(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 441 672 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
13.02.2019 Bulletin 2019/07

(51) Int Cl.:
F23Q 7/00 *(2006.01)*

(21) Application number: **18186372.1**

(22) Date of filing: **30.07.2018**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **09.08.2017 JP 2017153847**
12.06.2018 JP 2018111561

(71) Applicant: **NGK Spark Plug Co., Ltd.**
Nagoya-shi,
Aichi 4678525 (JP)

(72) Inventors:
- **OKADA, Hirofumi**
  Aichi, 4678525 (JP)
- **EJIRI, Makoto**
  Aichi, 4678525 (JP)

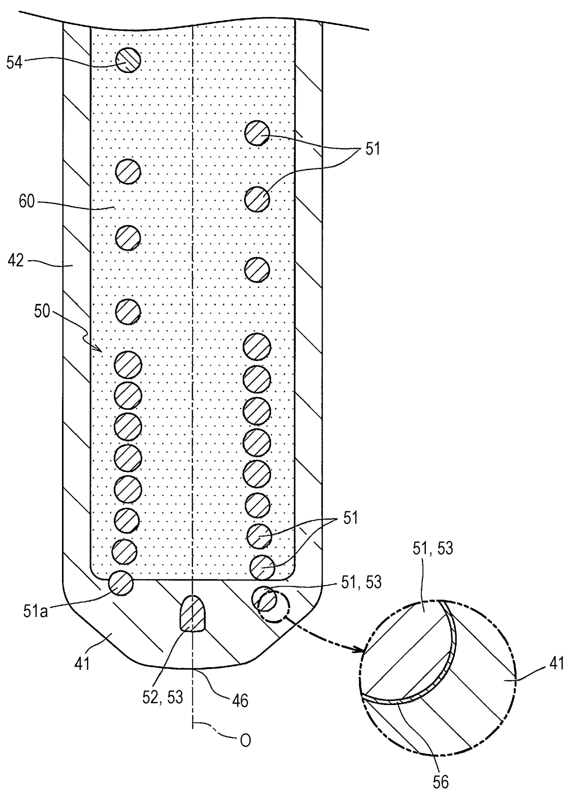
(74) Representative: **J A Kemp**
14 South Square
Gray's Inn
London WC1R 5JJ (GB)

(54) GLOW PLUG

(57) [Object] To provide a glow plug that can improve the durability of a heat generating coil while maintaining quick-temperature-increasing ability.

[Solving Means] A glow plug includes a metal tube that extends along an axial line, and a heat generating coil (50) that is disposed inside the tube and mainly composed of tungsten, an embedded portion in a front end portion (41) of the heat generating coil being embedded in a front end portion of the tube. The heat generating coil includes a helical portion that includes at least a part of the embedded portion and that is continuously formed from the embedded portion to an inside of the tube. In the heat generating coil that is present in a longitudinal section of the glow plug including the axial line, a first average value, which is calculated by dividing a first sum that is a sum of areas of cross sections of the helical portion in the embedded portion by the number of the cross sections of the helical portion in the embedded portion, is smaller than a second average value, which is calculated by dividing a second sum that is a sum of areas of cross sections of the helical portion inside the tube by the number of the cross sections of the helical portion inside the tube.

FIG. 3



EP 3 441 672 A1

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a glow plug, and, in particular, to a glow plug that can generate high-temperature heat.

2. Description of the Related Art

[0002] A glow plug is used as an auxiliary heat source of an internal combustion engine that uses a compression ignition method, such as a diesel engine. It is required that a glow plug have an ability to increase temperature to a predetermined temperature in a short time (hereinafter referred to as "quick-temperature-increasing ability"). It is also required that a glow plug can generate high-temperature heat, as regulations on internal combustion engines have become stricter. PTL 1 describes a technology in which, in a glow plug in which a front end portion of a heat generating coil is embedded in a front end portion of a metal tube, a coil that is mainly composed of tungsten, having a high melting point, is used as the heat generating coil in order to enable the glow plug to generate high-temperature heat.

Citation List

Patent Literature

[0003] PTL 1: International Publication No. 2014/206847

[0004] However, with the existing technology described above, when the heat generating coil generates heat, a stress is applied to the heat generating coil due to thermal expansion of the heat generating coil and the tube. If the wire diameter of the heat generating coil is increased in order to reduce breakage of the heat generating coil against the stress, the volume of the front end portion of the tube, in which the front end portion of the heat generating coil is embedded, increases. As a result, a problem arises in that the heat capacity of the tube increases and the quick-temperature-increasing ability decreases.

SUMMARY OF THE INVENTION

[0005] The present invention has been made in order to solve the problem described above, and an object of the present invention is to provide a glow plug that can improve the durability of a heat generating coil while maintaining quick-temperature-increasing ability.

[0006] In order to achieve the object, a glow plug according to a first aspect of the present invention includes a metal tube that extends along an axial line, a front end of the tube in an axial-line direction being closed; and a heat generating coil that is disposed inside the tube and mainly composed of tungsten, an embedded portion in a front end portion of the heat generating coil being embedded in a front end portion of the tube. The heat generating coil includes a helical portion that includes at least a part of the embedded portion and that is continuously formed from the embedded portion to an inside of the tube. In the heat generating coil that is present in a longitudinal section of the glow plug including the axial line, a first average value, which is calculated by dividing a first sum that is a sum of areas of cross sections of the helical portion in the embedded portion by the number of the cross sections of the helical portion in the embedded portion, is smaller than a second average value, which is calculated by dividing a second sum that is a sum of areas of cross sections of the helical portion inside the tube by the number of the cross sections of the helical portion inside the tube.

[0007] With the glow plug according to the first aspect, in the heat generating coil that is present in the longitudinal section of the glow plug including the axial line, a first average value, which is calculated by dividing a first sum that is a sum of areas of cross sections of the helical portion in the embedded portion by the number of the cross sections of the helical portion in the embedded portion, is smaller than a second average value, which is calculated by dividing a second sum that is a sum of areas of cross sections of the helical portion inside the tube by the number of the cross sections of the helical portion inside the tube. That is, the wire diameter of the embedded portion is smaller than the wire diameter of the helical portion inside the tube, and therefore the helical portion inside the tube can have a sufficiently large wire diameter. As a result, breakage of the heat generating coil can be reduced, and the durability of the heat generating coil can be improved. Moreover, because the wire diameter of the embedded portion is smaller than the wire diameter of the helical portion inside the tube, the volume of the front end portion of the tube, in which the embedded portion is embedded, can be reduced, compared with a case where the wire diameter of the helical portion inside the tube is the same as the wire diameter of the embedded portion. As a result, the heat capacity of the tube can be reduced, and therefore quick-temperature-increasing ability can be obtained.

[0008] In a glow plug according to a second aspect, a fused portion in which the embedded portion and the front end portion of the tube are fused with each other is formed. In the heat generating coil that is present in the longitudinal section of the glow plug including the axial line, a third average value, which is calculated by dividing a sum of a sum of areas of cross sections of the fused portion and the first sum by the number of the cross sections of the helical portion in the embedded portion, is smaller than the second average value. That is, also when the embedded portion is embedded in the front end portion in such a way that the fused portion may not be exposed from the front end portion of the tube, the volume of the front end portion can be reduced, compared with a case where the wire diameter of the embedded portion is the same as the wire diameter of the helical portion inside the tube. By embedding the embedded portion and the fused portion in the front end portion, oxidation of the fused portion due to exposure of the fused portion can be prevented. Therefore, in addition to the advantage described above, decrease of durability due to oxidation of the embedded portion can be suppressed.

[0009] In a glow plug according to a third aspect, in the heat generating coil that is present in the longitudinal section of the glow plug including the axial line, each of the areas of the cross sections of the helical portion inside the tube is 1.3 times the first average value or smaller. In this case, in addition to the advantages of the first and second aspects, breakage of the helical portion inside the tube can be prevented, and durability can be improved.

[0010] In a glow plug according to a fourth aspect, the front end portion of the tube includes a convex portion that is convex inward. In the heat generating coil that is present in the longitudinal section of the glow plug including the axial line, a fourth average value, which is calculated by dividing a third sum that is a sum of areas of cross sections of a first helical portion that is a portion of the helical portion inside the tube at least a part of which is disposed around the convex portion by the number of the cross sections of the first helical portion, is smaller than a fifth average value, which is calculated by dividing a difference between the second sum and the third sum by a difference between the number of the cross sections of the helical portion inside the tube and the number of the cross sections of the first helical portion.

[0011] In this case, the resistance of the first helical portion per unit length can be made larger than the resistance of the helical portion other than the first helical portion per unit length. Although the heat capacity of the front end portion of the tube is larger than that of a part of the tube on the rear side relative to the front end portion, because the amount of heat generated by the first helical portion can be increased by increasing the resistance of the first helical portion located near the front end portion, the temperature of the front end portion can be increased easily. Thus, in addition to the advantages of the first to third aspects, quick-temperature-increasing ability can be improved.

[0012] In a glow plug according to a fifth aspect, in the heat generating coil that is present in the longitudinal section of the glow plug including the axial line, a sixth average value, which is calculated by dividing a fourth sum that is a sum of areas of cross sections of a second helical portion that is a portion of the helical portion inside the tube at least a part of which is located within 3 mm from the front end of the tube toward a rear side by the number of the cross sections of the second helical portion, is smaller than a seventh average value, which is calculated by dividing a difference between the second sum and the fourth sum by a difference between the number of the cross sections of the helical portion inside the tube and the number of the cross sections of the second helical portion. In this case, the resistance of the second helical portion per unit length can be made larger than the resistance of the helical portion other than the second helical portion per unit length, and therefore an advantage similar to that of the fourth aspect can be obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013]

Fig. 1 is a longitudinal half-sectional view of a glow plug according to a first embodiment.
Fig. 2 is a partially enlarged longitudinal sectional view of the glow plug.
Fig. 3 is a longitudinal sectional view of the glow plug including an axial line.
Fig. 4 is a longitudinal sectional view of a glow plug according to a second embodiment including an axial line.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] Hereinafter, embodiments of the present invention will be described with reference to the drawings. Fig. 1 is a longitudinal half-sectional view of a glow plug 10 according to a first embodiment, showing a longitudinal section of a part of the glow plug 10 on one side of an axial line O. Fig. 2 is a partially enlarged longitudinal sectional view of the glow plug 10. In Figs. 1 and 2, a center rod 20, a heat generating coil 50, and other elements that extend along the axial line O are shown in side views. The lower side in the sheets of Figs. 1 and 2 will be referred to as the "front side" of the glow plug 10, and the upper side in the sheets of Figs. 1 and 2 will be referred to as the "rear side" of the glow plug 10 (the same applies to Figs. 3 and 4).

[0015] As illustrated in Fig. 1, the glow plug 10 includes the center rod 20, a metal shell 30, a tube 40, and the heat generating coil 50. These members are assembled together along the axial line O of the glow plug 10. The glow plug 10 is an auxiliary heat source that is used, for example, to start an internal combustion engine (not shown), such as a diesel engine.

[0016] The center rod 20 is a cylindrical metal conductor for supplying electric power to the heat generating coil 50. The heat generating coil 50 is electrically connected to a front end of the center rod 20. The center rod 20 is inserted into the metal shell 30 in a state in which the rear end thereof projects from the metal shell 30.

[0017] In the present embodiment, a connection portion 21, which has an external thread, is formed in a rear end portion of the center rod 20. On the rear end portion of the center rod 20, an O-ring 22, which is made of an insulating rubber; an insulator 23, which is a tubular member made of a synthetic resin; a ring 24, which is a tubular member made of a metal; and a nut 25, which is made of a metal, are assembled to together, in order from the front side. The connection portion 21 is a portion to which a connector (not shown) of a cable, for supplying electric power from a power source such as a battery, is to be connected. The nut 25 is used to fix the connector (not shown) connected to the connection portion 21.

[0018] The metal shell 30 is a substantially cylindrical member made of carbon steel or the like. The metal shell 30 has an axial hole 31 extending therethrough along the axial line O and a threaded portion 32 formed on the outer peripheral surface. The metal shell 30 has a tool engagement portion 33 on the rear side of the threaded portion 32. The axial hole 31 is a through-hole into which the center rod 20 is inserted. A gap is formed between the center rod 20 and the axial hole 31, because the inside diameter of the axial hole 31 is larger than the outside diameter of the center rod 20. The threaded portion 32 is an external thread to be fitted into an internal combustion engine (not shown). The tool engagement portion 33 has a shape (such as a hexagonal shape) that is engageable with a tool, which is used to tighten the threaded portion 32 into a threaded hole (not shown) of the internal combustion engine or to remove the threaded portion 32 from the threaded hole.

[0019] The metal shell 30 holds the center rod 20 in a rear end portion of the axial hole 31 via the O-ring 22 and the insulator 23. The position of the insulator 23 in the axial direction is fixed by crimping the ring 24 onto the center rod 20 in a state in which the ring 24 is in contact with the insulator 23. The insulator 23 insulates a rear end portion of the metal shell 30 and the ring 24 from each other. The tube 40 is fixed to a front end portion of the axial hole 31 of the metal shell 30.

[0020] The tube 40 is a cylindrical metal tube having a closed front end. The tube 40 is fixed to the metal shell 30 by pressing a rear end portion of the tube 40 into the axial hole 31. Examples of the material of the tube 40 include heat resistant alloys, such as a nickel-based alloy and a stainless steel.

[0021] The tube 40 includes a front end portion 41, a first portion 42, a second portion 43, and a third portion 44, which are connected in order from the front end thereof. The front end portion 41 blocks the front end of a hollow part of the tube 40, which is formed in the first to third portions 42 to 44. The first portion 42 and the third portion 44 each have a diameter that is uniform from the front end to the rear end thereof. The outside diameter of the first portion 42 is smaller than the outside diameter of the third portion 44. The second portion 43 connects the first portion 42 and the third portion 44 to each other and has an outer peripheral surface that is tapered.

[0022] A front end portion of the center rod 20 is inserted into the third portion 44 of the tube 40. A gap is formed between the center rod 20 and the third portion 44, because the inside diameter of the third portion 44 is larger than the outside diameter of the center rod 20. A sealing member 45 is a cylindrical insulating member interposed between the front end portion of the center rod 20 and the third portion 44. The sealing member 45 keeps the distance between the center rod 20 and the tube 40 and hermetically seals a space between the center rod 20 and the tube 40. The heat generating coil 50 is contained in the tube 40 along the axial line O. The tube 40 is filled with insulating powder 60.

[0023] As illustrated in Fig. 2, the heat generating coil 50 includes a helical portion 51, which is helically wound, and a linear portion 52, which is connected to a front end of the helical portion 51. The linear portion 52 is formed at a terminal end of the heat generating coil 50. The linear portion 52 is located on a plane including the axial line O, in contrast to the helical portion 51, which intersects a plane including the axial line O.

[0024] A part of the helical portion 51 and the linear portion 52 constitute an embedded portion 53, which is embedded in the front end portion 41 of the tube 40. The reliability of joint between the embedded portion 53 and the front end portion 41 can be improved, because not only the linear portion 52 but also a part of the helical portion 51 is embedded in the front end portion 41. Because the embedded portion 53 is embedded in and joined to the front end portion 41, the helical portion 51 is disposed in a region from the embedded portion 53 to the inside of the tube 40 (the first portion 42 in the present embodiment).

[0025] The heat generating coil 50 is formed continuously by winding a wire that is mainly composed of tungsten. The phrase "mainly composed of tungsten" means that the tungsten content of the wire of the heat generating coil 50 is 50 wt% or larger. In the present embodiment, in order to increase the amount of heat generated by a front end portion of the heat generating coil 50 larger than the amount of heat generated by a rear end portion of the heat generating coil 50, the pitch of the front end portion is smaller than the pitch of the rear end portion. A rear end of the heat generating coil 50 is welded to a rear end coil 54. A joint portion 55 is formed between the heat generating coil 50 and the rear end coil 54 by melting a weld metal in welding and solidifying the weld metal.

[0026] The rear end coil 54 is connected in series with the heat generating coil 50 via the joint portion 55. The rear end coil 54 is made of an electroconductive material having a resistance ratio R2 that is smaller than a resistance ratio R1 of the heat generating coil 50. The resistance R_2 of the rear end coil 54 at 20°C is larger than the resistance R_1 of the heat generating coil 50 at 20°C. The term "the resistance ratio R1 of the heat generating coil 50" refers to the ratio of the resistance of the heat generating coil 50 at 1000°C to the resistance at 20°C. The term "the resistance ratio R2 of the rear end coil 54" refers to the ratio of the resistance of the rear end coil 54 at 1000°C to the resistance at 20°C.

[0027] Examples of the material of the rear end coil 54 include a FeCrAl alloy and a NiCr alloy. The rear end coil 54 is contained in the tube 40 (the first portion 42 and the third portion 44) along the axial line O, and a rear end of the rear end coil 54 is welded to a front end of the center rod 20. The center rod 20 is electrically connected to the tube 40 via the rear end coil 54 and the heat generating coil 50.

[0028] The insulating powder 60 has electrically insulation property and has heat conductivity at high temperature. A space between the heat generating coil 50 and the rear end coil 54 and the tube 40, a space between the center rod 20 and the tube 40, and a space inside of the heat generating coil 50 and the rear end coil 54 are filled with the insulating powder 60. The insulating powder 60 has a function of transferring heat from the heat generating coil 50 to the tube 40, a function of preventing a short-circuit between the heat generating coil 50 and the rear end coil 54 and the tube 40, and a function of reducing vibration of the heat generating coil 50 and the rear end coil 54 to prevent breakage of wire. Examples of the insulating powder 60 include oxide powder, such as MgO powder or Al_2O_3 powder. Powder of CaO, ZrO_2, SiO_2, Si, or the like may be added to the oxide powder, such as MgO powder or Al_2O_3 powder.

[0029] The glow plug 10 is manufactured, for example, as follows. First, the heat generating coil 50 and the rear end coil 54 are each manufactured by winding a resistive heating wire having a predetermined composition. Next, the joint portion 55 is formed by welding end portions of the heat generating coil 50 and the rear end coil 54 to each other, and the rear end coil 54 is joined to the front end of the center rod 20. A tube precursor, which has an open front end and has a tapered shape, is manufactured by forming a steel pipe (original pipe), which has a predetermined composition, so as to have a diameter larger than the final diameter of the tube 40 and by reducing the diameter of a front end part of the steel pipe to a diameter smaller than those of the other parts of the steel pipe.

[0030] Next, the heat generating coil 50 and the rear end coil 54, which are integrated with the center rod 20, are inserted into the tube precursor, and the front end of the heat generating coil 50 is placed inside the tapered opening portion of the tube precursor. While forming the front end portion 41 by melting the opening portion of the tube precursor and closing a front end part of the tube precursor, a front end part of the heat generating coil 50 is welded to the front end portion 41, and the front end part of the heat generating coil 50 is embedded in the front end portion 41. Thus, a heater precursor, in which the heat generating coil 50 and the rear end coil 54 are contained inside the tube 40 (original pipe), is formed.

[0031] Next, after filling the inside of the tube 40 of the heater precursor with the insulating powder 60, the tube 40 is sealed by inserting the sealing member 45 into a space between the opening portion at the rear end of the tube 40 and the center rod 20. Next, the tube 40 is swaged until the outside diameter of the tube 40 becomes a predetermined outside diameter. By swaging the tube 40 (original pipe) to reduce the diameter of the tube 40, unevenness in the filling density of the insulating powder 60 is reduced while increasing the filling density. Thus, conductivity of heat from the heat generating coil 50 to the tube 40 can be increased by using the insulating powder 60.

[0032] Next, the tube 40 after swaging is pressed into the axial hole 31 of the metal shell 30, and the O-ring 22 and the insulator 23 are fitted into a space between the metal shell 30 and the center rod 20 from the rear end of the center rod 20. The center rod 20 is crimped with the ring 24, thereby obtaining the glow plug 10.

[0033] When a voltage V is applied between the connection portion 21 and the metal shell 30 of the glow plug 10, a current I, which is equal to $V/(R_1 + R_2)$, where R_1 is the resistance of the heat generating coil 50 and R_2 is the resistance of the rear end coil 54, flows through the heat generating coil 50 and the rear end coil 54. The amount of heat generated by the heat generating coil 50 per hour is $R_1 \cdot I^2$, and the amount of heat generated by the rear end coil 54 per hour is $R_2 \cdot I^2$.

[0034] Because the resistance R_2 of the rear end coil 54 at 20°C is larger than the resistance R_1 of the heat generating coil 50 at 20°C, a sufficient current I (inrush current) can flow through the heat generating coil 50 at room temperature and the heat generating coil 50 can generate heat. Because the resistance ratio R2 of the rear end coil 54 is smaller than the resistance ratio R1 of the heat generating coil 50, as temperature increases due to heat generated by the heat generating coil 50, the resistance R_1 of the heat generating coil 50 becomes larger than the resistance R_2 of the rear end coil 54. As a result, the amount of heat $R_1 \cdot I^2$ generated by the heat generating coil 50 per hour can be made larger than the amount of heat $R_2 \cdot I^2$ generated by the rear end coil 54 per hour. Because the heat generating coil 50 is made of a high-melting-point metal that is mainly composed of tungsten, the heat generating coil 50 can generate high-temperature heat.

[0035] Fig. 3 is a longitudinal sectional view of the glow plug 10 including the axial line O. In Fig. 3, cross sections of the heat generating coil 50 that are present in a longitudinal section of the glow plug 10 including the axial line O are illustrated, but cross sections of the rear end coil 54 on the rear side relative to the first turn of the rear end coil 54 are omitted. As illustrated in Fig. 3, a fused portion 56, in which the embedded portion 53 and the front end portion 41 are fused with each other, is formed in the front end portion 41 of the glow plug 10.

[0036] The embedded portion 53 is a part of the heat generating coil 50 whose outer periphery is completely surrounded by the front end portion 41. Accordingly, a helical portion 51a, which is a portion of the helical portion 51 a part of which is in contact with the front end portion 41 and the remaining part of which is in contact with the insulating powder 60, is not included in the embedded portion 53.

[0037] Because the heat generating coil 50 is mainly composed of tungsten, the melting point of the heat generating coil 50 is higher than that of the material of the tube 40. Therefore, the embedded portion 53 remains in the front end portion 41, and the fused portion 56, in which the embedded portion 53 and the front end portion 41 are fused with each other, is formed. The thickness of the fused portion 56, which depends on the composition of the heat generating coil 50 and the input energy of welding, is 10 μm or smaller. The fused portion 56, which is present in a region where the embedded portion 53 and the front end portion 41 are in contact with each other, can be detected by, for example, performing wavelength-dispersive X-ray spectroscopy (WDS) analysis using an electron probe microanalyzer (EPMA).

[0038] Cross sections of the heat generating coil 50 are present in the longitudinal section of the glow plug 10 including the axial line O. The cross sections of the heat generating coil 50 can be observed by using a microscope, such as a scanning electron microscope (SEM). The areas of the cross sections of the heat generating coil 50 can be calculated by digitizing an image in a field of vision by using image analysis software (such as AnalysisFive made by Soft Imaging System GmbH).

[0039] In the heat generating coil 50 that is present in the longitudinal section of the glow plug 10 including the axial line O, a first average value (A/B), which is calculated by dividing a first sum (A) that is the sum of the areas of cross sections of the helical portion 51 in the embedded portion 53 by the number (B) of the cross sections of the helical portion 51 in the embedded portion 53, is smaller than a second average value (C/D), which is calculated by dividing a second sum (C) that is the sum of the areas of cross sections of the helical portion 51 inside the tube 40 by the number (D) of the cross sections of the helical portion 51 inside the tube 40.

[0040] The first sum (A) is the sum of the areas of cross sections of the helical portion 51 in the embedded portion 53 surrounded by the front end portion 41. Because the helical portion 51a, a part of which is in contact with the front end portion 41 and the remaining part of which is not in contact with the insulating powder 60, is not included in the embedded portion 53, the area of the cross section of the helical portion 51a is not included in the first sum. The area of the cross section of the linear portion 52 in the embedded portion 53 is not included in the first sum either. This is in order to obtain the areas of cross sections of the wire of the helical portion 51, which are cut along a plane that is substantially perpendicular to the wire-length direction (longitudinal direction) of the wire.

[0041] The number (B) of cross sections of the helical portion 51 in the embedded portion 53 is the number of cross sections of the helical portion 51 surrounded by the front end portion 41. In the present embodiment, B = 1. The first average value (A/B) is the average of B pieces of cross sections of the helical portion 51 surrounded by the front end portion 41.

[0042] The second sum (C) is the sum of the areas of cross sections of the helical portion 51 that is inside the tube 40 (the first portion 42) and that is in contact with the insulating powder 60. In the helical portion 51 inside the first portion 42, the helical portion 51a, a part of which is in contact with the front end portion 41 and the remaining part of which is in contact the insulating powder 60, is included in the second sum. The areas of cross sections of the rear end coil 54 that are present inside the tube 40 are not included in the second sum. This is in order to obtain the areas of cross sections of the wire of the helical portion 51, which are cut along a plane that is substantially perpendicular to the wire-length direction (longitudinal direction) of the wire.

[0043] The number (D) of cross sections of the helical portion 51 inside the tube 40 is the number of cross sections of the helical portion 51 in contact with the insulating powder 60. In the present embodiment, D = 22. The second average value (C/D) is the average of D pieces of cross sections of the helical portion 51 in contact with the insulating powder 60.

[0044] Making the first average value (measured in mm^2) smaller than the second average value (measured in mm^2) is equivalent to making the wire diameter of the helical portion 51 in contact with the insulating powder 60 larger than the wire diameter of the helical portion 51 surrounded by the front end portion 41. Thus, the helical portion 51 inside the tube 40 (in contact with the insulating powder 60) can have a sufficiently large wire diameter, and therefore it is possible to reduce breakage of the heat generating coil 50 against a stress that is applied to the heat generating coil 50 due to thermal expansion of the heat generating coil 50 and the tube 40. Thus, the durability of the heat generating coil 50 can be improved.

[0045] Moreover, because the wire diameter of the helical portion 51 surrounded by the front end portion 41 is smaller than the wire diameter of the helical portion 51 in contact with the insulating powder 60, compared with a case where the wire diameter of the helical portion 51 in contact with the insulating powder 60 is the same as the wire diameter of the helical portion 51 surrounded by the front end portion 41, the volume of the front end portion 41, in which the embedded portion 53 is embedded, can be reduced. As a result, the heat capacity of the tube 40 can be reduced, and therefore quick-temperature-increasing ability can be obtained. Thus, the temperature of the tube 40 can be quickly increased to a desired temperature (for example, 1000°C).

[0046] The first average value (mm^2) and the second average value (mm^2) are rounded off to the third decimal place and compared with each other. This is because, if there is no difference between the first average value (mm^2) rounded off to the third decimal place and the second average value (mm^2) rounded off to the third decimal place, there is no significant difference in the quick-temperature-increasing ability or the durability of the heat generating coil 50.

[0047] Because the pitch of the front end portion of the heat generating coil 50 is smaller than the pitch of the rear end portion of the heat generating coil 50, the amount of heat generated by the front end portion of the heat generating coil 50 can be made larger than the amount of heat generated by the rear end portion of the heat generating coil 50. Accordingly, the temperature of a part (front end part) of the first portion 42 that surrounds the front end portion of the heat generating coil 50 can be quickly increased. Moreover, because the outside diameter of the first portion 42 of the tube 40 is smaller than the outside diameter of the third portion 44 of the tube 40, the heat capacity of a part of the tube 40 near the front end portion 41 (the first portion 42 and the front end portion 41) can be reduced, compared with a case where the outside diameter of the entirety of the tube 40 is the same as the outside diameter of the third portion 44. Thus, quick-temperature-increasing ability can be easily obtained.

[0048] Moreover, because the third portion 44 of the tube 40, which has a larger outside diameter than the first portion 42, is pressed into the metal shell 30, it is not necessary to reduce the inside diameter of the metal shell 30 in accordance with the outside diameter of the first portion 42. Because the front end of the center rod 20 is inserted into the third portion 44, it is not necessary to reduce the diameter of the center rod 20 in accordance with the inside diameter of the third portion 44. That is, the outside diameter of the center rod 20 and the inside diameter of the metal shell 30 can be set independently from the outside diameter of the first portion 42, and therefore the center rod 20 and the metal shell 30 can be designed with high degree of freedom.

[0049] In the present embodiment, the outside diameter of the first portion 42 of the tube 40 is set to be Φ3.5 mm or smaller. Thus, it is possible to prevent the heat capacity of the first portion 42, in which the heat generating coil 50 is disposed, from becoming excessively large, and therefore quick-temperature-increasing ability can be easily obtained.

[0050] In the heat generating coil 50 that is present in the longitudinal section of the glow plug 10 including the axial line O, a third average value (F/B), which is calculated by dividing the sum (F) of the sum (E) of the areas of cross sections of the fused portion 56 and the first sum (A) by the number (B) of cross sections of the helical portion 51 in the embedded portion 53, is smaller than the second average value (C/D). The sum (E) of the areas of cross sections of the fused portion 56 is the sum of the areas of cross sections of the fused portion 56 formed in the helical portion 51 in the embedded portion 53 surrounded by the front end portion 41. Because the helical portion 51a is not included in the embedded portion 53, the area of the cross section of the fused portion formed in the helical portion 51a is not included in the sum (E). Because the linear portion 52 of the embedded portion 53 is not included in the helical portion 51, the cross-sectional area of the fused portion formed in the linear portion 52 is not included in the sum (E).

[0051] Thus, also when the embedded portion 53 is embedded in the front end portion 41 so that the fused portion 56 may not be exposed from the front end portion 41 of the tube 40, the volume of the front end portion 41 can be reduced, compared with a case where the wire diameter of the helical portion 51 surrounded by the front end portion 41 is the same as the wire diameter of the helical portion 51 surrounded by the insulating powder 60. By embedding the embedded portion 53 and the fused portion 56 in the front end portion 41, it is possible to prevent oxidation of the fused portion 56 and the embedded portion 53, which may occur if the fused portion 56 is exposed to the outside of the tube 40. Thus, it is possible to suppress decrease of the durability of the heat generating coil 50 due to oxidation of the embedded portion 53, while maintaining quick-temperature-increasing ability.

[0052] In the present embodiment, the first average value (A/B) of the heat generating coil 50 is made smaller than the second average value (C/D) by swaging the tube 40. When the diameter of the first portion 42 of the tube 40 is reduced by pressing the first portion 42 from the outside in the radial direction by swaging, the helical portion 51 in contact with the insulating powder 60 is compressed in the radial direction, and therefore the coil average diameter of the helical portion 51 decreases. However, because the volume of the helical portion 51 is constant, by an amount by which the coil average diameter of the helical portion 51 decreases, it is possible to increase the diameter of the wire of the helical portion 51, that is, the areas of cross sections of the helical portion 51 (in particular, a front end part where the pitch is small) that are present in the longitudinal section of the glow plug 10 including the axial line O.

[0053] On the other hand, the shape of the coil of the helical portion 51 surrounded by the front end portion 41 (at least a part of the embedded portion 53) is restricted by the front end portion 41, which is present inside and outside of the helical portion 51. Moreover, because the hardness of the helical portion 51, which is mainly composed of tungsten, is higher than that of the front end portion 41, the helical portion 51 surrounded by the front end portion 41 is only negligibly affected by the swaging of the first portion 42. Accordingly, the diameter of the wire of the helical portion 51 surrounded by the front end portion 41, that is, the area of the cross section of the helical portion 51 present in the longitudinal section of the glow plug 10 including the axial line O only negligibly changes before and after the swaging.

[0054] Accordingly, by using the difference in deformability between a part of the helical portion 51 surrounded by the front end portion 41 and a part of the helical portion in contact with the insulating powder 60, the first average value (the cross-sectional area of the helical portion 51 surrounded by the front end portion 41) can be made smaller than the second average value (the cross-sectional area of the helical portion 51 in contact with the insulating powder 60). To be specific, by setting the shrink ratio of swaging (the diameter of the first portion 42 before swaging/the diameter of the first portion 42 after swaging) to be in the range of 1.08 to 1.24, the first average value (mm^2) rounded off to the third decimal place can be made smaller than the second average value (mm^2). Thus, the durability of the heat generating coil 50 can be improved, while maintaining the durability of the heat generating coil 50.

[0055] Preferably, in the heat generating coil 50 present in the longitudinal section of the glow plug 10 including the axial line O, each of the areas of the cross sections of the helical portion 51 inside the tube 40 (in contact with the insulating powder 60) is 1.3 times the first average value or smaller. In this case, when setting the first average value and the second average value by using swaging, the wire of the helical portion 51 in contact with the insulating powder 60 can be prevented from being excessively pressed, and therefore the wire is prevented from irregularly shrinking and breaking easily.

[0056] Means for setting the first and second average values is not limited to adjustment of the shrink ratio of swaging. For example, a heat generating coil 50 in which the wire diameter of a part of the helical portion 51 to be disposed inside the tube 40 is larger than the wire diameter of a part of the helical portion 51 to be embedded in the front end portion 41 may be used. In this case, it is possible to make the first average value smaller than the second average value, irrespective of the shrink ratio of swaging.

[0057] Referring to Fig. 4, a second embodiment will be described. Fig. 4 is a longitudinal sectional view of a glow plug according to the second embodiment including the axial line O. Fig. 4 illustrates only a front end part of a tube 70 of the glow plug. The tube 70 is disposed instead of the tube 40 of the glow plug 10 according to the first embodiment. Parts of the second embodiment that are the same as those of the first embodiment will be denoted by the same numerals, and descriptions of such parts will be omitted.

[0058] The tube 70 is made of a heat resistant alloy, such as a nickel-based alloy. The tube 70 includes a front end portion 71 and a first portion 72, which is on the rear side of and adjacent to the front end portion 71. The second portion 43 and the third portion 44 (see Fig. 2) are serially connected to the rear side of the first portion 72. The front end portion 71 has a surface that is in contact with the insulating powder 60, and the surface has a shape such that an inner part thereof in the radial direction protrudes further rearward (upward in Fig. 4) than an outer part thereof in the radial direction. That is, the front end portion 71 has a convex portion 71a that is convex toward the inside of the tube 70.

[0059] A heat generating coil 80 includes a helical portion 81, which is formed by helically winding a wire that is mainly composed of tungsten. The rear end coil 54 is connected to the rear end of the helical portion 81 via the joint portion 55 (see Fig. 2). The helical portion 81 is composed of an embedded portion 82, first parts 83 and 84, a second part 85, and a third part 86. The embedded portion 82 is a part whose outer periphery is completely surrounded by the front end portion 71. The first parts 83 and 84, the second part 85, and the third part 86 are parts that are disposed inside the tube 70 (the first portion 72). A fused portion 87, in which the embedded portion 82 and the front end portion 71 are fused with each other, is formed in the embedded portion 82. The thickness of the fused portion 87 is 10 μm or smaller.

[0060] At least a part of each of the first parts 83 and 84 (first helical portion) is located on the front side (the lower side in Fig. 4) relative to a rear end 73, which is the rearmost portion of the front end portion 71 (the convex portion 71a). The first helical portion is a portion at least a part of which is disposed around the convex portion 71a (between the convex portion 71a and the tube 70 (the first portion 72)). A part of the first part 83 is in contact with the front end portion 71, and the remaining part of the first part 83 is in contact with the insulating powder 60. The first part 83, a part of which is in contact with the insulating powder 60, is not included in the embedded portion 82. The outer periphery of the first part 84 is completely surrounded by the insulating powder 60. Each of the first parts 83 and 84 intersects an imaginary straight line 74, which passes through the rear end 73 of the front end portion 71 and is perpendicular to the axial line O, or is located nearer than the imaginary straight line 74 to a front end 75 of the tube 70.

[0061] Each of the first parts 83 and 84 and the second part 85 (second helical portion) is a portion of the helical portion 81 (the first parts 83 and 84, the second part 85, and the third part 86) inside the tube 70 (the first portion 72) at least a part of which is located within 3 mm from the front end 75 of the tube 70 toward the rear side. Each of the first parts 83 and 84 and the second part 85 intersects an imaginary straight line 76, which passes through a point on the axial line O that is separated by 3 mm from the front end 75 of the tube 70 and which is perpendicular to the axial line O, or is located nearer than the imaginary straight line 76 to the front end 75 of the tube 70. The third part 86 is located on the rear side relative to the imaginary straight line 76.

[0062] In the second embodiment, as in the first embodiment, a first average value (A/B), which is calculated by dividing a first sum (A) that is the sum of the areas of cross sections of the helical portion 81 in the embedded portion 82 by the number (B) (4, in the present embodiment) of the cross sections of the helical portion 81 in the embedded portion 82, is smaller than a second average value (C/D), which is calculated by dividing a second sum (C) that is the sum of the areas of cross sections of the helical portion 81 (the first parts 83 and 84, the second part 85, and the third part 86) inside the tube 70 (the first portion 72) by the number (D) of cross sections of the helical portion 81 inside the tube 70.

[0063] A third average value (F/B), which is calculated by dividing the sum (F) of the sum (E) of the areas of cross sections of the fused portion 87 and the first sum (A) by the number (B) of cross sections of the helical portion 81 in the embedded portion 82, is smaller than the second average value (C/D).

[0064] A fourth average value (G/H), which is calculated by dividing a third sum (G) that is the sum of the areas of cross sections of the first helical portion (the first parts 83 and 84) that is a portion of the helical portion 81 inside the tube 70 (the first portion 72) at least a part of which is disposed around the convex portion 71a by the number (H) (3, in the present embodiment) of the cross sections of the first helical portion, is smaller than a fifth average value ((C - G)/(D - H)), which is calculated by dividing the difference (C - G) between the second sum (C) and the third sum (G) by the difference (D - H) between the number (D) of the cross sections of the helical portion 81 inside the tube 70 and the number (H) of the cross sections of the first helical portion.

[0065] Thus, the area of the cross section of the first helical portion (the first parts 83 and 84) can be made relatively small, and therefore the resistance of the first helical portion per unit length can be made larger than the resistance of the helical portion 81 (the second part 85 and the third part 86) other than the first helical portion per unit length. Although the heat capacity of the front end portion 71 is larger than that of the first portion 72 of the tube 70, because the amount of heat generated by the first helical portion can be increased by increasing the resistance of the first helical portion, which is located near the front end portion 71, per unit length, the temperature of the front end portion 71 can be increased easily. Thus, quick-temperature-increasing ability can be improved.

[0066] A sixth average value (I/J), which is calculated by dividing a fourth sum (I) that is the sum of the areas of cross sections of the second helical portion (the first parts 83 and 84 and the second part 85) that is a portion of the helical portion 81 inside the tube 70 (the first portion 72) at least a part of which is located within 3 mm from the front end 75 of the tube 70 toward the rear side by the number (J) of the cross sections of the second helical portion, is smaller than a seventh average value ((C - I)/(D - J)), which is calculated by dividing the difference (C - I) between the second sum (C) and the fourth sum (I) by the difference (D - J) between the number (D) of the cross sections of the helical portion 81 inside the tube 70 and the number (J) of the cross sections of the second helical portion.

[0067] Thus, the area of the cross section of the second helical portion (the first parts 83 and 84 and the second part 85) can be made relatively small, and therefore the resistance of the second helical portion per unit length can be made larger than the resistance of the helical portion 81 (the third part 86) other than the second helical portion per unit length. Although the heat capacity of the front end portion 71 is larger than that of the first portion 72 of the tube 70, because the amount of heat generated by the second helical portion can be increased by increasing the resistance of the second helical portion, which is located near the front end portion 71, per unit length, the temperature of the front end portion 71 can be increased easily. Thus, quick-temperature-increasing ability can be improved.

[0068] As in the first embodiment, means for setting the fourth to seventh average values is not limited to adjustment of the shrink ratio of swaging. For example, a heat generating coil 80 in which the wire diameter of a part thereof to be disposed in a rear end portion of the tube 70 is larger than the wire diameter of a part thereof to be disposed near the front end portion 71 may be used. In this case, it is possible to make the fourth average value smaller than the fifth average value and to make the fifth average value smaller than the sixth average value, irrespective of the shrink ratio of swaging.

EXAMPLES

[0069] The present invention will be described further in detail by using examples. However, the present invention is not limited to these examples.

Production of Samples

[0070] The heat generating coils 50, composed of tungsten and unavoidable impurities and having various wire diameters, and the rear end coils 54, made of a NiCr alloy and having a wire diameter of Φ0.38 mm, were prepared. By welding the rear end coils 54 to the heat generating coils 50, various coils, in each of which the rear end coil 54 and the heat generating coil 50 were connected in series, were produced. The wire length and the wire diameter of each of the coils were adjusted so that the resistance of the coil at 20°C, measured by using a four-terminal method, was 0.33 Ω.

[0071] By using the coils, glow plugs, each having a structure the same as that of the glow plug 10 illustrated in Fig. 1, were produced as described above, and glow plugs of samples 1 to 9 shown in Table 1 were obtained. Two pieces of each sample, produced under the same conditions, were prepared. One of the pieces was used in a test for evaluating durability, and the other piece was cut along a plane including the axial line and the area of the cross section the heat generating coil 50 present in the longitudinal section was measured.

[0072] The glow plugs in samples 1 to 9 were produced so that the outside diameter of the first portion 42 of the tube 40 was Φ3.25 mm and the outside diameter of the third portion 44 was Φ4.00 mm after swaging by changing the shrink ratio of swaging (the diameter of the first portion 42 before swaging/the diameter of the first portion 42 after swaging).

Table 1

No.	Shrink Ratio	First Average Value (mm^2)	Second Average Value (mm^2)	Maximum Ratio of Area of Cross Section to First Average Value	Durability
1	1.05	0.031	0.031	1.03	B
2	1.08	0.031	0.033	1.05	A
3	1.09	0.031	0.034	1.08	A
4	1.11	0.031	0.035	1.10	A
5	1.19	0.031	0.039	1.25	A
6	1.24	0.031	0.041	1.30	A
7	1.26	0.031	0.042	1.35	C
8	1.13	0.049	0.055	1.12	A
9	1.07	0.057	0.057	1.04	B

Measurement of Areas of Cross Sections of Heat Generating Coil

[0073] Each of the samples, for which the areas of cross sections of the heat generating coil 50 were to be measured, was cut along a plane including the axial line O, and the cross sections of the sample were observed under a microscope. By using image analysis software, the areas of cross sections of the helical portion 51 present in the front end portion 41, the areas of cross sections of the helical portion 51 present inside the first portion 42, and the number of cross sections of the helical portion 51 were measured. The first average value was calculated by dividing the sum of the areas of the cross sections of the helical portion 51 present in the front end portion 41 by the number of the cross sections of the helical portion 51. Likewise, the second average value was calculated by dividing the sum of the areas of the cross sections of the helical portion 51 present in the first portion 42 by the number of the cross sections of the helical portion 51. The first average value and the second average value (mm^2) were rounded off to the third decimal place. The ratios of the areas of cross sections of the helical portion 51 present inside the first portion 42 to the first average value were calculated, and the maximum value of the ratios was obtained. The calculation results are shown in Table 1.

Evaluation of Durability

[0074] For each of the samples whose durability was to be evaluated, the temperature of a region near the front end portion 41 of the tube 40 was measured by joining a PR thermocouple to a part on the surface of the tube 40 separated by 2 mm from the front end of the tube 40 in the direction of the axial line O. Instead of the PR thermocouple, a radiation thermometer may be used.

[0075] A direct-current voltage was applied between the connection portion 21 and the metal shell 30 of each sample so that the temperature of the region near the front end portion 41 of the tube 40 became 1000°C at 2 seconds after starting application of the voltage, and then a rated voltage was applied so that the temperature of the region near the front end portion 41 of the tube 40 saturated at 1100°C. After applying the rated voltage for 180 seconds, application of the voltage was stopped, the front end portion 41 of the tube 40 was cooled by air for 120 seconds, and the temperature of the region near the front end portion 41 of the tube 40 was returned to room temperature. This cycle was repeated for a plurality of times in the test.

[0076] A sample in which the wire of the coil (heat generating coil) broke in 100 hours (approximately 1200 cycles) from starting the test was evaluated as "C", a sample in which the wire of the coil (heat generating coil) broke in a period from 100 to 500 hours (approximately 6000 cycles) from starting the test was evaluated as "B", and a sample in which the wire of the coil (heat generating coil) did not break in 500 hours from starting the test was evaluated as "A". The evaluation results are shown in Table 1.

[0077] For samples 1 to 9, it was found that the temperature of the region near the front end portion 41 of the tube 40 increased from room temperature to 1000°C at 2 seconds after starting application of the voltage. Thus, it was found that quick-temperature-increasing ability can be obtained.

[0078] Regarding durability, the evaluation of samples 2 to 6 and 8, in which the first average value, calculated by dividing the sum of the areas of cross sections of the helical portion 51 present in the front end portion 41 by the number of the cross sections, was smaller than the second average value, calculated by dividing the sum of the areas of cross sections of the helical portion 51 present inside the first portion 42 by the number of the cross sections, was "A". On the other hand, evaluation of samples 1 and 9, in which the first average value was the same as the second average value, was "B".

[0079] It is considered that, in samples 1 and 9, the helical portion 51 present inside the first portion 42 broke because of a stress caused by thermal expansion of the heat generating coil 50 and the tube 40. In contrast, it is considered that, in samples 2 to 6 and 8, in which the first average value was smaller than the second average value, breakage of the helical portion 51, which might be caused by a stress due to thermal expansion of the heat generating coil 50 and the tube 40, was prevented and the durability was improved while maintaining quick-temperature-increasing ability.

[0080] The evaluation of durability of sample 7, in which the maximum value of the ratios of the areas of the cross sections of the helical portion 51 present inside the first portion 42 to the first average value was 1.35, was "C". By observing sample 7 under an X-ray fluoroscope, it was found that more than half of the helical portion 51 of the heat generating coil 50 was irregularly shrunk and parts having small cross-sectional areas were locally present in the helical portion 51. It is considered that, in sample 7, an excessively large pressure was applied to the helical portion 51, because the shrink ratio of swaging was 1.26.

[0081] According to the examples, it was found that durability can be improved while maintaining quick-temperature-increasing ability by making the first average value smaller than the second average value. Moreover, it was found that, by making the maximum value of the ratios of the areas of the cross sections the helical portion 51 present inside the first portion 42 to the first average value be 1.3 or smaller, in particular, in the range of 1.05 to 1.30, breakage of the helical portion 51 present inside the tube 40 can be prevented and durability can be improved.

[0082] Heretofore, the present invention has been described by using embodiments and examples. However, the present invention is not limited to the embodiments and the examples, and it is easy to see that the embodiments and the examples can be improved or modified within the scope of the present invention. For example, the shape of each of the tubes 40 and 70 is not particularly limited, as long as the shape is tubular. The cross-sectional shape of each of the tubes 40 and 70 perpendicular to the axial line O may be circular, elliptical, polygonal, or the like. The wire diameter and the coil diameter of each of the heat generating coils 50 and 80 and the thickness and the diameter of each of the tubes 40 and 70 may be set at any appropriate values in consideration of the heat capacities of the heat generating coils 50 and 80 and the tubes 40 and 70.

[0083] In the embodiments, the outside diameter of the third portion 44 of the tubes 40 and 70 pressed into the metal shell 30 is larger than the outside diameter of the first portions 42 and 72 adjacent to the front end portions 41 and 71 of the tubes 40 and 70. However, this is not a limitation. Except for the front end portions 41 and 71, the tubes 40 and 70 each may have a uniform outside diameter.

[0084] In the first embodiment, the linear portion 52 is formed at the terminal end of the heat generating coil 50. However, this is not a limitation. The linear portion 52 may be omitted. Likewise, a linear portion may be formed at the terminal end of the heat generating coil 80 (the helical portion 81) described in the second embodiment, and the linear portion may be embedded in the front end portion 71. The number of turns and the pitch of each of the heat generating coils 50 and 80 may be set at any appropriate values. Likewise, the number of turns of each of the helical portions 51 and 81 in the embedded portions 53 and 82 may be set at any appropriate value.

[0085] In the embodiments, the fused portions 56 and 87 are formed in the embedded portions 53 and 82. However, this is not a limitation. The compositions of the heat generating coils 50 and 80 and the temperatures and the like when forming the front end portions 41 and 71 may be appropriately adjusted so as not to form the fused portions 56 and 87.

[0086] In the embodiments, the rear end coil 54, which is made of FeCrAl alloy, NiCr alloy, or the like, is connected to each of the heat generating coils 50 and 80, which are mainly composed of tungsten. However, this is not a limitation. The material of the rear end coil 54 is not limited to these and may be changed to any appropriate material. The rear end coil 54 may be omitted, and only the heat generating coils 50 and 80, mainly composed of tungsten, may be disposed inside the tubes 40 and 70.

[0087] In the first embodiment, as in the second embodiment, a sixth average value (I/J), which is calculated by dividing a fourth sum (I) that is the sum of the areas of cross sections of the second helical portion that is a portion of the helical portion 51 inside the tube 40 (the first portion 42) at least a part of which is located within 3 mm from a front end 46 of the tube 40 toward the rear side by the number (J) of the cross sections of the second helical portion, is smaller than a seventh average value ((C - I)/(D - J)), which is calculated by dividing the difference (C - I) between the second sum (C) and the fourth sum (I) by the difference (D - J) between the number (D) of the cross sections of the helical portion 51 inside the tube 40 and the number (J) of the cross sections of the second helical portion. Thus, as with the second embodiment, quick-temperature-increasing ability can be improved.

[0088] In the embodiments described above, the following invention is also disclosed. A method of manufacturing a glow plug including a metal tube that extends along an axial line, a front end of the tube in an axial direction being closed, and a heat generating coil that is disposed inside the tube and mainly composed of tungsten, an embedded portion in a front end portion of the heat generating coil being embedded in a front end portion of the tube, the method comprising: a filling step of filling the tube, in the front end portion of which the embedded portion of the heat generating coil is embedded, with insulating powder; and a processing step of swaging the tube, wherein, in the processing step, a shrink ratio, which is a ratio of an outside diameter of the tube before processing to an outside diameter of the tube after processing, is in a range of 1.08 to 1.24.

[0089] With the method of manufacturing the glow plug, because the shrink ratio in the processing step is in the range of 1.08 to 1.24, the heat generating coil is compressed in the radial direction via the insulating powder, and the cross-sectional area of the wire of the heat generating coil inside the tube can be made larger than the cross-sectional area of the wire of the heat generating coil in the embedded portion. As a result, breakage of the heat generating coil can be reduced and durability can be improved. Moreover, the volume of the front end portion of the tube, in which the embedded portion is embedded, can be reduced, compared with a case where the cross-sectional area of the wire of the heat generating coil inside the tube is the same as the cross-sectional are of the wire in the embedded portion. As a result, the heat capacity of the tube can be reduced, and quick-temperature-increasing ability can be maintained.

Claims

1. A glow plug (10) comprising:

   a metal tube (40, 70) that extends along an axial line (O), a front end of the tube (40, 70) in an axial-line direction being closed; and
   a heat generating coil (50, 80) that is disposed inside the tube (40, 70) and mainly composed of tungsten, an embedded portion (53, 82) in a front end portion of the heat generating coil (50, 80) being embedded in a front end portion (41, 71) of the tube (40, 70),
   wherein the heat generating coil (50, 80) includes a helical portion (51, 81) that includes at least a part of the embedded portion (53, 82) and that is continuously formed from the embedded portion (53, 82) to an inside of the tube (40, 70), and
   wherein, in the heat generating coil (50, 80) that is present in a longitudinal section of the glow plug (10) including the axial line (O), a first average value, which is calculated by dividing a first sum that is a sum of areas of cross sections of the helical portion (51, 81) in the embedded portion (53, 82) by the number of the cross sections of the helical portion (51, 81) in the embedded portion (53, 82), is smaller than a second average value, which is calculated by dividing a second sum that is a sum of areas of cross sections of the helical portion (51, 81) inside the tube (40, 70) by the number of the cross sections of the helical portion (51, 81) inside the tube (40, 70).

2. The glow plug (10) according to Claim 1,
   wherein a fused portion (56, 87) in which the embedded portion (53, 82) and the front end portion (41, 71) of the tube (40, 70) are fused with each other is formed, and
   wherein, in the heat generating coil (50, 80) that is present in the longitudinal section of the glow plug (10) including the axial line (O), a third average value, which is calculated by dividing a sum of a sum of areas of cross sections of the fused portion (56, 87) and the first sum by the number of the cross sections of the helical portion (51, 81) in the embedded portion (53, 82), is smaller than the second average value.

3. The glow plug (10) according to Claim 1 or 2, wherein, in the heat generating coil (50, 80) that is present in the longitudinal section of the glow plug (10) including the axial line (O), each of the areas of the cross sections of the helical portion (51, 81) inside the tube (40, 70) is 1.3 times the first average value or smaller.

4. The glow plug (10) according to any one of Claims 1 to 3,
   wherein the front end portion (71) of the tube (70) includes a convex portion (71a) that is convex inward, and
   wherein, in the heat generating coil (80) that is present in the longitudinal section of the glow plug (10) including the axial line (O), a fourth average value, which is calculated by dividing a third sum that is a sum of areas of cross sections of a first helical portion (83, 84) that is a portion of the helical portion (81) inside the tube (70) at least a part of which is disposed around the convex portion (71a) by the number of the cross sections of the first helical portion (83, 84), is smaller than a fifth average value, which is calculated by dividing a difference between the second sum and the third sum by a difference between the number of the cross sections of the helical portion (81) inside the tube (70) and the number of the cross sections of the first helical portion (83, 84).

5. The glow plug (10) according to any one of Claims 1 to 3, wherein, in the heat generating coil (50, 80) that is present in the longitudinal section of the glow plug (10) including the axial line (O), a sixth average value, which is calculated by dividing a fourth sum that is a sum of areas of cross sections of a second helical portion (83, 84, 85) that is a portion of the helical portion (51, 81) inside the tube (40, 70) at least a part of which is located within 3 mm from the front end (46, 75) of the tube (40, 70) toward a rear side by the number of the cross sections of the second helical

portion (83, 84, 85), is smaller than a seventh average value, which is calculated by dividing a difference between the second sum and the fourth sum by a difference between the number of the cross sections of the helical portion (51, 81) inside the tube (40, 70) and the number of the cross sections of the second helical portion (83, 84, 85).

FIG. 1

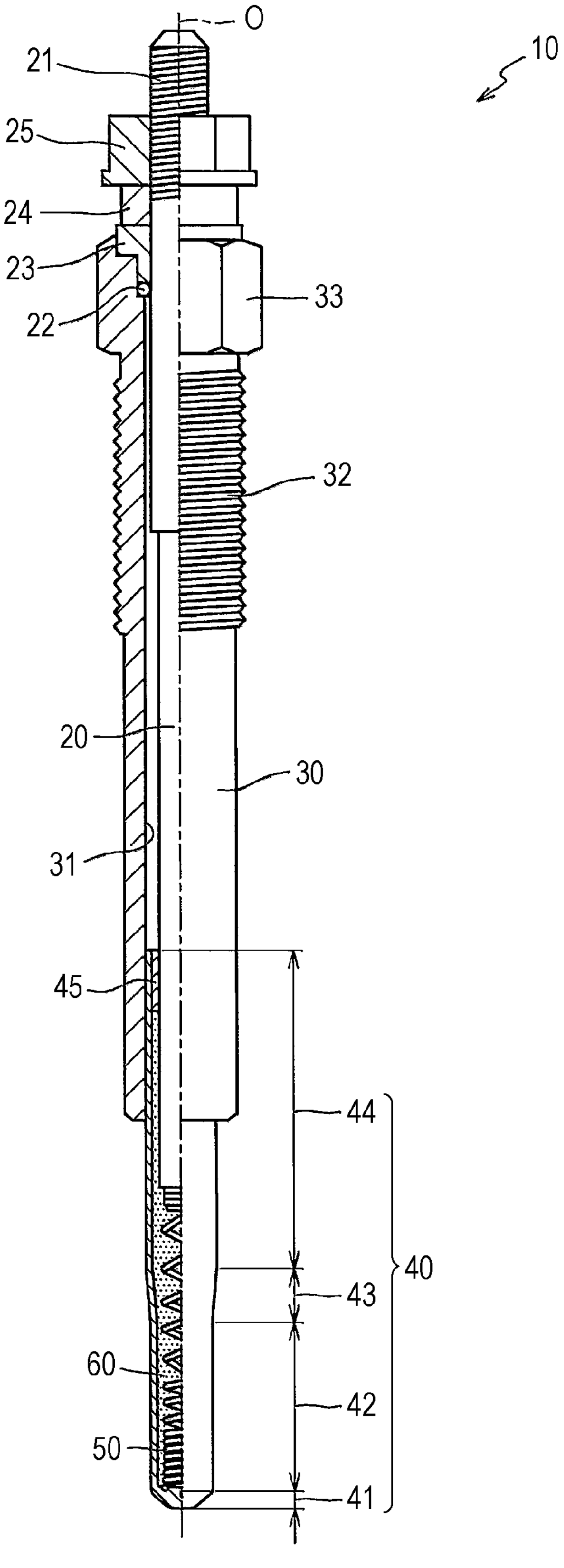


FIG. 2

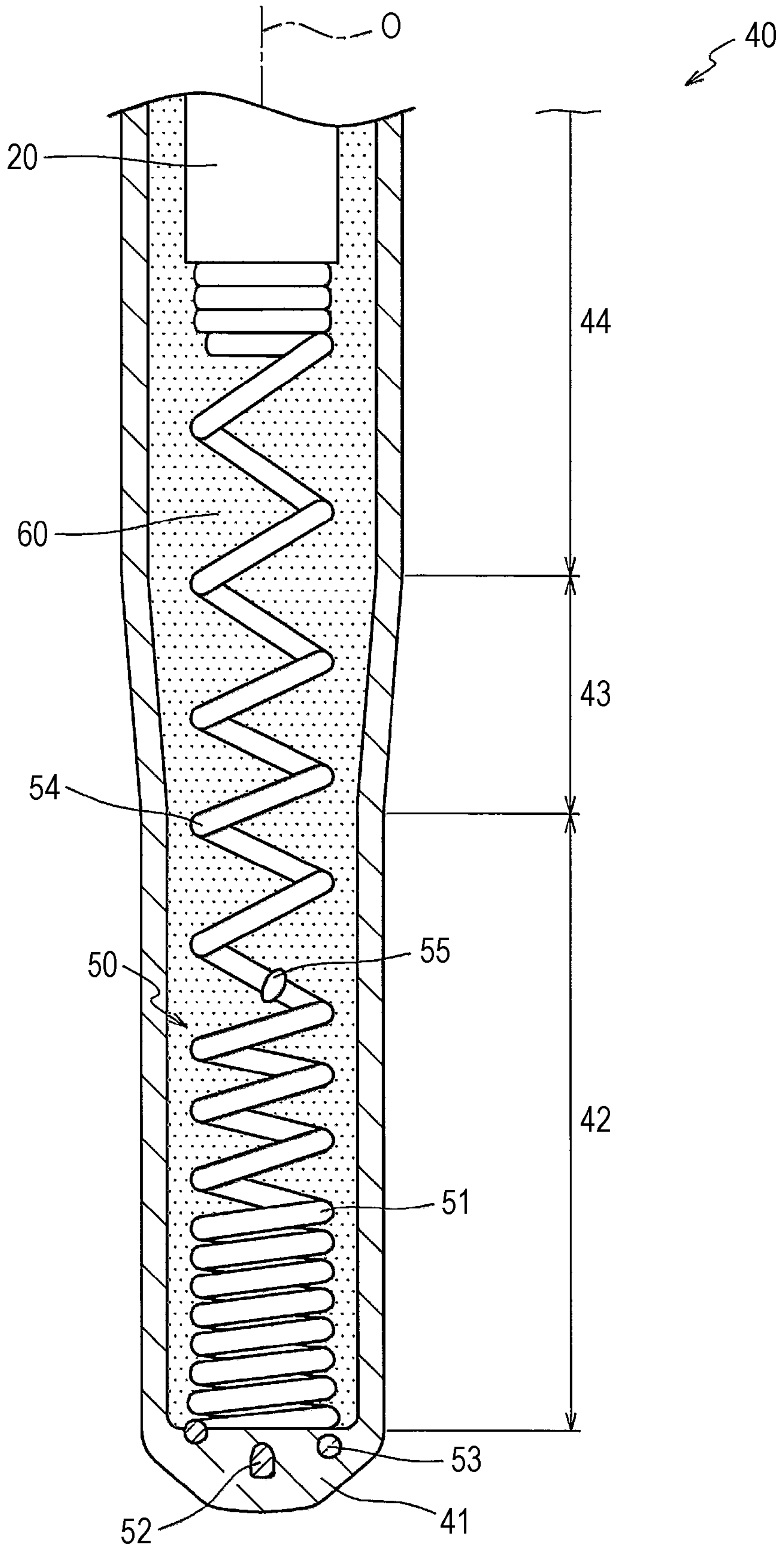


FIG. 3

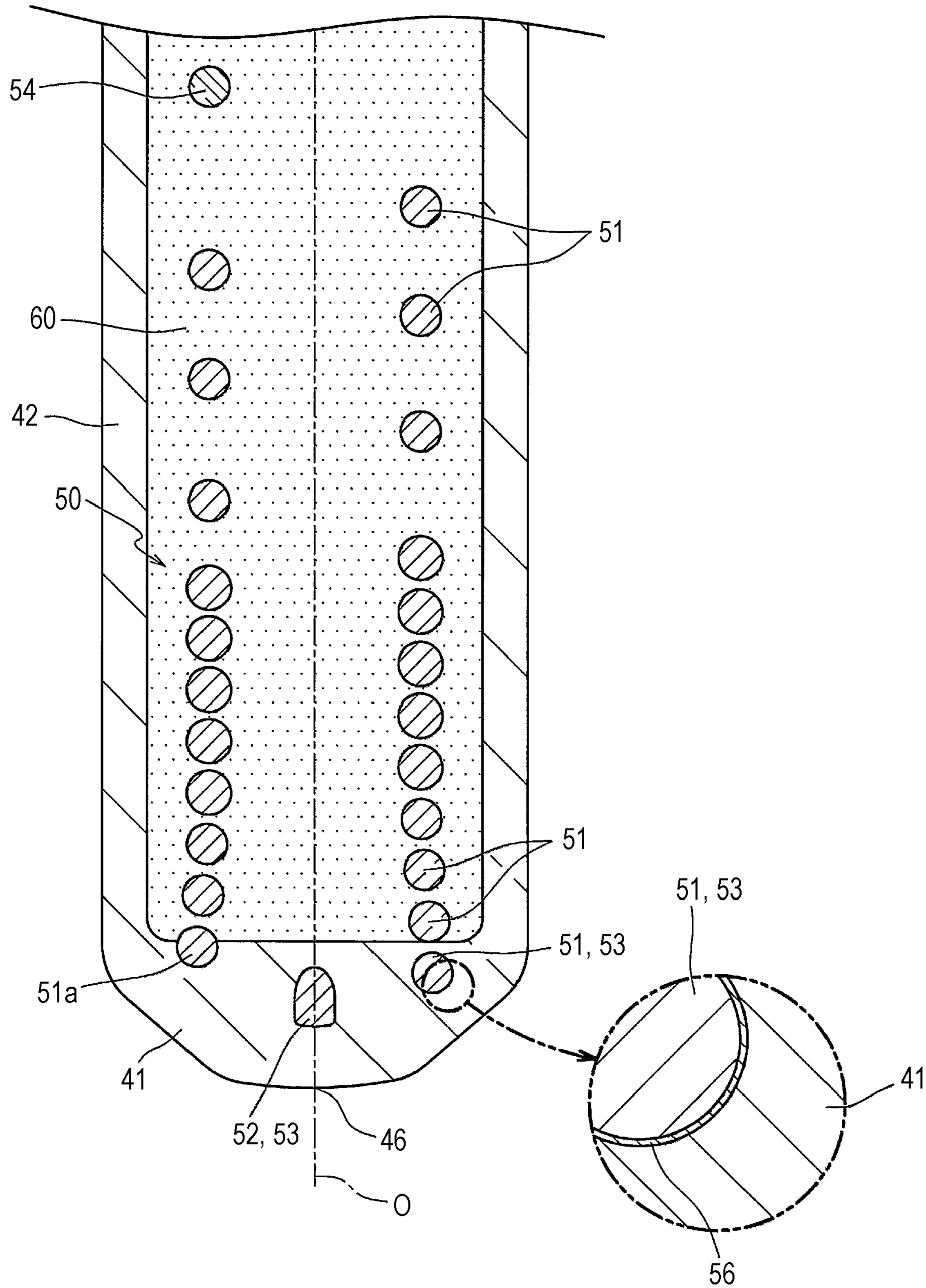
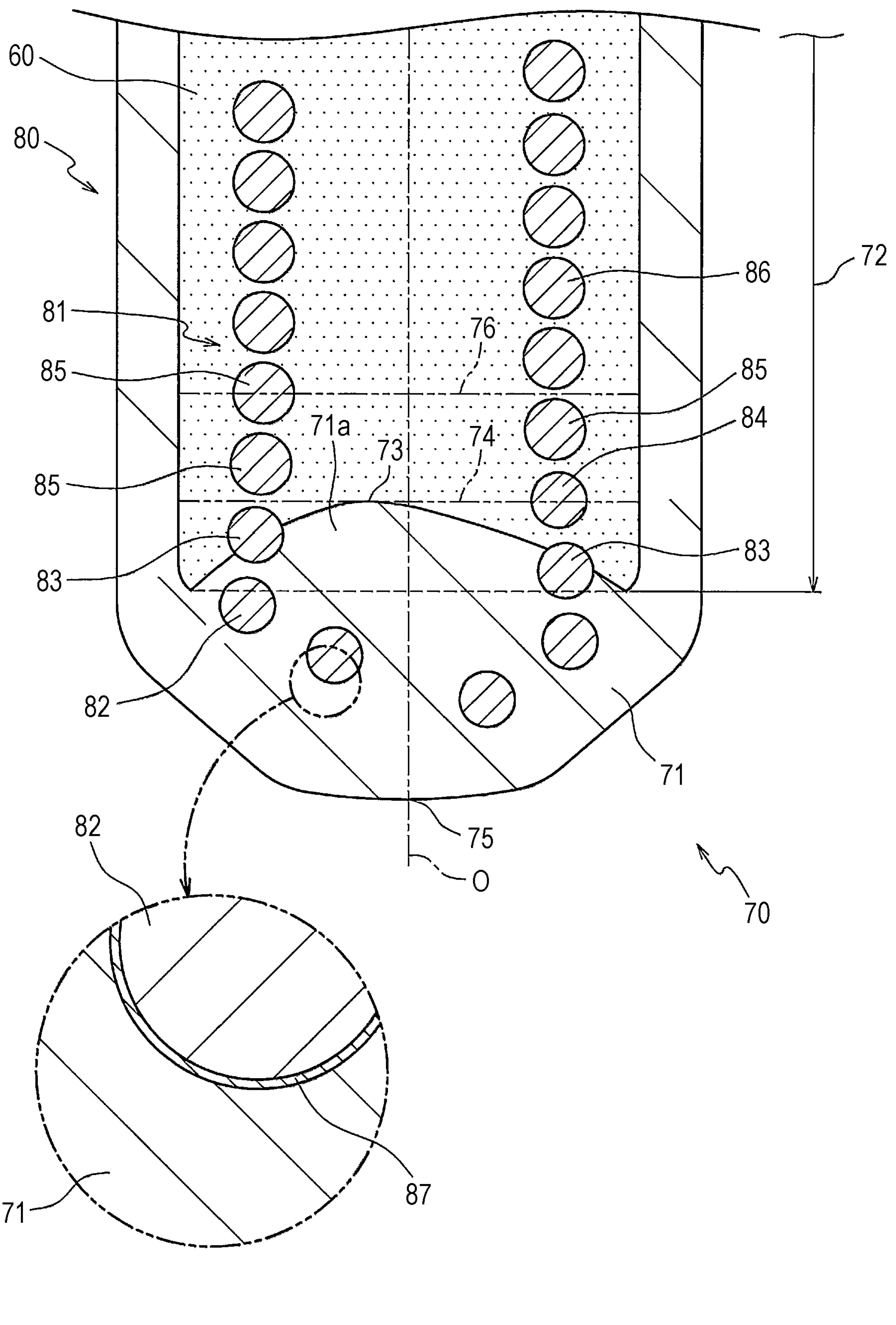


FIG. 4



Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 18 18 6372

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	DE 10 2013 212283 A1 (BOSCH GMBH ROBERT [DE]) 31 December 2014 (2014-12-31) * paragraphs [0014], [0031] - paragraph [0033]; figures 3,4 * -----	1-5	INV. F23Q7/00
Y	JP 2016 003817 A (NGK SPARK PLUG CO) 12 January 2016 (2016-01-12) * paragraph [0037] - paragraph [0040]; figures 5,6 * -----	1-5	
Y	US 5 118 921 A (AOTA TAKASHI [JP] ET AL) 2 June 1992 (1992-06-02) * column 5, line 19 - line 38; figures 4a,4b * -----	2	
A	DE 10 2011 077239 A1 (NGK SPARK PLUG CO [JP]) 22 December 2011 (2011-12-22) * paragraphs [0109], [0110]; figures 1-8 * -----	1	
A	DE 101 12 781 A1 (DENSO CORP [JP]) 4 October 2001 (2001-10-04) * paragraphs [0033], [0034], [0050] * -----	1	TECHNICAL FIELDS SEARCHED (IPC): F23Q

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	23 November 2018	Harder, Sebastian

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 18 18 6372

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

23-11-2018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 102013212283 A1	31-12-2014	CN 105308392 A	03-02-2016
		DE 102013212283 A1	31-12-2014
		EP 3014184 A1	04-05-2016
		WO 2014206847 A1	31-12-2014
JP 2016003817 A	12-01-2016	JP 6392000 B2	19-09-2018
		JP 2016003817 A	12-01-2016
US 5118921 A	02-06-1992	JP H04119 A	06-01-1992
		JP 2852552 B2	03-02-1999
		US 5118921 A	02-06-1992
DE 102011077239 A1	22-12-2011	DE 102011077239 A1	22-12-2011
		EP 2587156 A1	01-05-2013
		JP 5255706 B2	07-08-2013
		JP WO2011162074 A1	19-08-2013
		WO 2011162074 A1	29-12-2011
DE 10112781 A1	04-10-2001	DE 10112781 A1	04-10-2001
		JP 4288850 B2	01-07-2009
		JP 2001330249 A	30-11-2001

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2014206847 A **[0003]**