of the heating resistor (9) is 0.2 mm or more, and
an average pitch of a portion of the heating resistor (9) between the front end of the heating resistor (9) and the position 6 mm away from the front end toward the rear end of the heating resistor (9) along the center axis of the tube (7) is set smaller than an average pitch of a portion of the heating resistor (9) positioned on a more rear end side than the position 6 mm away from the front end toward the rear end of the heating resistor (9) along the center axis of the tube (7) by 0.9 mm or more.

**10.** The glow plug (1) according to any one of claims 7 to 9, wherein the glow plug (1) includes insulation powder (10) which is filled in the tube (7) and around the periphery of the heating resistor (9), and
the insulation powder (10) is powder which contains magnesium oxide as a main component.

**11.** The glow plug (1) according to any one of claims 7 to 10, wherein the seal portion (11) is made of a material having oxygen permeability of $2.0 \times 10^{-9}$ ($cm^3 \cdot cm/sec \cdot cm^2 \cdot cmHg$) or less.

**12.** The glow plug (1) according to any one of claims 7 to 11, wherein a front end portion of the heating resistor (9) is joined to a front end portion of the tube (7), and
the front end portion of the tube (7) does not contain tungsten but contains chromium whose content is equal to or more than a content of chromium in the metal material.

**13.** A method of manufacturing a glow plug (1) which includes: a cylindrical tube (7) with a closed front end portion; a heating resistor (9) which is inserted into the inside of the tube (7); and a seal portion (11) which is formed on a rear-end-side opening of the tube (7) and seals the inside of the tube (7), the method of manufacturing a glow plug (1) comprising the steps of:

arranging the heating resistor (9) made of a metal material containing tungsten or molybdenum as a main component in the tube (7) which is made of an alloy containing 0.5 mass% or more and 5.0 mass% or less of aluminum and 20 mass% or more and 40 mass% or less of chromium;
sealing the inside of the tube (7) by forming the seal portion (11) on the rear-end-side opening of the tube (7); and
heating an outer surface of the tube (7) after the sealing step.

*FIG.1*

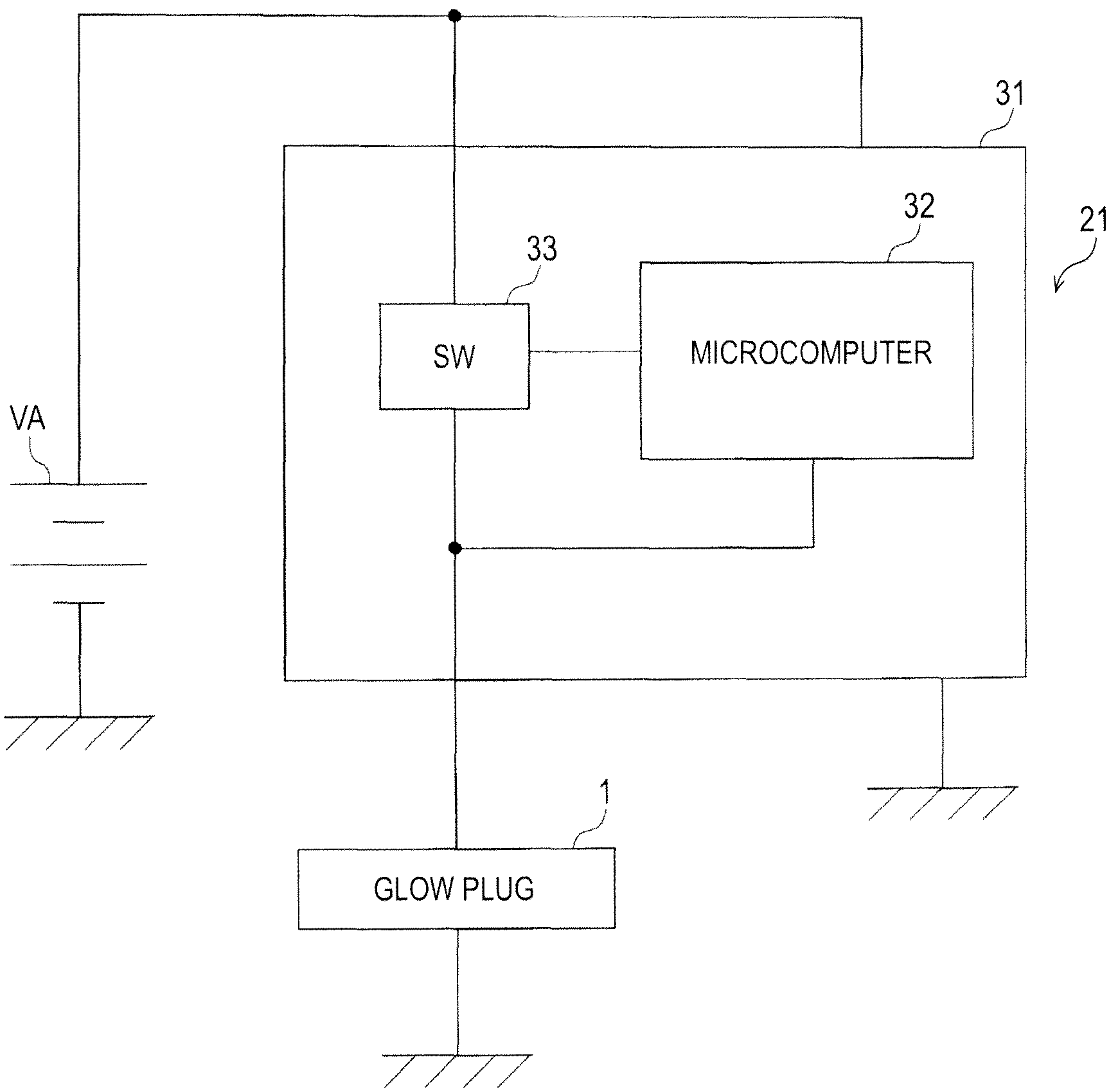


FIG.2A

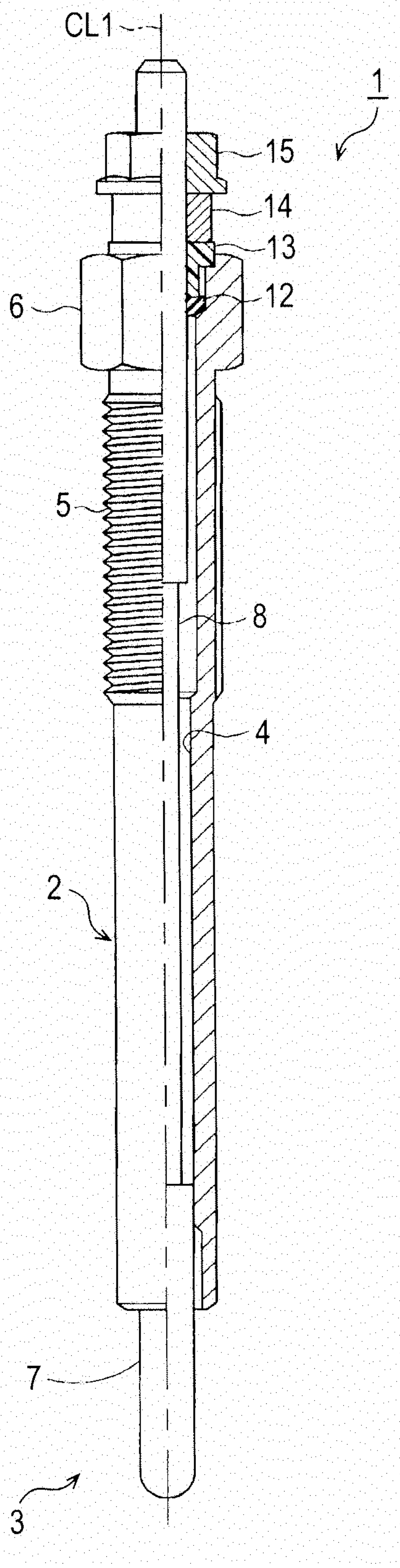



FIG.2B

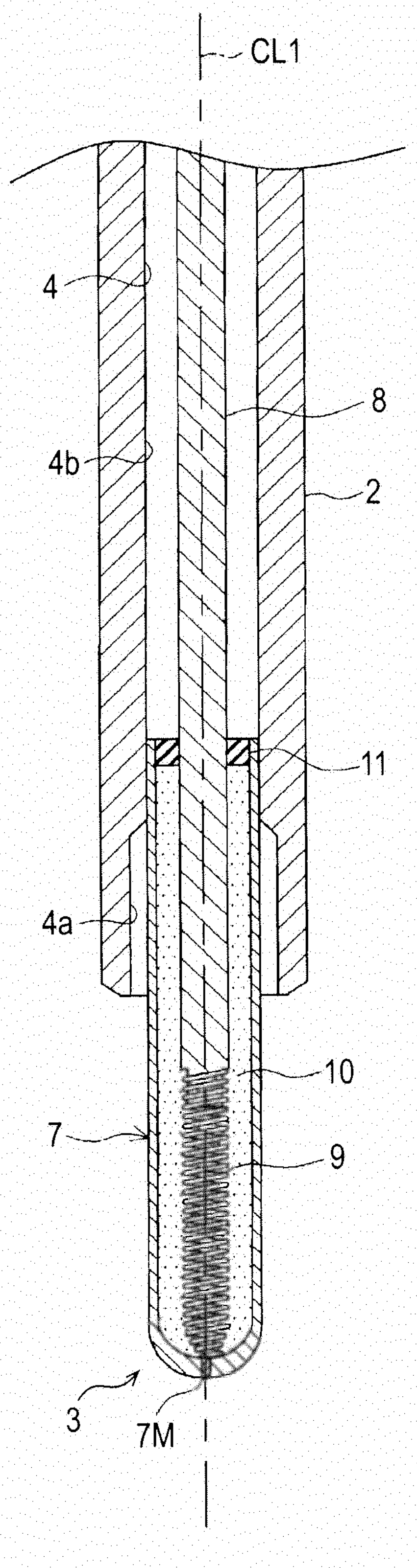


*FIG.3*

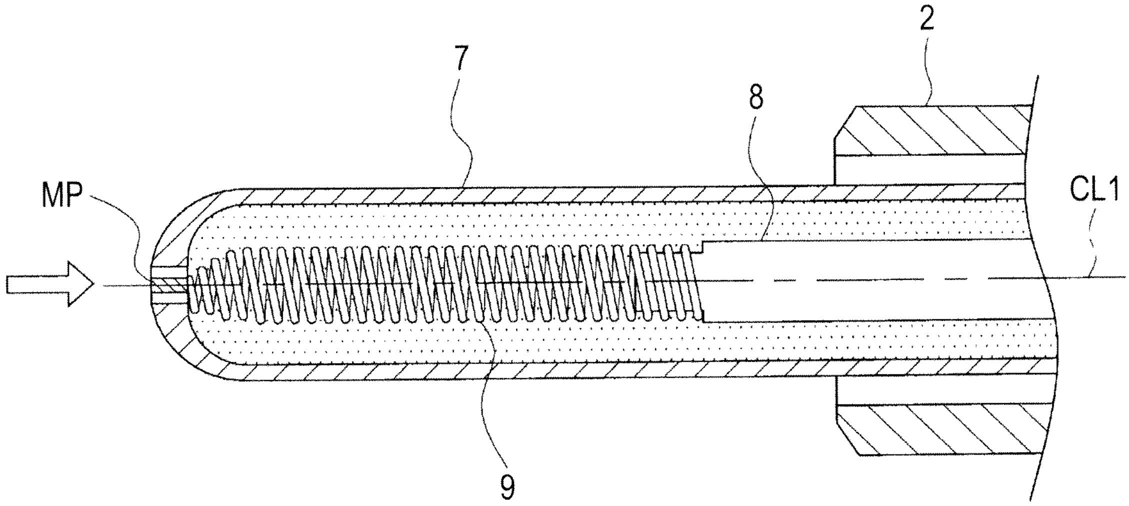


FIG.4

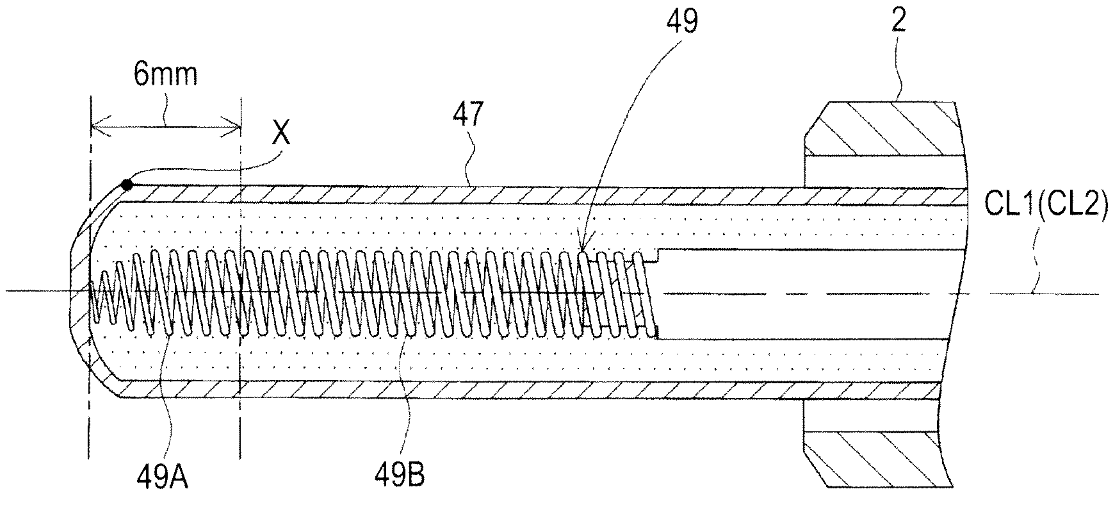


*FIG.5*

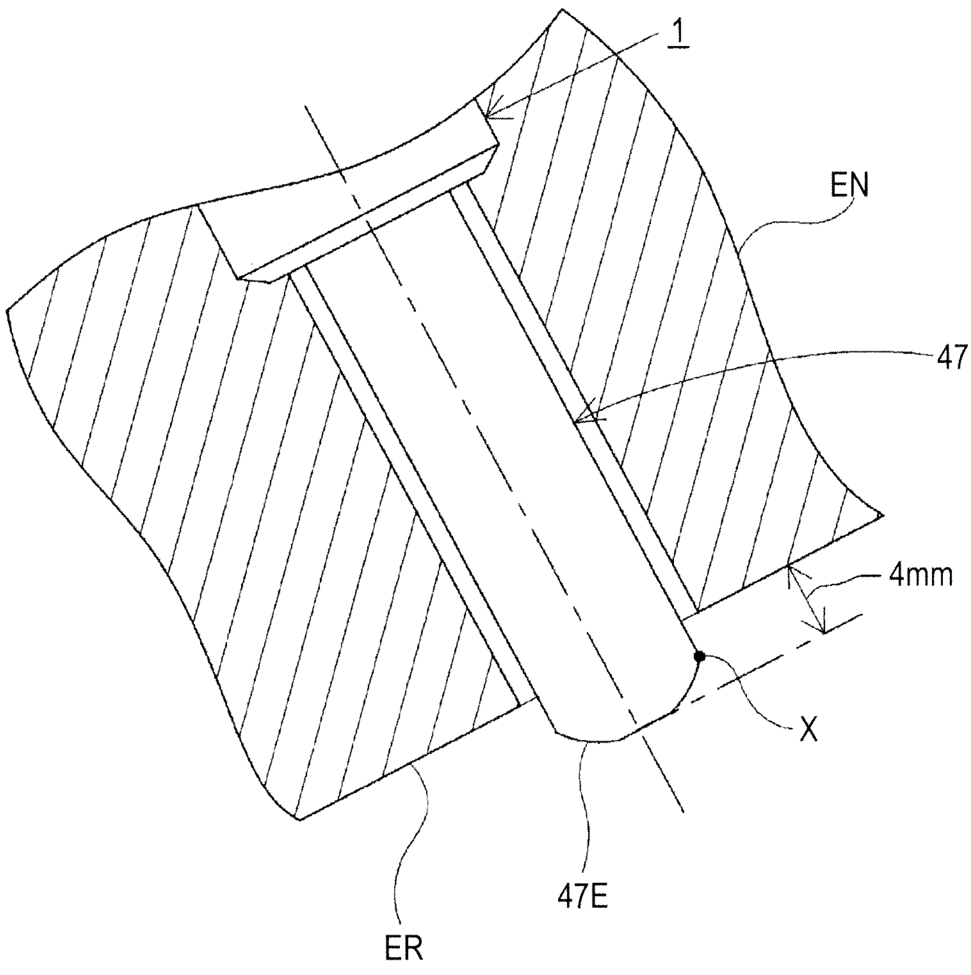


*FIG.6*

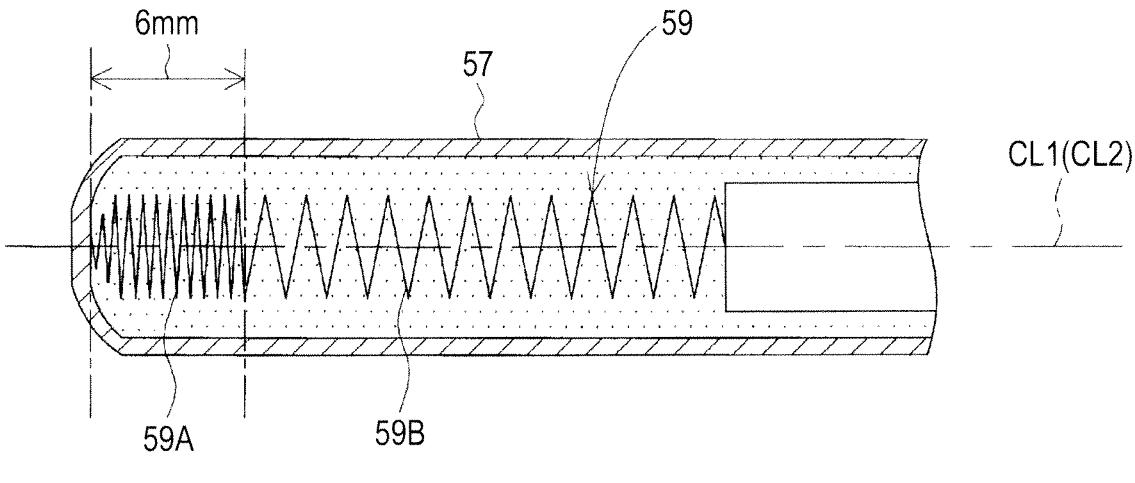
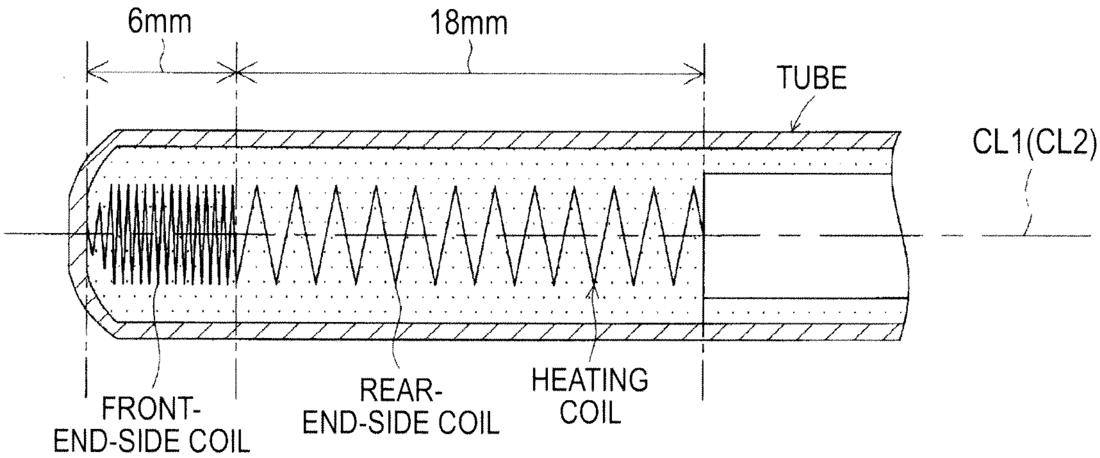


FIG.7A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18mm
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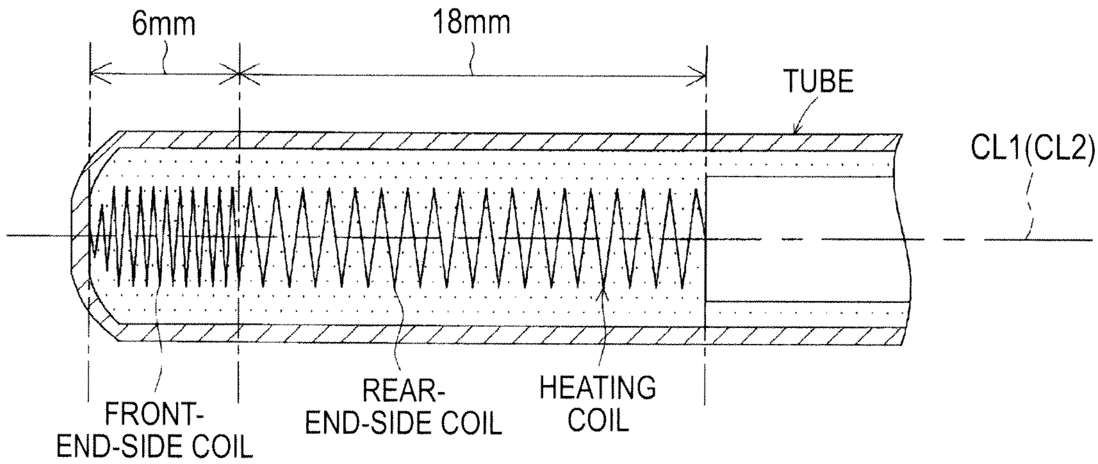
CL1(CL2)
FRONT-
END-SIDE COIL
REAR-
END-SIDE COIL
HEATING
COIL

FIG.7B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CL1(CL2)
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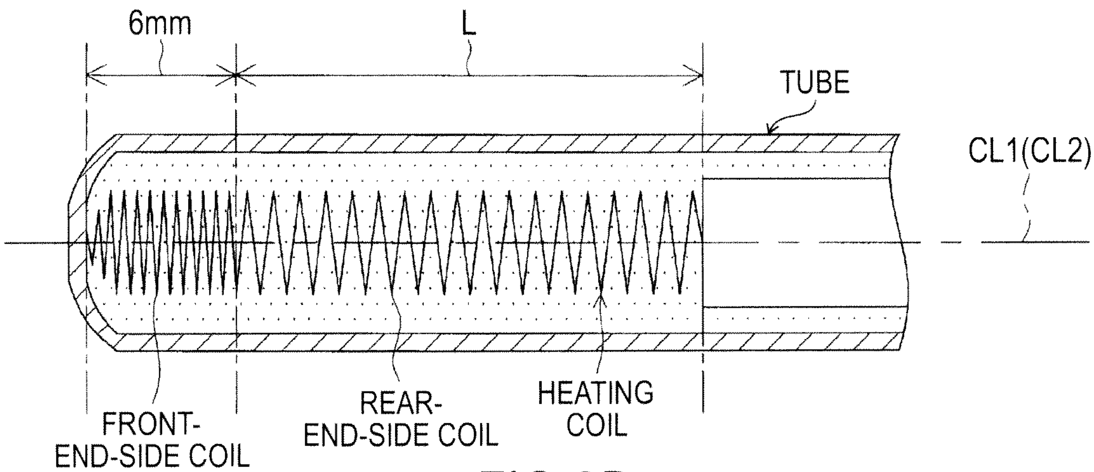
HEATING
COIL

FIG.8A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HEATING
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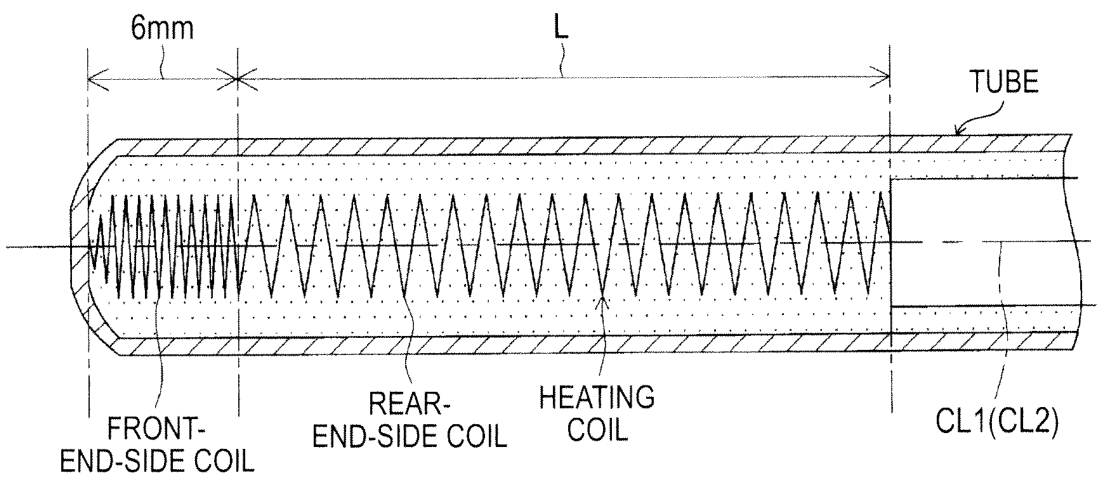
FIG.8B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**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2011/062373

A. CLASSIFICATION OF SUBJECT MATTER
*F23Q7/00*(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F23Q7/00

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

| | | | |
|---|---|---|---|
| Jitsuyo Shinan Koho | 1922-1996 | Jitsuyo Shinan Toroku Koho | 1996-2011 |
| Kokai Jitsuyo Shinan Koho | 1971-2011 | Toroku Jitsuyo Shinan Koho | 1994-2011 |

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | JP 7-19474 A (Isuzu Ceramics Research Institute Co., Ltd.), 20 January 1995 (20.01.1995), entire text; all drawings (Family: none) | 1-13 |
| A | JP 2-86086 A (Hitachi, Ltd.), 27 March 1990 (27.03.1990), entire text; all drawings (Family: none) | 1-13 |
| A | WO 2009/84453 A1 (NGK Spark Plug Co., Ltd.), 09 July 2009 (09.07.2009), entire text; all drawings & JP 2009-156560 A | 1-13 |

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 20 July, 2011 (20.07.11) | 02 August, 2011 (02.08.11) |

| Name and mailing address of the ISA/ | Authorized officer |
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| Japanese Patent Office | |
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**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2011/062373

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
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| A | JP 2006-153306 A (NGK Spark Plug Co., Ltd.), 15 June 2006 (15.06.2006), entire text; all drawings (Family: none) | 1-13 |

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## REFERENCES CITED IN THE DESCRIPTION

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### Patent documents cited in the description

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