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GLOW PLUG

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A glow plug includes: a sheath tube (810) extending in the axial direction and whose forward end is closed; an axial rod (200) inserted into the sheath tube; a spiral forward coil (820) disposed in the sheath tube and connected to a forward-end inner wall surface of the sheath tube; and a spiral rear coil (830) disposed in the sheath tube and connected between a rear end portion of the forward coil and a forward end portion of the axial rod. A resistance ratio R1 and a resistance ratio R2 satisfy the relational expression $R1 > R2$, where the resistance ratio R1 is the ratio of the resistance of the forward coil at 1,000°C to the resistance of the forward coil at 20°C, and the resistance ratio R2 is the ratio of the resistance of the rear coil at 1,000°C to the resistance of the rear coil at 20°C.

A main component of the forward coil is tungsten (W) or molybdenum (Mo) to restrain melting thereof when high-temperature control is performed.

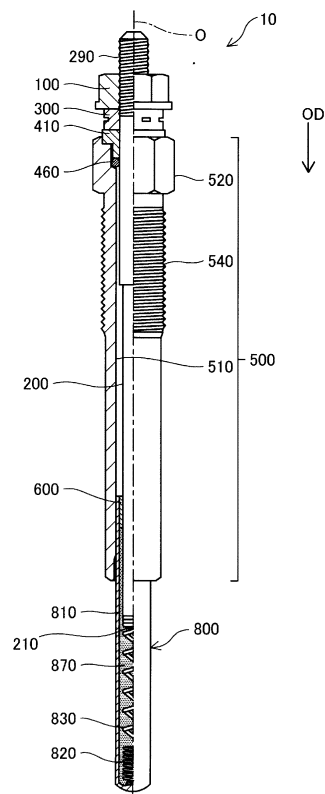


FIG. 2

Description

[0001] The present invention relates to a glow plug.

[0002] Conventionally known glow plugs include a glow plug having only a heat generation coil within a sheath tube, and a glow plug having the heat generation coil and a control coil within the sheath tube (Patent Document 1). In the glow plug described in Patent Document 1 and having the heat generation coil and the control coil, the heat generation coil contains molybdenum (Mo) or tungsten (W) as a main component, and the control coil is formed of a metal material which contains Co or Ni as a main component, as represented by a cobalt (Co)-nickel (Ni)-iron (Fe) alloy. In this glow plug, a resistance change of a forward end coil caused by a temperature change thereof (the resistance ratio of the forward end coil) is smaller than that of a rear coil; in the course of heating up (at the time of a relatively low temperature), the resistance of the control coil becomes lower than the resistance of the heat generation coil to thereby intensify heat generation of the heat generation coil; and upon saturation of temperature as a result of heating up of the glow plug, the resistance of the control coil becomes higher than the resistance of the heat generation coil, whereby heat generation of the heat generation coil can be controlled. Meanwhile, Patent Document 2 discloses a glow plug having a forward coil formed of, for example, a cobalt (Co)-nickel (Ni)-iron (Fe) alloy and a rear coil formed of a nickel (Ni)-iron (Fe) alloy, wherein the resistance ratio of the forward coil is made greater than the resistance ratio of the rear coil, whereby a temperature change of a forward end portion of the glow plug is accurately transmitted to the control circuit.

[Prior Art Documents]

[Patent Documents]

[0003]

[Patent Document 1] International Publication No. WO2011/162074

[Patent Document 2] Japanese Patent Application Laid-Open (*kokai*) No. 2004-191040

[0004] In recent years, control for maintaining the temperature of a glow plug at a temperature higher than 1,000°C (hereinafter, may be called high-temperature control) has been desired. However, the glow plug described in Patent Document 2 is configured on the assumption that the glow plug is controlled such that its temperature is maintained at 1,000°C (Patent Document 2, FIG. 4). Thus, if the above-mentioned high-temperature control is performed on the glow plug, since the forward coil formed of, for example, a cobalt (Co)-nickel (Ni)-iron (Fe) alloy is of relatively low melting point, the glow plug has potentially involved melting of the forward coil. Therefore, there has been desired a technique for

restraining melting of the forward coil of such a glow plug even when high-temperature control is performed on the glow plug.

[0005] The present invention has been conceived to solve the above problem and can be embodied in the following modes.

(1) A mode of the present invention provides a glow plug comprising: a sheath tube extending in a direction of an axial line and whose forward end is closed; an axial rod inserted into the sheath tube; a spiral forward coil disposed in the sheath tube and connected to a forward-end inner wall surface of the sheath tube; and a spiral rear coil disposed in the sheath tube and connected between a rear end portion of the forward coil and a forward end portion of the axial rod. In this glow plug, a resistance ratio $R1$ and a resistance ratio $R2$ satisfy a relational expression $R1 > R2$, where the resistance ratio $R1$ is a ratio of a resistance of the forward coil at 1,000°C to a resistance of the forward coil at 20°C, and the resistance ratio $R2$ is a ratio of a resistance of the rear coil at 1,000°C to a resistance of the rear coil at 20°C; and a main component of the forward coil is tungsten (W) or molybdenum (Mo). According to the glow plug of the present mode, since the resistance change $R1$ of the forward coil caused by a temperature change thereof is greater than the resistance change $R2$ of the rear coil caused by a temperature change thereof, the temperature change of the forward coil can be accurately transmitted to a control circuit. Also, since the main component of the forward coil is tungsten (W) or molybdenum (Mo), there can be restrained the melting of the forward coil when high-temperature control is performed.

(2) In the glow plug of the above mode, the total of the resistance of the forward coil at 20°C and the resistance of the rear coil at 20°C may be greater than 0.275 Ω. Even in execution of such rapid heat-up as to raise the surface temperature of a forward-end portion of the sheath tube to 1,000°C or higher within three seconds from start of heat-up through application of a voltage of 11 V to the glow plug, the melting of the forward coil can be restrained as in the case of high-temperature control, by means of the main component of the forward coil being tungsten (W) or molybdenum (Mo). However, performing rapid heat-up may cause excess current (hereinafter, may be called overcurrent) to flow to the control circuit. In this connection, the glow plug of the present mode can restrain flow of excess current to the control circuit even though rapid heat-up is performed.

(3) In the glow plug of the above mode, the total of the resistance of the forward coil at 20°C and the resistance of the rear coil at 20°C may be equal to or less than 0.600 Ω. According to the glow plug of the present mode, sufficient current can be caused to flow to the forward coil and to the rear coil; there-

fore, the glow plug can effectively generate heat. Thus, the glow plug is suited for rapid heat-up.

(4) In the glow plug of the above mode, the resistance of the rear coil at 20°C may be greater than the resistance of the forward coil at 20°C. According to the glow plug of the present mode, since, at the early stage of heat-up of the glow plug, the rear coil generates more heat than does the forward coil, transmission of heat from the forward coil to the rear coil can be restrained in the course of heat-up; accordingly, the forward coil can effectively heat up a forward end portion of the glow plug. Therefore, the glow plug can be heated up more rapidly.

(5) In the glow plug of the above mode, the resistance of the rear coil at 20°C may be six times or less the resistance of the forward coil at 20°C. According to the glow plug of the present mode, the glow plug can be heated up more rapidly, and there can be restrained an increase in power consumption, which could otherwise result from excess heat generation of the rear coil.

(6) In the glow plug of the above mode, the resistance ratio R1 of the forward coil may be 5.0 or higher, and the resistance ratio R2 of the rear coil may be 0.80 to 1.2. According to the glow plug of the present mode, when the temperature of a forward end portion of the glow plug changes, the resistance of the forward coil changes greatly. By contrast, even when a portion of the glow plug where the rear coil is positioned changes in temperature, a change of resistance of the rear coil is small. Thus, a temperature change of a forward end portion of the glow plug can be appropriately (accurately) transmitted to the control circuit while the influence of the rear coil is restrained.

(7) In the glow plug of the above mode, the rear coil may be formed of an alloy which contains iron (Fe), chromium (Cr), and aluminum (Al), or an alloy which contains nickel (Ni) and chromium (Cr). According to the glow plug of the present mode, since the resistance ratio R2 of the rear coil is small, a temperature change of a forward end portion of the glow plug can be accurately transmitted to the control circuit.

(8) In the glow plug of the above mode, a wire diameter of the rear coil may be greater than a wire diameter of the forward coil. According to the glow plug of the present mode, there can be restrained excess heat generation of the rear coil in the course of heat-up of the glow plug. Thus, the glow plug is suited for rapid heat-up.

(9) In the glow plug of the above mode, a length L1 and a length L2 may satisfy a relational expression $L1 < L2$, where the length L1 is a length of the forward coil along the axial line from the forward-end inner wall surface of the sheath tube to a connection with the rear coil, and the length L2 is a length of the rear coil along the axial line from the connection with the

forward coil to a forward end surface of the axial rod. According to the glow plug of the present mode, since the length L1 of the forward coil is shorter than the length L2 of the rear coil, a region to be heated by the forward coil can be reduced. Thus, power consumption of the glow plug can be reduced.

(10) In the glow plug of the above mode, an average pitch P1 of turns of a spiral portion of the forward coil and an average pitch P2 of turns of a spiral portion of the rear coil may satisfy a relational expression $P2/P1 \geq 3.5$. According to the glow plug of the present mode, since heat generation can be concentrated at a forward end portion of the glow plug where the forward coil is positioned, power consumption of the glow plug can be reduced.

(11) In the glow plug of the above mode, the resistance of the forward coil at a predetermined temperature in excess of 1,000°C may be higher than the resistance of the rear coil at the predetermined temperature in excess of 1,000°C. According to the glow plug of the present mode, as compared with the case where the resistance of the forward coil at the predetermined temperature in excess of 1,000°C is equal to or less than the resistance of the rear coil at the predetermined temperature in excess of 1,000°C, there can be reduced electric power which the rear coil consumes for the forward coil to generate heat having the predetermined temperature in excess of 1,000°C.

(12) In the glow plug of the above mode, the sheath tube comprises a side surface portion extending in the direction of the axial line, the forward coil is spaced from the side surface portion, and an outer diameter D1 and an inner diameter D2 satisfy a relational expression $(D2-D1)/2 \leq 0.8$ (mm), where the outer diameter is an outer diameter of the forward coil, and the inner diameter D2 is an inner diameter of the side surface portion that corresponds to a portion of the sheath tube in which the forward coil is disposed. According to the glow plug of the present mode, the forward coil can effectively heat up a forward end portion of the glow plug. Therefore, the glow plug can be heated up more rapidly.

[0006] The present invention can be embodied in various forms other than the glow plug. For example, the present invention can be embodied in a method of manufacturing a glow plug, and an igniter having a glow plug.

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

FIG. 1 is a block diagram showing a glow plug control system having a glow plug according to an embodiment of the present invention.

FIG. 2 is an explanatory view showing the glow plug.

FIG. 3 is a sectional view showing the structure of a sheath heater in detail.

FIG. 4 is a table showing the results of experiment 1.
 FIG. 5 is a table showing the results of experiment 2.
 FIG. 6 is a table showing the results of experiment 3.
 FIG. 7 is a table showing the results of experiment 4.

A. Embodiment

A1. Configuration of Glow Plug Control System

[0008] FIG. 1 is a block diagram showing a glow plug control system 21 according to an embodiment of the present invention. The glow plug control system 21 includes a glow plug 10, a control unit 32, and a switch 33. FIG. 1 shows only a single glow plug 10. However, an actual engine has a plurality of cylinders, and the glow plug 10 and the switch 33 are provided for each cylinder.

[0009] The control unit 32 is a microcomputer having a CPU, ROM, RAM, etc. The control unit 32 controls energization of the glow plug 10 by PWM (Pulse Width Modulation) control. The control unit 32 can calculate the voltage applied to the glow plug 10 on the basis of an input voltage. The switch 33 switches on/off energization of the glow plug 10 from a battery VA according to an instruction from the control unit 32. The switch 33 is configured to operate an FET (Field Effect Transistor) having a current detecting function through an NPN transistor, etc. The control unit 32 obtains resistance of the glow plug 10 from an applied voltage and current which flows to the glow plug 10 and is measured at the switch 33. Further, in the present embodiment, when the engine key is turned on, the control unit 32 can perform preglow energization for rapidly raising temperature of the glow plug 10 and, after preglow energization, afterglow energization for maintaining the glow plug 10 at a predetermined temperature for a predetermined period of time.

[0010] In preglow energization, the control unit 32 applies a voltage of 11 V to the glow plug 10, thereby performing rapid heat-up; specifically, raising the surface temperature of a sheath tube of the glow plug 10 at a position located 2 mm rearward in the axial direction OD from the forward end (to be described later) of the sheath tube, to 1,000°C or higher within three seconds from start of the voltage application. In preglow energization, the control unit 32 makes a curve indicative of the relation between power applied to the glow plug 10 and elapsed time coincide with a reference curve prepared in advance, thereby rapidly raising the temperature of the glow plug 10 to a target temperature. Specifically, by use of a relational expression or table indicative of the reference curve prepared in advance, the control unit 32 obtains power to be applied at individual points of elapsed time from start of energization. The control unit 32 obtains voltage to be applied to the glow plug 10 at a certain point of elapsed time from the relation between current flowing to the glow plug 10 and power to be applied at the point of elapsed time, thereby controlling voltage to be applied to the glow plug 10 by PWM control. Thus, power is applied in such a manner as to follow the reference curve,

whereby the glow plug 10 generates heat according to integrated quantity of power applied up to individual points of elapsed time in the course of heating up. Therefore, upon completion of application of power along the reference curve, the glow plug 10 reaches a target temperature in a period of time indicated by the reference curve.

[0011] In afterglow energization, power to be supplied to the glow plug 10 is adjusted so as to maintain the surface temperature of the sheath tube of the glow plug 10 at a temperature higher than 1,000°C for a relatively long period of time (e.g., about 180 seconds). In afterglow energization, the control unit 32 controls energization of the glow plug 10 such that the resistance of the glow plug 10 becomes equal to a resistance (a target resistance) thereof at the time when the glow plug 10 is heated to a target temperature (high-temperature control). Specifically, the control unit 32 calculates an effective voltage to be applied to the glow plug 10, from a difference between the current resistance of the glow plug 10 and the target resistance by, for example, PI (Proportional-Integral) control. On the basis of the calculated effective voltage, the control unit 32 determines a duty ratio, which is the quotient of dividing a pulse width by a pulse period, and controls energization accordingly.

A2. Structure of Glow Plug

[0012] FIG. 2 is an explanatory view showing the glow plug 10. The glow plug 10 includes a sheath heater (heat generation device) 800 for generating heat and functions as a heat source for assisting ignition at startup of an internal combustion engine (not shown) such as a diesel engine. The glow plug 10 includes the sheath heater 800, an axial rod 200, and a metallic shell 500. These component members of the glow plug 10 are assembled together along the axial direction OD of the glow plug 10. FIG. 2 shows an external structure on the right side of an axial line O and a sectional structure on the left side of the axial line O. In the present specification, a side toward the sheath heater 800 in the glow plug 10 is called the "forward side," and a side toward an engagement member 100 is called the "rear side."

[0013] The metallic shell 500 is a tubular member formed of carbon steel. The metallic shell 500 holds the sheath heater 800 at a forward end portion. Also, the metallic shell 500 holds the axial rod 200 at a rear end portion through an insulation member 410 and an O-ring 460. The position along the axial line O of the insulation member 410 is fixed as a result of a ring 300 in contact with the rear end of the insulation member 410 being crimped to the axial rod 200. Further, a portion of the axial rod 200 extending from the insulation member 410 to the sheath heater 800 is disposed in an axial hole 510 of the metallic shell 500. The axial hole 510 is a through hole formed along the axial line O and is greater in diameter than the axial rod 200. In a state in which the axial rod 200 is positioned in the axial hole 510, a gap is formed

between the axial rod 200 and the wall of the axial hole 510 for electrically insulating them from each other. The sheath heater 800 is press-fitted into a forward end portion of the axial hole 510 to thereby be joined to the forward end portion. The metallic shell 500 further includes a tool engagement portion 520 and an external thread portion 540. A tool (not shown) is engaged with the tool engagement portion 520 of the metallic shell 500 for attaching and detaching the glow plug 10. The external thread portion 540 meshes with an internal thread formed in an internal combustion engine (not shown).

[0014] The axial rod 200 is a circular columnar (rodlike) member formed of an electrically conductive material. While being inserted through the axial hole 510 of the metallic shell 500, the axial rod 200 is disposed in position along the axial line O. The axial rod 200 includes a forward end portion 210 formed at the forward end side and an external thread portion 290 provided at the rear end side. The forward end portion 210 is inserted into the sheath heater 800. The external thread portion 290 protrudes rearward from the metallic shell 500. The engagement member 100 meshes with the external thread portion 290.

[0015] FIG. 3 is a sectional view showing the structure of a sheath heater 800 in detail. With the forward end portion 210 of the axial rod 200 inserted into the sheath heater 800, the sheath heater 800 is press-fitted into the axial hole 510 of the metallic shell 500. The sheath heater 800 includes a sheath tube 810, a forward coil 820, a rear coil 830, and an insulator 870.

[0016] The sheath tube 810 is a tubular member extending in the axial direction OD and whose forward end 811 is closed. The sheath tube 810 accommodates therein the forward coil 820, the rear coil 830, and the insulator 870. The sheath tube 810 includes a forward end portion 813 curved outward and a side surface portion 814 extending in the axial direction OD and connected to the forward end portion 813. A rear end portion 819 of the side surface portion 814 opens in a direction opposite the forward end portion 813. The forward end portion 210 of the axial rod 200 is inserted into the sheath tube 810 from the rear end portion 819. The sheath tube 810 is electrically insulated from the axial rod 200 by a packing 600 and the insulator 870. Meanwhile, the sheath tube 810 is in contact with the metallic shell 500 to thereby be electrically connected to the metallic shell 500. The sheath tube 810 is formed of, for example, austenitic stainless steel which contains iron (Fe), chromium (Cr), and carbon (C), or a nickel (Ni)-based alloy such as INCONEL (INCONEL is a registered trademark) or Alloy602 (corresponding to DIN2.4633 alloy specified by German Industrial Standard (DIN)).

[0017] The insulator 870 is powder of an electrical insulation material. For example, magnesium oxide (MgO) powder is used as the insulator 870. The insulator 870 is filled (disposed) in gaps between the sheath tube 810, and the forward coil 820 and the rear coil 830, thereby providing electrical insulation in gaps between the sheath

tube 810, and the forward coil 820, the rear coil 830, and the axial rod 200.

[0018] The forward coil 820 is disposed in the sheath tube 810 along the axial direction OD and generates heat by energization thereof. The forward coil 820 includes a forward end portion 821, which is a forward coil end portion, and a rear end portion 829, which is a rear coil end portion. The forward end portion 821 is welded to an inner wall surface 812 of the forward end portion 813 of the sheath tube 810 to thereby be electrically connected to the sheath tube 810. The rear end portion 829 is electrically connected to the rear coil 830 through a connection 840 formed as a result of welding of the forward coil 820 and the rear coil 830. The forward coil 820 is formed of, for example, tungsten (W), molybdenum (Mo), or a tungsten (W) alloy and contains tungsten (W) or molybdenum (Mo) as a main component. Notably, in the present embodiment, the main component is a substance whose content (% by mass) is 50% by mass or higher. In the present embodiment, the forward coil 820 is formed of tungsten (W).

[0019] The rear coil 830 includes a forward end portion 831, which is a forward coil end portion, and a rear end portion 839, which is a rear coil end portion. The forward end portion 831 is electrically connected to the forward coil 820 through the connection 840. The rear end portion 839 is joined to the forward end portion 210 of the axial rod 200 to thereby be electrically connected to the axial rod 200. The rear coil 830 is formed of, for example, a nickel (Ni)-chromium (Cr) alloy or an iron (Fe)-chromium (Cr)-aluminum (Al) alloy. In the present embodiment, the rear coil 830 is formed of an iron (Fe)-chromium (Cr)-aluminum (Al) alloy.

[0020] Meanwhile, the forward coil 820 and the rear coil 830 are configured such that their resistance changes (resistance ratios) caused by a temperature change satisfy the following relational expression (1).

[0021] A ratio R_{11000}/R_{120} (hereinafter, called the resistance ratio R1) and a ratio R_{21000}/R_{220} (hereinafter, called the resistance ratio R2) satisfy the following relational expression (1), where the resistance ratio R1 is the ratio of the resistance R_{11000} of the forward coil 820 at 1,000°C to the resistance R_{120} of the forward coil 820 at 20°C, and the resistance ratio R2 is the ratio of the resistance R_{21000} of the rear coil 830 at 1,000°C to the resistance R_{220} of the rear coil 830 at 20°C. In the present embodiment, the resistance ratio R1 of the forward coil 820 is 5.0 or higher, and the resistance ratio R2 of the rear coil 830 is 0.80 to 1.2.

$$R1 > R2 \dots (1)$$

[0022] Hereinafter, the specification of the glow plug 10 which satisfies the relational expression (1) and in which the main component of the forward coil 820 is tungsten (W) or molybdenum (Mo) may also be called "spec-

ification 1."

[0023] Since the thus-configured glow plug 10 of the present embodiment is such that the resistance change R1 of the forward coil 820 caused by a temperature change, and the resistance change R2 of the rear coil 830 caused by the temperature change satisfy the above-mentioned relational expression (1), the temperature change of the forward coil 820 can be accurately transmitted to the glow plug control system 21 (control unit 32) as compared with the case where the resistance change R1 of the forward coil 820 caused by the temperature change is smaller than the resistance change R2 of the rear coil 830 caused by the temperature change. Also, since the main component of the forward coil 820 is tungsten (W) or molybdenum (Mo), even when high-temperature control is performed, the melting of the forward coil 820 can be restrained.

[0024] Preferably, the glow plug 10 of the present embodiment further conform to one or more of the following specifications 2 to 12. The specifications and the reason why conformance to the specifications is preferred will be described below.

<Specification 2>

[0025] The total ($R_{1_{20}} + R_{2_{20}}$) of the resistance R1₂₀ of the forward coil 820 at 20°C and the resistance R2₂₀ of the rear coil 830 at 20°C is greater than 0.275 Ω.

[0026] Even in execution of such rapid heat-up as to raise the surface temperature of a forward-end portion of the sheath tube 810 to 1,000°C within three seconds from start of heat-up through application of a voltage of 11 V to the glow plug 10, the melting of the forward coil 820 can be restrained as in the case of high-temperature control, by means of the main component of the forward coil 820 being tungsten (W) or molybdenum (Mo). Meanwhile, in execution of such rapid heat-up, if the total ($R_{1_{20}} + R_{2_{20}}$) is equal to or less than 0.275 Ω, a current of 40 A or more will flow to the glow plug 10. In such a case, a wire breakage may occur in a control circuit of the glow plug control system 21 as a result of flow of overcurrent to the control circuit. However, if the total ($R_{1_{20}} + R_{2_{20}}$) is greater than 0.275 Ω, even in execution of rapid heat-up, the occurrence of a wire breakage in the control circuit can be restrained.

<Specification 3>

[0027] The total of the resistance of the forward coil 820 at 20°C and the resistance of the rear coil 830 at 20°C is 0.600 Ω or less.

[0028] In the case of application of a fixed voltage to the glow plug 10, as resistance R (Ω) increases, current I (A) decreases. Since the amount of generated heat P (W) is the product of the resistance R (Ω) and the square (I^2) of the current I (A), as the resistance R of the glow plug 10 increases, the amount of generated heat P decreases greatly in proportion to the square of current.

However, in the case of a resistance total ($R_{1_{20}} + R_{2_{20}}$) of 0.600 Ω or less, since a decrease in current can be restrained, sufficient current can be caused to flow to the forward coil 820 and to the rear coil 830. Thus, the glow plug 10 can effectively generate heat and is suited for rapid heat-up.

<Specification 4>

[0029] The resistance of the rear coil 830 at 20°C is greater than the resistance of the forward coil 820 at 20°C.

[0030] In the case of the glow plug 10 conforming to the present specification, at the early stage of heat-up of the glow plug 10, the rear coil 830 generates more heat than does the forward coil 820. Thus, since transmission of heat from the forward coil 820 to the rear coil 830 can be restrained in the course of heat-up, the forward coil 820 can effectively heat up a forward end portion of the glow plug 10. Therefore, the glow plug 10 can be heated up more rapidly.

<Specification 5>

[0031] The resistance of the rear coil 830 at 20°C may be six times or less the resistance of the forward coil 820 at 20°C.

[0032] In the glow plug 10 which conforms to the present specification, since sufficient current can be caused to flow to the forward coil 820 and to the rear end coil 830, the glow plug 10 can be effectively heated up. Thus, the glow plug 10 is suited for rapid heat-up. Also, there can be restrained an increase in power consumption, which could otherwise result from excess heat generation of the rear coil 830.

<Specification 6>

[0033] The resistance ratio R1 of the forward coil 820 is 5.0 or higher, and the resistance ratio R2 of the rear coil 830 is 0.80 to 1.2.

[0034] In the glow plug 10 which conforms to the present specification, when a forward end portion of the glow plug 10 where the forward coil 820 is positioned changes in temperature, the resistance of the forward coil 820 changes greatly. By contrast, even when a portion of the glow plug 10 where the rear coil 830 is positioned changes in temperature, a change of resistance of the rear coil 830 is small. Thus, a temperature change of a forward end portion of the glow plug 10 can be accurately transmitted to the control circuit while the influence of the rear coil 830 is restrained. The glow plug 10 of the present embodiment conforms to the present specification.

<Specification 7>

[0035] The rear coil 830 is formed of an alloy which

contains iron (Fe), chromium (Cr), and aluminum (Al), or an alloy which contains nickel (Ni) and chromium (Cr).

[0036] In the glow plug 10 which conforms to specification 6, since the resistance ratio R2 of the rear coil 830 is small, a temperature change of a forward end portion of the glow plug 10 can be transmitted more accurately to the control circuit. The glow plug 10 of the present embodiment conforms to the present specification.

<Specification 8>

[0037] The wire diameter of the rear coil 830 is greater than the wire diameter of the forward coil 820.

[0038] The glow plug 10 which conforms to the present specification can restrain excess heat generation of the rear coil 830 in the course of heat-up thereof and thus is suited for rapid heat-up. The glow plug 10 of the present embodiment conforms to the present specification; specifically, the wire diameter of the forward coil 820 is 0.2 mm, whereas the wire diameter of the rear coil 830 is 0.4 mm.

<Specification 9>

[0039] FIG. 3 shows length L1 along the axial line O of the forward coil 820 from the forward-end inner wall surface 812 of the sheath tube 810 to the connection 840 with the rear coil 830, and length L2 along the axial line O of the rear coil 830 from the connection 840 with the forward coil 820 to a forward end surface 211 of the axial rod 200. The length L1 and the length L2 satisfy the following relational expression (2).

$$L1 < L2 \dots (2)$$

[0040] In the glow plug 10 which satisfies the above relational expression (2), since the length L1 of the forward coil 820 is shorter than the length L2 of the rear coil 830, a region to be heated by the forward coil 820 can be reduced, whereby the glow plug 10 can concentrate heat generation on its forward end portion where the forward coil 820 is positioned. Thus, power consumption of the glow plug 10 can be reduced.

<Specification 10>

[0041] An average pitch P1 of turns of a spiral portion of the forward coil 820 and an average pitch P2 of turns of a spiral portion of the rear coil 830 satisfy the following relational expression (3). The term "pitch" indicates an interval between turns of a spiral portion of the coil (e.g., interval p1 of the forward coil 820 shown in FIG. 3, and interval p2 of the rear coil 830 shown in FIG. 3). The average pitch is an average interval at a spiral portion of the coil where intervals are stable. In the present embodiment, the average pitch P1 of the forward coil 820 is

obtained by averaging the intervals of a spiral portion, indicated by T1 in FIG. 3, remaining after eliminating a spiral portion of three turns extending rearward from the forward-end inner wall surface 812 of the sheath tube 810 and a spiral portion of three turns extending from the connection 840 toward a forward end 811 of the sheath tube 810. The average pitch P2 of the rear coil 830 is obtained by averaging the intervals of a spiral portion, indicated by T2 in FIG. 3, remaining after eliminating a spiral portion of one turn extending rearward from the connection 840 and a spiral portion of one turn extending forward from the forward end surface 211 of the axial rod 200.

$$P2/P1 \geq 3.5 \dots (3)$$

[0042] In the glow plug 10 which conforms to specification 10 (the above relational expression (3)), since heat generation can be concentrated at a forward end portion of the glow plug 10 where the forward coil 820 is positioned, power consumption of the glow plug 10 can be reduced. More preferably, the average pitch P1 and the average pitch P2 satisfy the relational expression $P2/P1 \geq 4.0$.

<Specification 11 >

[0043] The resistance of the forward coil 820 at a predetermined temperature in excess of 1,000°C is higher than the resistance of the rear coil 830 at the predetermined temperature in excess of 1,000°C.

[0044] According to the glow plug 10 which conforms to the present specification, as compared with the case where the resistance of the forward coil 820 at the predetermined temperature in excess of 1,000°C is equal to or less than the resistance of the rear coil 830 at the predetermined temperature in excess of 1,000°C, there can be reduced electric power which the rear coil 830 consumes for the forward coil 820 to generate heat having the predetermined temperature in excess of 1,000°C. Therefore, the power consumption of the glow plug 10 can be reduced.

<Specification 12>

[0045] FIG. 3 shows outer diameter D1 of the forward coil 820, and inner diameter D2 of the side surface portion 814 that corresponds to a portion of the sheath tube 810 where the forward coil 820 is disposed. The outer diameter D1 and the inner diameter D2 satisfy the following relational expression (4).

$$(D2-D1)/2 \leq 0.8(\text{mm}) \dots (4)$$

[0046] In the glow plug 10 which satisfies the above

relational expression (4), the forward coil 820 can effectively heat up a forward end portion of the glow plug 10. Therefore, the glow plug 10 can be heated up more rapidly.

<Specification 13>

[0047] Length L1 of the forward coil 820 is 6.0 mm or less.

[0048] In the case of the glow plug 10 whose forward coil 820 has a length L1 of 6.0 mm or less, in a state in which the glow plug 10 is attached to an engine head, the forward coil 820 is positioned within a combustion chamber; therefore, the forward coil 820 can effectively generate heat within the combustion chamber. Thus, power consumption of the glow plug 10 can be reduced. In the glow plug 10 of the present embodiment, the length L1 of the forward coil 820 is 5.0 mm or less.

[0049] The reason why, in execution of high-temperature control, melting of the forward coil 820 can be restrained through conformance to the above specification 1 will be described below on the basis of the results of experiment 1. The reason why the glow plug 10 is suited for rapid heat-up through conformance to the above specification 2 or 3 will be described on the basis of the results of experiment 2. The reason why the glow plug 10 is suited for rapid heat-up through conformance to the above specification 8 or 9 (relational expression (2)) will be described on the basis of the results of experiment 3. The reason why power consumption of the glow plug 10 can be reduced through conformance to the above specification 9 (relational expression (2)) or 10 (relational expression (3)) will be described on the basis of the results of experiment 4.

B. Description and Results of Experiments

B1. Description and Results of Experiment 1

[0050] FIG. 4 is a table showing the results of experiment 1. FIG. 4 shows the material of the forward coil 820; the material of the rear coil 830; the relation (magnitude relation) between the resistance ratio R1 and the resistance ratio R2, where the resistance ratio R1 is the ratio of the resistance of the forward coil 820 at 1,000°C to the resistance of the forward coil 820 at 20°C, and the resistance ratio R2 is the ratio of the resistance of the rear coil 830 at 1,000°C to the resistance of the rear coil 830 at 20°C; and the results of judgment. This experiment prepared samples 1 to 6 of the glow plugs 10 which differed in the material of the forward coil 820 and in the material of the rear coil 830, and examined the samples for influence of coil materials on melting of the coils. Samples 1 to 6 satisfy the above-mentioned relational expression (1).

<Wire diameter of coil>

[0051]

- 5 Wire diameter of forward coil: 0.20 mm
- Wire diameter of rear coil: 0.40 mm
- <Coil lengths L1 and L2>
- Forward coil length L1: 7 mm
- Rear coil length L2: 12 mm
- 10 <Average pitch and pitch ratio>
- Average pitch P1 of forward coil: 0.30 mm
- Average pitch P2 of rear coil: 2.5 mm
- Average pitch ratio P2/P1: 8.33

15 **[0052]** In experiment 1, samples 1 to 6 underwent 6,000 cycles of a cycle test consisting of the following steps 1 and 2 as one cycle. Temperature was measured by use of a thermocouple.

20 **[0053]** (Step 1): A voltage of 11 V was applied to the samples to raise the surface temperature of the sheath tube 810 at a position located 2 mm along the axial direction OD rearward from the forward end 811 of the sheath heater 800 (sheath tube 810) to 1,000°C in two seconds after start of voltage application; then, the surface temperature of the sheath tube 810 was maintained at 1,100°C. Application of voltage stopped 180 seconds after start of voltage application. Application of voltage started at room temperature (about 20°C).

25 **[0054]** (Step 2): After application of voltage was stopped, the sheath heater 800 was cooled for 120 seconds by air blow.

30 **[0055]** After subjection to 6,000 cycles of the cycle test, the forward coils 820 were observed to judge the samples by the following criteria.

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A: The forward coil is not broken; the minimum wire diameter of the forward coil after the test is greater than 0.8 times the wire diameter before test; and the resistance of the forward coil after test is higher than 0.9 times the resistance before test.

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B: The forward coil is not broken, and the minimum wire diameter of the forward coil after the test is equal to or less than 0.8 times the wire diameter before test. Alternatively, the forward coil is not broken, and the resistance of the forward coil after test is equal to or less than 0.9 times the resistance before test.

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F: The forward coil broke before completion of 6,000 cycles of the cycle test.

50 **[0056]** The samples judged "A" or "B" can be said to be restrained from melting of the forward coil 820.

[0057] Upon completion of experiment 1, sample 1 whose forward coil 820 was formed of tungsten (W) and whose rear coil 830 was formed of a nickel (Ni)-chromium (Cr) alloy, and sample 3 whose forward coil 820 was formed of tungsten (W) and whose rear coil 830 was formed of a nickel (Ni)-tungsten (W) alloy were free from wire breakage of the forward coil 820. Also, in samples

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1 and 3, the minimum wire diameter of the forward coil 820 after test was greater than 0.8 times the wire diameter before test, and the resistance of the forward coil 820 after test was greater than 0.9 times the resistance before test. Thus, samples 1 and 3 were judged "A." Sample 2 whose forward coil 820 was formed of molybdenum (Mo) and whose rear coil 830 was formed of an iron (Fe)-chromium (Cr)-aluminum (Al) alloy was free from wire breakage of the forward coil 820. Also, in sample 2, the minimum wire diameter of the forward coil 820 after test was equal to or less than 0.8 times the wire diameter before test, and the resistance of the forward coil 820 after test was equal to or less than 0.9 times the resistance before test. Thus, sample 2 was judged "B." By contrast, a wire breakage of the forward coil 820 occurred in sample 4 whose forward coil 820 was formed of a cobalt (Co)-nickel (Ni)-iron (Fe) alloy and whose rear coil 830 was formed of an iron (Fe)-chromium (Cr)-aluminum (Al) alloy, sample 5 whose forward coil 820 was formed of a cobalt (Co)-nickel (Ni)-iron (Fe) alloy and whose rear coil 830 was formed of nickel (Ni), and sample 6 whose forward coil 820 was formed of a nickel (Ni)-chromium (Cr) alloy and whose rear coil 830 was formed of an iron (Fe)-chromium (Cr)-aluminum (Al) alloy. Thus, samples 4 to 6 were judged "F."

[0058] According to the results of experiment on samples 1 to 3 and samples 4 to 6, in the case where the forward coil 820 is formed of tungsten (W) or molybdenum (Mo), irrespective of material of the rear coil 830, melting of the forward coil 820 is restrained in execution of high-temperature control. Also, according to the results of experiment on samples 1 to 3, as compared with the forward coil 820 formed of molybdenum (Mo), the forward coil 820 formed of tungsten (W) is restrained from a reduction in its wire diameter and from a reduction in its resistance in execution of high-temperature control.

B2. Description and Results of Experiment 2

[0059] FIG. 5 is a table showing the results of experiment 2. FIG. 5 shows the total of the resistance R_{120} of the forward coil 820 at 20°C and the resistance R_{220} of the rear coil 830 at 20°C (total " $R_{120} + R_{220}$ "); the results of judgment on rapid heat-up performance; the results of judgment on inrush current; and the results of synthetic judgment. This experiment examined the influence of the total " $R_{120} + R_{220}$ " on rapid heat-up performance and on inrush current. Samples 7 to 10 satisfy the above-mentioned relational expression (1). Also, since the forward coils 820 of samples 7 to 10 are formed of tungsten (W) as shown below, samples 7 to 10 conform to the above-mentioned specification 1.

<Material of coil>

[0060]

Material of forward coil: tungsten (W)

Material of rear coil: iron (Fe)-chromium (Cr)-aluminum (Al) alloy

<Coil lengths L1 and L2>

Forward coil length L1: 7 mm

Rear coil length L2: 12 mm

<Average pitch and pitch ratio>

Average pitch P1 of forward coil: 0.30 mm

Average pitch P2 of rear coil: 2.5 mm

Average pitch ratio P2/P1: 8.33

[0061] In experiment 2, in order to evaluate rapid heat-up performance in relation to the total " $R_{120} + R_{220}$," a voltage of 11 V was applied to samples 7 to 10 to measure the length of time from start of voltage application until the surface temperature of the sheath tube 810 at a position located 2 mm rearward in the axial direction OD from the forward end 811 of the sheath tube 810 reached 1,000°C. The temperature was measured by use of a thermocouple. Application of voltage started at room temperature (about 20°C).

[0062] From the results of measurement of the length of time until 1,000°C was reached, rapid heat-up performance of the samples was judged by the following criteria.

A: 1,000°C was reached within 1.9 seconds from start of voltage application.

B: 1,000°C was reached in a time which is longer than 1.9 seconds but not longer than three seconds from start of voltage application.

F: 1,000°C was reached in a time of longer than three seconds from start of voltage application.

[0063] The samples which reach 1,000°C within three seconds from start of voltage application (the samples judged "A" or "B") can be said to have sufficient rapid heat-up performance. The samples which reach 1,000°C within 1.9 seconds from start of voltage application (the samples judged "A") can be said to be more suited for rapid heat-up, because these samples can reach 1,000°C within a period of time shorter than 3 seconds from start of voltage application.

[0064] Experiment 2 also measured samples 7 to 10 for current (inrush current) which flowed when a voltage of 11 V was applied. From measured inrush currents, the samples were judged by the following criteria.

A: A current of less than 40 A flows to the control circuit in execution of rapid heat-up.

F: A current of 40 A or more flows to the control circuit in execution of rapid heat-up.

[0065] In the samples judged "A," there is restrained flow of excess current to the control circuit of the glow plug control system 21 in execution of rapid heat-up, whereby the occurrence of a wire breakage in the control circuit can be restrained.

[0066] Further, from the results of judgment on rapid

heat-up and inrush current, the samples were synthetically judged by the following criteria.

A: Judgment "A" with respect to rapid heat-up performance and judgement "A" with respect to inrush current.

F: Judgment "B" or "F" with respect to at least one of rapid heat-up performance and inrush current.

[0067] The samples synthetically judged "A" can be said to be suited for rapid heat-up and be capable of restraining the occurrence of a wire breakage in the control circuit in execution of rapid heat-up.

[0068] According to the results of experiment 2, with regard to rapid heat-up performance, sample 7 having a total " $R_{120} + R_{220}$ " of 0.275Ω , sample 8 having a total of 0.280Ω , and sample 9 having a total of 0.600Ω reached $1,000^\circ\text{C}$ within 1.9 seconds from start of voltage application. Thus, samples 7 to 9 were judged "A." Sample 10 having a total of 0.605Ω reached $1,000^\circ\text{C}$ in a time of longer than 1.9 seconds to three seconds from start of voltage application. Thus, sample 10 was judged "B." The results of experiment indicate that samples 7 to 10 can perform such rapid heat-up as to raise the surface temperature of the sheath tube 810 at a position located 2 mm rearward along the axial direction OD from the forward end 811 of the sheath tube 810 to $1,000^\circ\text{C}$ or higher within three seconds from start of heat-up. Particularly, since samples 7 to 9 having a total of 0.600Ω or smaller can reach $1,000^\circ\text{C}$ within 1.9 seconds, through employment of a total of 0.600Ω or smaller; i.e., through conformance to the above-mentioned specification 3, the glow plug 10 can be suited for rapid heat-up.

[0069] In samples 8 to 10 having a total of greater than 0.275Ω , inrush current was less than 40 A. Thus, samples 8 to 10 were judged "A." By contrast, in sample 7 having a total of 0.275Ω , inrush current was equal to or greater than 40 A. Thus, sample 7 was judged "F." The results of experiment indicate that, through employment of a total of greater than 0.275Ω ; i.e., through conformance to the above-mentioned specification 2, flow of excess current to the control circuit can be restrained even in execution of rapid heat-up.

[0070] From the above results of experiment, samples 8 and 9 were synthetically judged "A," and samples 7 and 10 were synthetically judged "F." The results of synthetic judgement indicate that the glow plug 10 which conform to specifications 2 and 3 is suitable for rapid heat-up and can restrain occurrence of a wire breakage in the control circuit even in execution of rapid heat-up.

B3. Description and Results of Experiment 3

[0071] FIG. 6 is a table showing the results of experiment 3. FIG. 6 shows wire diameter d1 of the forward coil 820; wire diameter d2 of the rear coil 830; the magnitude relation between wire diameter d1 of the forward coil 820 and wire diameter d2 of the rear coil 830; and

the results of judgment. Experiment 3 examined the influence of the magnitude relation between wire diameter d1 of the forward coil 820 and wire diameter d2 of the rear coil 830 on rapid heat-up performance. Samples 11 to 13 satisfy the above-mentioned relational expression (1), and the forward coils 820 of samples 11 to 13 are formed of tungsten (W); therefore, samples 11 to 13 conform to the above-mentioned specification 1.

<Material of coil>

[0072]

Material of forward coil: tungsten (W)

Material of rear coil: nickel (Ni)-chromium (Cr) alloy
<Total of resistance R_{120} at 20°C of forward coil and resistance R_{220} at 20°C of rear coil>

Total " $R_{120} + R_{220}$ ": 0.35Ω

<Coil lengths L1 and L2>

[0073]

Forward coil length L1: 7 mm

Rear coil length L2: 12 mm

[0074] In experiment 3, similar to experiment 2, a voltage of 11 V was applied to samples 11 to 13 to measure the length of time from start of voltage application until the surface temperature of the sheath tube 810 at a position located 2 mm rearward in the axial direction OD from the forward end 811 of the sheath tube 810 reached $1,000^\circ\text{C}$. Rapid heat-up performance was judged by the following criteria. Application of voltage started at room temperature (about 20°C).

[0075] Judgment was made by the following criteria.

A: $1,000^\circ\text{C}$ was reached in a time of 1.8 seconds or less from start of voltage application.

B: $1,000^\circ\text{C}$ was reached in a time of longer than 1.8 seconds to three seconds from start of voltage application.

F: $1,000^\circ\text{C}$ was reached in a time of longer than three seconds from start of voltage application.

[0076] The samples which reach $1,000^\circ\text{C}$ within three seconds from start of voltage application (the samples judged "A" or "B") can be said to have sufficient rapid heat-up performance. The samples which reach $1,000^\circ\text{C}$ within 1.8 seconds from start of voltage application (the samples judged "A") can be said to be more suited for rapid heat-up.

[0077] According to the results of experiment 3, samples 11 and 12 in which wire diameter d2 of the rear coil 830 was greater than wire diameter d1 of the forward coil 820 reached $1,000^\circ\text{C}$ within 1.8 seconds from start of voltage application. Thus, samples 11 and 12 were judged "A." Sample 13 in which wire diameter d2 of the

rear coil 830 was smaller than wire diameter d1 of the forward coil 820 reached 1,000°C in a time of longer than 1.8 seconds to three seconds from start of voltage application. Thus, sample 13 was judged "B."

[0078] The results of experiment indicate that samples 11 to 13 can perform such rapid heat-up as to raise the surface temperature of the sheath tube 810 at a position located 2 mm rearward along the axial direction OD from the forward end 811 of the sheath tube 810 to 1,000°C or higher within three seconds from start of heat-up. Particularly, since samples 11 and 12 in which wire diameter d2 of the rear coil 830 is greater than wire diameter d1 of the forward coil 820 can reach 1,000°C within 1.8 seconds, by means of wire diameter d2 of the rear coil 830 being greater than wire diameter d1 of the forward coil 820; i.e., through conformance to the above-mentioned specification 8, the glow plug 10 can be more suited for rapid heat-up.

B4. Description and Results of Experiment 4

[0079] FIG. 7 is a table showing the results of experiment 4. FIG. 7 shows average pitch P1 (mm) of the forward coil 820; average pitch P2 (mm) of the rear coil 830; ratio P2/P1 between average pitch P1 and average pitch P2; relation (magnitude relation) between length L1 of the forward coil 820 and length L2 of the rear coil 830; and the results of judgment. Experiment 4 examined the influence of the length relation between the coils on power consumption by use of samples 15 and 26 which had the same pitch ratio and differed in the magnitude relation between lengths L1 and L2 of the coils. Also, experiment 4 examined the influence of ratio P2/P1 on power consumption by use of samples 14 to 25 in which coil length L1 was longer than coil length L2 and which differed in ratio P2/P1. Samples 14 to 26 satisfy the above-mentioned relational expression (1), and the forward coils 820 of samples 14 to 26 are formed of tungsten (W); therefore, samples 14 to 26 conform to the above-mentioned specification 1. In samples 14 to 25, the resistance R1₂₀ of the forward coil 820 at 20°C is 0.08 Ω to 0.15 Ω, and the resistance R2₂₀ of the rear coil 830 at 20°C is 0.22 Ω to 0.45 Ω. That is, samples 14 to 25 conform to the above-mentioned specifications 2 to 5.

<Material and wire diameter of coil>

[0080]

Material of forward coil: tungsten (W)
Wire diameter of forward coil: 0.20 mm
Material of rear coil: iron (Fe)-chromium (Cr)-aluminum (Al) alloy
Wire diameter of rear coil: 0.40 mm

<Coil lengths L1 and L2>

[0081]

Samples 1 to 12: L1 = 5 mm, L2 = 18 mm

Sample 13: L1 = 18 mm, L2 = 5 mm

[0082] In experiments on samples 14 to 26, current was measured in application of such voltage as to maintain the surface temperature of the sheath tube 810 at a position located 2 mm rearward in the axial direction OD from the forward end 811 of the sheath tube 810 at 1,000°C, and, from the applied voltage and the measured current, power to be consumed (power consumption) was calculated. The temperature was measured by use of a thermocouple. On the basis of power consumption (about 33 W or greater) of an ordinary glow plug which can perform rapid heat-up, power consumption of the samples was judged by the following criteria.

[0083] AA: Power consumption is 28 W or less (power consumption is greatly reduced as compared with an ordinary glow plug which can perform rapid heat-up).

A: Power consumption is greater than 28 W and less than 33 W (power consumption is reduced as compared with an ordinary glow plug which can perform rapid heat-up).

F: Power consumption is equal to or greater than 33 W (power consumption is equivalent to that of an ordinary glow plug which can perform rapid heat-up).

<Influence of magnitude relation between lengths on power consumption>

[0084] According to the results of experiment on samples 15 and 26 having the same pitch ratio, sample 15 in which length L1 of the forward coil 820 was shorter than length L2 of the rear coil 830 exhibited a power consumption of 28 W or less. Thus, sample 15 was judged "AA." By contrast, sample 26 in which length L1 of the forward coil 820 was longer than length L2 of the rear coil 830 exhibited a power consumption of 33 W or greater. Thus, sample 13 was judged "F." In sample 26, since length L1 of the forward coil 820 is longer than length L2 of the rear coil 830, conceivably, much power was consumed until the surface temperature of the sheath tube 810 reached 1,000°C through heat generation of the forward coil 820.

[0085] If the forward coil 820 is longer than the rear coil 830, difficulty may be encountered in concentrating heat generation at a forward end portion of the glow plug 10; as a result, heat generation at a forward end portion of the glow plug 10 requires application of large power to the glow plug 10, potentially resulting in an increase in power consumption. However, the above results of experiment indicate that, by means of length L1 of the forward coil 820 being shorter than length L2 of the rear coil 830; i.e., through conformance to the above-mentioned specification 9, power consumption of the glow plug 10 can be reduced.

<Influence of average pitch ratio $P2/P1$ on power consumption>

[0086] According to the results of experiment on samples 14 to 25 in which coil length $L1$ was longer than coil length $L2$ and which differed in average pitch ratio $P2/P1$, samples 14 to 25 having an average pitch ratio $P2/P1$ of 3.5 or higher exhibited a power consumption of less than 33 W. Particularly, samples 14 to 22 having an average pitch ratio $P2/P1$ of 4.0 or higher exhibited a power consumption of 28 W or less. Thus, samples 14 to 22 were judged "AA," and samples 23 and 24 were judged "A."

[0087] The above results of experiment indicate that, by means of average pitch $P1$ and average pitch $P2$ satisfying the relational expression " $P2/P1 \geq 3.5$ " (specification 10 (relational expression (3))), power consumption of the glow plug 10 can be reduced. Also, the results of experiment indicate that, through satisfaction of the relational expression " $P2/P1 \geq 4.0$," power consumption of the glow plug 10 can be more reduced.

C. Modifications

• Modification 1

[0088] In the above embodiment, resistance ratio $R1$ of the forward coil 820 is 5.0 or higher, and resistance ratio $R2$ of the rear coil 830 is 0.80 to 1.2. However, resistance ratio $R1$ of the forward coil 820 and resistance ratio $R2$ of the rear coil 830 may assume other values so long as resistance ratio $R1$ and resistance ratio $R2$ satisfy the above-mentioned relational expression (1). For example, resistance ratio $R1$ may be 4.0 or 3.5, and resistance ratio $R2$ may be 0.7 or 2.0. Notably, at a resistance ratio $R2$ of 1.0, the influence of resistance change of the rear coil 830 can be further restrained in transmission of a temperature change of a forward end portion of the glow plug 10 to the control circuit.

• Modification 2

[0089] The rear coil 830 may be formed of an alloy or metal other than a nickel (Ni)-chromium (Cr) alloy and an iron (Fe)-chromium (Cr)-aluminum (Al) alloy so long as use of such a material allows resistance ratio $R1$ and resistance ratio $R2$ to satisfy the above-mentioned relational expression (1).

• Modification 3

[0090] The wire diameter of the rear coil 830 may be smaller than the wire diameter of the forward coil 820.

• Modification 4

[0091] Length $L1$ of the forward coil 820 may be longer than 6.0 mm.

• Modification 5

[0092] In the above embodiment, the rear coil 830 of the glow plug 10 is formed of a single coil. However, the rear coil 830 of the glow plug 10 may be formed of a plurality of coils. In this case, if the rear coil 830 is formed of a plurality of coils in such a manner as to satisfy the above relational expression (1), effects similar to those of the above embodiment will be yielded. Also, if the length $L1$ and the total length $L2$ along the axial line O of a plurality of coils of the rear coil 830 from the connection 840 with the forward coil 820 to the forward end surface 211 of the axial rod 200 satisfy the above-mentioned relational expression (2), power consumption of the glow plug 10 can be reduced. Also, if the rear coil 830 is formed of a plurality of coils such that average pitch ratio $P2/P1$ between the forward coil 820 and the rear coil 830 satisfies the above-mentioned relational expression (3), power consumption of the glow plug 10 can be reduced.

[0093] The present invention is not limited to the above embodiment and modifications, but may be embodied in various other forms without departing from the spirit of the invention. For example, in order to solve, partially or entirely, the above-mentioned problem or yield, partially or entirely, the above-mentioned effects, technical features of the embodiments and modifications corresponding to technical features of the modes described in the section "Summary of the Invention" can be replaced or combined as appropriate. Also, the technical feature(s) may be eliminated as appropriate unless the present specification mentions that the technical feature(s) is mandatory.

[Description of Reference Numerals]

[0094]

10: glow plug
21: glow plug control system
32: control unit
33: switch
100: engagement member
200: axial rod
210: forward end portion
211: forward end surface
290: external thread portion
300: ring
410: insulation member
460: O-ring
500: metallic shell
510: axial hole
520: tool engagement portion
540: external thread portion
800: sheath heater
810: sheath tube
811: forward end
812: inner wall surface
813: forward end portion

819: rear end portion
 820: forward coil
 821: forward end portion
 829: rear end portion
 830: rear coil
 831: forward end portion
 839: rear end portion
 840: connection
 870: insulator
 O: axial line
 OD: axial direction
 VA: battery

Claims

1. A glow plug (10) comprising:

a sheath tube (810) extending in a direction (OD) of an axial line and whose forward end (811) is closed;
 an axial rod (200) inserted into the sheath tube (810);
 a spiral forward coil (820) disposed in the sheath tube (810) and connected to a forward-end inner wall surface (812) of the sheath tube (810); and
 a spiral rear coil (830) disposed in the sheath tube (810) and connected between a rear end portion (829) of the forward coil (820) and a forward end portion (210) of the axial rod (200),
 wherein a resistance ratio R1 and a resistance ratio R2 satisfy a relational expression $R1 > R2$, where the resistance ratio R1 is a ratio ($R1_{1000}/R1_{20}$) of a resistance ($R1_{1000}$) of the forward coil (820) at 1,000°C to a resistance ($R1_{20}$) of the forward coil (820) at 20°C, and the resistance ratio R2 is a ratio ($R2_{1000}/R2_{20}$) of a resistance ($R2_{1000}$) of the rear coil (830) at 1,000°C to a resistance ($R2_{20}$) of the rear coil (830) at 20°C, and
 a main component of the forward coil (820) is tungsten (W) or molybdenum (Mo).

2. A glow plug (10) according to claim 1, wherein the total of the resistance ($R1_{20}$) of the forward coil (820) at 20°C and the resistance ($R2_{20}$) of the rear coil (830) at 20°C is greater than 0.275 Ω.

3. A glow plug (10) according to claim 2, wherein the total of the resistance ($R1_{20}$) of the forward coil (820) at 20°C and the resistance ($R2_{20}$) of the rear coil (830) at 20°C is equal to or less than 0.600 Ω.

4. A glow plug (10) according to any one of claims 1 to 3, wherein the resistance ($R2_{20}$) of the rear coil (830) at 20°C is greater than the resistance ($R1_{20}$) of the forward coil (820) at 20°C.

5. A glow plug (10) according to claim 4, wherein the resistance ($R2_{20}$) of the rear coil (830) at 20°C is six times or less the resistance ($R1_{20}$) of the forward coil (820) at 20°C.

6. A glow plug (10) according to any one of claims 1 to 5, wherein the resistance ratio R1 of the forward coil (820) is 5.0 or higher, and the resistance ratio R2 of the rear coil (830) is 0.80 to 1.2.

7. A glow plug (10) according to any one of claims 1 to 6, wherein the rear coil (830) is formed of an alloy which contains iron (Fe), chromium (Cr), and aluminum (Al), or an alloy which contains nickel (Ni) and chromium (Cr).

8. A glow plug (10) according to any one of claims 1 to 7, wherein a wire diameter of the rear coil (830) is greater than a wire diameter of the forward coil (820).

9. A glow plug (10) according to any one of claims 1 to 8, wherein a length L1 and a length L2 satisfy a relational expression $L1 < L2$, where the length L1 is a length of the forward coil (820) along the axial line (O) from the forward-end inner wall surface (812) of the sheath tube (810) to a connection (840) with the rear coil (830), and the length L2 is a length of the rear coil (830) along the axial line (O) from the connection (840) with the forward coil (820) to a forward end surface (211) of the axial rod (200).

10. A glow plug (10) according to any one of claims 1 to 9, wherein an average pitch P1 of turns of a spiral portion of the forward coil (820) and an average pitch P2 of turns of a spiral portion of the rear coil (830) satisfy a relational expression $P2/P1 \geq 3.5$.

11. A glow plug (10) according to any one of claims 1 to 10, wherein the resistance of the forward coil (820) at a predetermined temperature in excess of 1,000°C is higher than the resistance of the rear coil (830) at the predetermined temperature in excess of 1,000°C.

12. A glow plug (10) according to any one of claims 1 to 11, wherein the sheath tube (810) comprises a side surface portion (814) extending in the direction of the axial line (O), wherein the forward coil (820) is spaced from the side surface portion (814), and wherein an outer diameter D1 and an inner diameter D2 satisfy a relational expression $(D2-D1)/2 \leq 0.8(\text{mm})$, where the outer diameter D1 is an outer diameter of the forward coil (820), and the inner diameter D2 is an inner diameter of the side surface portion (814) that corresponds to a portion of the sheath tube (810) in which the forward coil (820) is disposed.

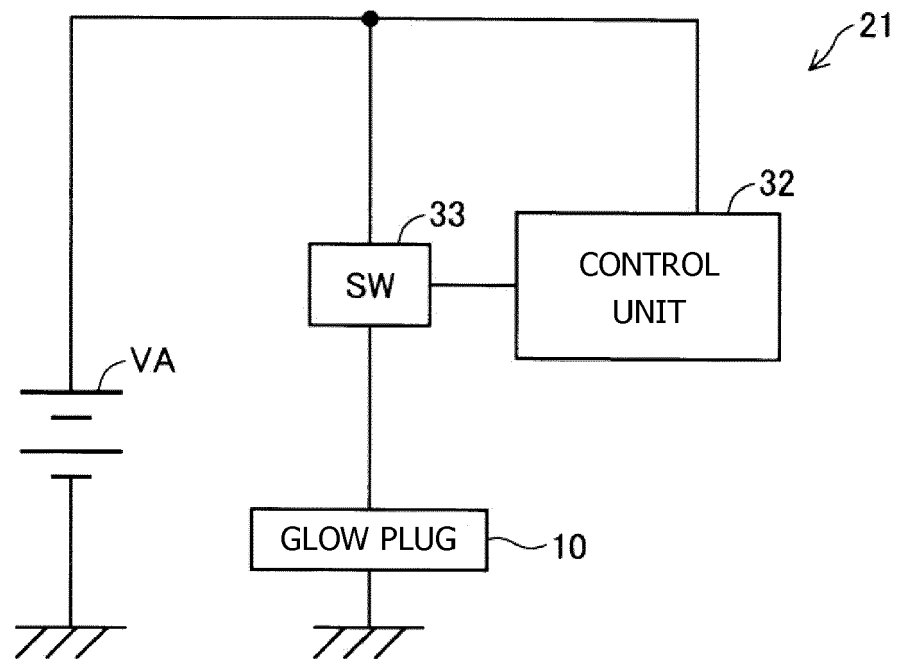


FIG. 1

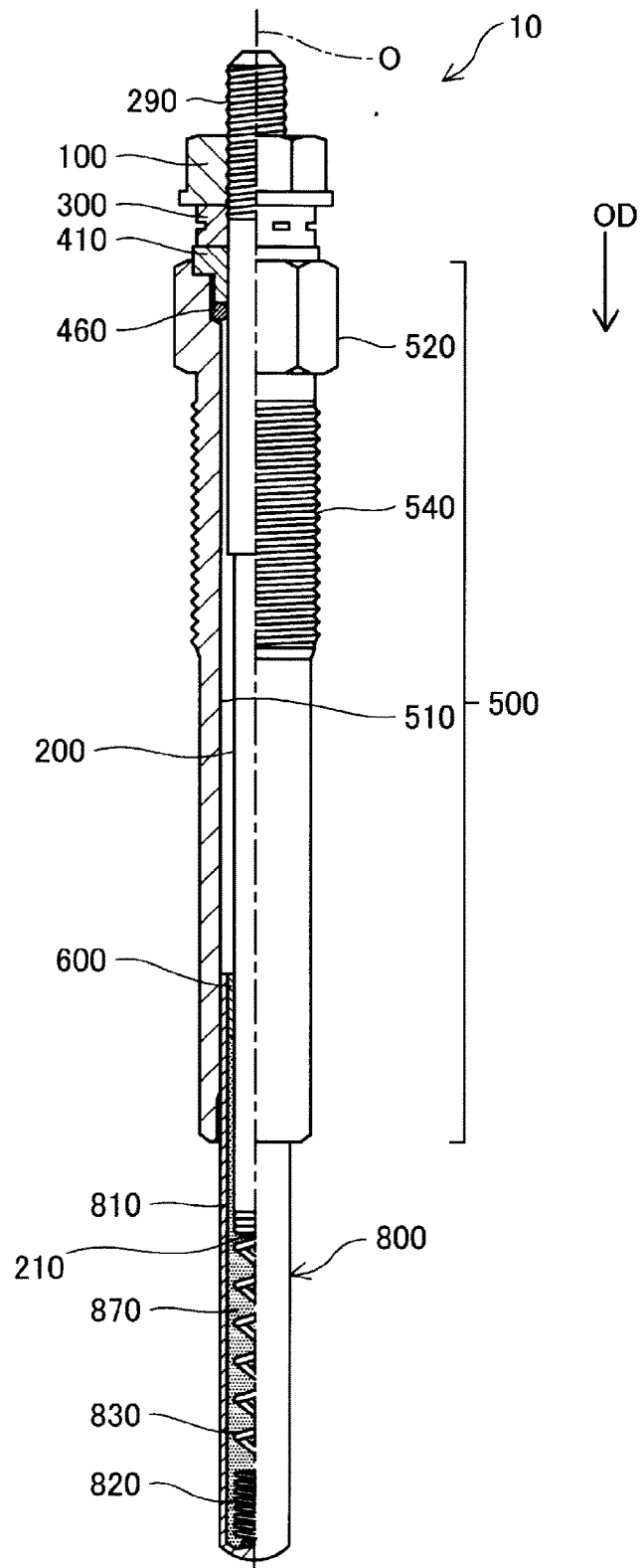


FIG. 2

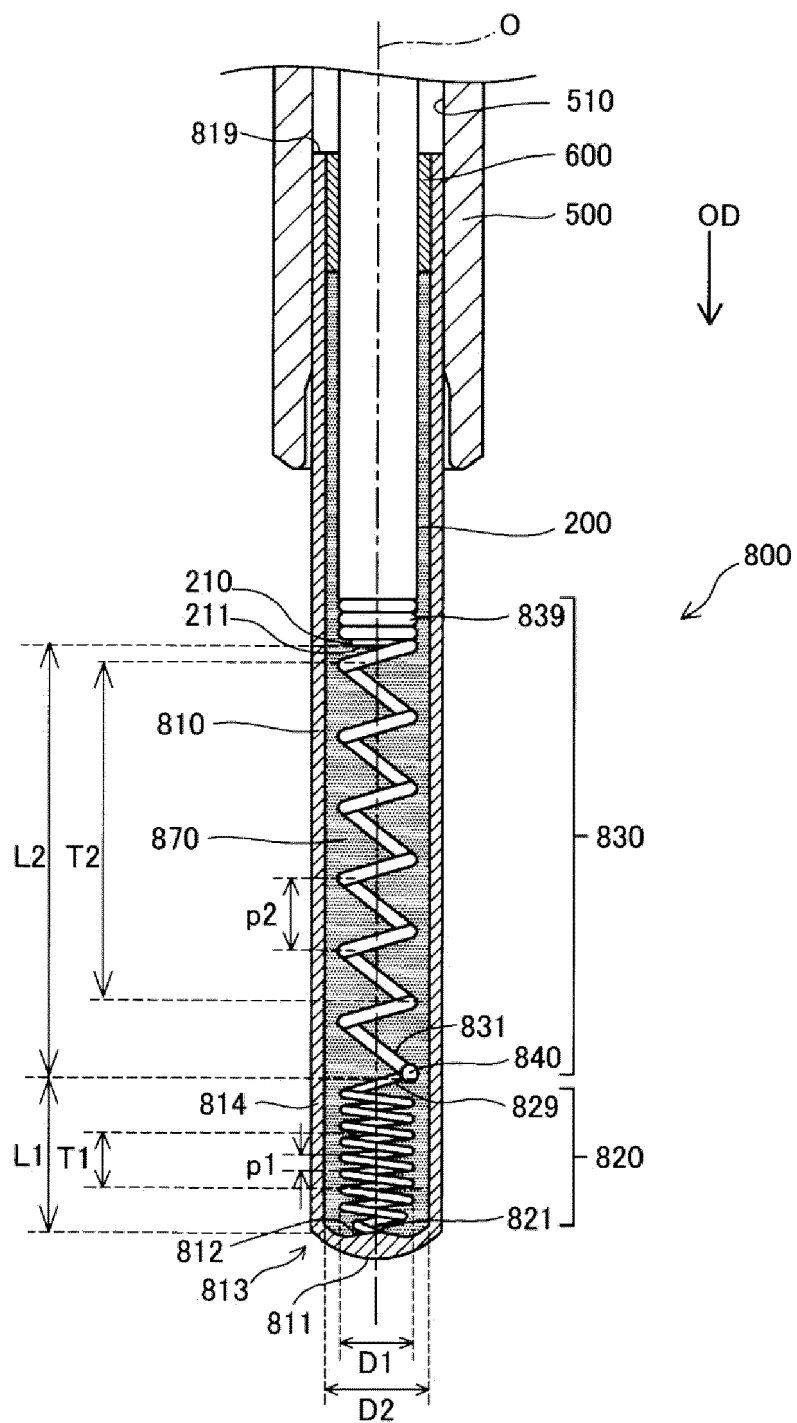


FIG. 3

Sample	Material of forward coil	Material of rear coil	Relation between R1 and R2	Judgment
1	W	Ni-Cr	$R1 > R2$	A
2	Mo	Fe-Cr-Al	$R1 > R2$	B
3	W	Ni-W	$R1 > R2$	A
4	Co-Ni-Fe	Fe-Cr-Al	$R1 > R2$	F
5	Co-Ni-Fe	Ni	$R1 > R2$	F
6	NiCr	Fe-Cr-Al	$R1 > R2$	F

FIG. 4

Sample	Total resistance	Rapid heat-up performance	Inrush current	Synthetic judgment
7	0.275	A	F	F
8	0.280	A	A	A
9	0.600	A	A	A
10	0.605	B	A	F

FIG. 5

Sample	Wire diameter d1 of forward coil (mm)	Wire diameter d2 of rear coil (mm)	Relation between wire diameter d1 of forward coil and wire diameter d2 of rear coil	Judgment
11	$\phi 0.20$	$\phi 0.35$	$d1 < d2$	A
12	$\phi 0.25$	$\phi 0.40$	$d1 < d2$	A
13	$\phi 0.25$	$\phi 0.20$	$d1 > d2$	B

FIG. 6

Sample	Average pitch P1 of forward coil (mm)	Average pitch P2 of rear coil (mm)	P2/P1	Relation between length L1 of forward coil and length L2 of rear coil	Judg- ment
14	0.25	2.83	11.3	$L1 < L2$	AA
15	0.25	3.41	13.6	$L1 < L2$	AA
16	0.25	2.43	9.7	$L1 < L2$	AA
17	0.38	2.83	7.4	$L1 < L2$	AA
18	0.38	3.41	9.0	$L1 < L2$	AA
19	0.38	2.43	6.4	$L1 < L2$	AA
20	0.38	1.80	4.7	$L1 < L2$	AA
21	0.22	4.00	18.2	$L1 < L2$	AA
22	0.38	1.53	4.0	$L1 < L2$	AA
23	0.38	1.49	3.9	$L1 < L2$	A
24	0.38	1.32	3.5	$L1 < L2$	A
25	0.38	1.30	3.4	$L1 < L2$	F
26	0.25	3.41	13.6	$L1 > L2$	F

FIG. 7



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