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

(11) EP 3 208 539 A1

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
23.08.2017 Bulletin 2017/34

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

(21) Application number: **17153358.1**

(22) Date of filing: **26.01.2017**

(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:
MA MD

(30) Priority: **16.02.2016 JP 2016027107**

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(54) **GLOW PLUG**

(57) [Objective] To provide a glow plug capable of facilitating transfer of heat from a heating element to a tube.

[Means for Solution] A heating element is electrically connected to a front end of a metal center rod, and a metal tube having a closed front end houses the heating element and a front side of the center rod. The heating element is electrically connected to the tube. Insulating powder is filled in the tube. In a volume-based particle size distribution measured by a laser diffraction method, a particle group in the insulating powder, which is disposed at a position corresponding to the heating element, has at least one maximum value of frequency of 6% or greater in a range of particle sizes of 12 μm or greater, and the particle group has only frequencies of 2.5 to 6% in a range of particle sizes of 4 to 8 μm.

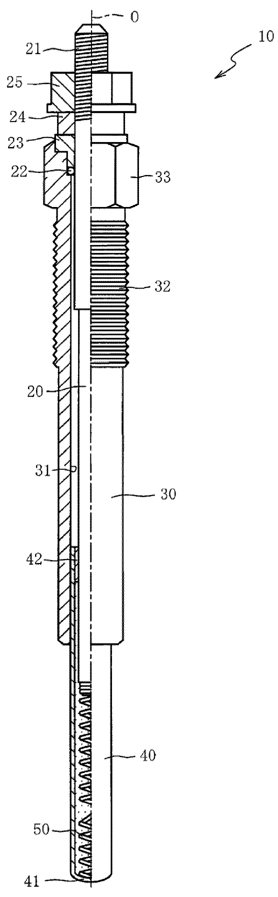

FIG. 1

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Description

[Technical Field]

[0001] The present invention relates to a glow plug, and particularly relates to a glow plug capable of facilitating transfer of heat from a heating element to a tube.

[Background Art]

[0002] A glow plug is used as an auxiliary heat source of an internal combustion engine such as a compression ignition-type diesel engine. The glow plug includes a metal center rod, a heating element electrically connected to the front end of the center rod, a metal tube having a closed front end and housing the heating element and the front side of the center rod, and insulating powder filled in the tube. When an energization between the center rod and the tube causes the heating element to generate heat, and the heat is transferred through the insulating powder to the tube because the heating element is electrically connected to the tube. In order to improve the fluidity and the dusting characteristics of the insulating powder, techniques as disclosed in Patent Documents 1 and 2 are available.

[Prior Art Document]

[Patent Document]

[0003]

[Patent Document 1] Japanese Patent Application Laid-Open (*kokai*) No. S63-21706
[Patent Document 2] Japanese Patent Publication (*kokoku*) No. H02-18560

[0004] However, in order to enhance the startability of the internal combustion engine, there has been a need to raise the temperature of the glow plug to a predetermined temperature in a short period of time (hereinafter referred to as "rapid temperature rising property"), and to set the predetermined temperature to a high temperature (hereinafter referred to as "increase in heating temperature"). In order to achieve increase in heating temperature while ensuring the rapid temperature rising property, it is necessary to further facilitate transfer of heat from the heating element to the tube.

[0005] The present invention has been made to meet the above-described need, and an object of the invention is to provide a glow plug capable of facilitating transfer of heat from a heating element to a tube.

[Means for Solving the Problems]

[0006] To attain this object, in a glow plug according to a first aspect, a heating element is electrically connected to a front end of a metal center rod, and a metal tube having a closed front end houses the heating element and a front side of the center rod. The heating element is electrically connected to the tube. A sealing member is interposed between the tube and the center rod, and the sealing member seals a space between the center rod and the tube. Insulating powder is filled in the tube. In a volume-based particle size distribution measured by a laser diffraction method, a particle group in the insulating powder, which is disposed at a position corresponding to the heating element, has at least one maximum value of frequency of 6% or greater in a range of particle sizes of 12 μm or greater. Further, the particle group has only frequencies of 2.5 to 6% in a range of particle sizes of 4 to 8 μm.

[0007] A glow plug according to a second aspect is the glow plug according to the first aspect, wherein the particle group has a cumulative frequency of 4 to 26% in a range of particle sizes of 34 μm or greater in the particle size distribution.

[0008] A glow plug according to a third aspect is the glow plug according to the first or second aspect, wherein the particle group has a cumulative frequency of 0.1 to 5% in a range of particle sizes of 1.0 μm or less in the particle size distribution.

[Effects of the Invention]

[0009] The glow plug according to the first to third aspect can secure the filling of the particle group, and therefore heat from the heating element is readily transferred to the tube.

[Brief Description of the Drawings]

[0010]

[FIG. 1] A half-side cross-sectional view of a glow plug.
[FIG. 2] A partial enlarged cross-sectional view of the glow plug.
[FIG. 3] Example of a particle size distribution of insulating powder.

[Modes for Carrying Out the Invention]

[0011] Hereinafter, preferred embodiments of the present invention will be described with reference to the accompanying drawings. A glow plug 10 according to an embodiment of the present invention will be described with reference to FIGS. 1 and 2. FIG. 1 is a half-side cross-sectional view of the glow plug 10. FIG. 2 is a partial enlarged cross-sectional view of the glow plug 10. In FIGS. 1 and 2, the lower side of the plane of paper is referred to as the front side of the glow plug 10, and the upper side of the plane of paper is referred to as the rear side of the glow plug 10.
[0012] As shown in FIG. 1, the glow plug 10 includes a center rod 20, a metal shell 30, a tube 40, and a heating element 50. These members are assembled along a center axis O of the glow plug 10. The glow plug 10 is an auxiliary heat source used at the time of starting an internal combustion engine (not shown), including, for example, a diesel engine.
[0013] The center rod 20 is a metal conductor having a columnar shape, and serves as a member for supplying electric power to the heating element 50. The heating element 50 is electrically connected to the front end of the center rod 20. The center rod 20 is inserted in the metal shell 30, with the rear end thereof protruding from the metal shell 30.
[0014] In the present embodiment, a connecting portion 21 composed of an external thread is formed at the rear end of the center rod 20. An 0-ring 22 made of 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 metal, and a nut 25 made of metal are assembled at the rear end of the center rod 20 in this order from the front side. The connecting portion 21 is a portion to which a connector (not shown) of a cable that supplies electric power from a power source such as a battery is connected. The nut 25 is a member for fixing the connected connector (not shown).
[0015] The metal shell 30 is a substantially cylindrical member formed of carbon steel or the like. The metal shell 30 includes an axial hole 31 extending therethrough along the center axis O, a thread portion 32, a tool engagement portion 33 formed on the rear side relative to the thread portion 32. The axial hole 31 is a through hole in which the center rod 20 is inserted. The inner diameter of the axial hole 31 is larger than the outer diameter of the center rod 20, so that a gap is formed between the center rod 20 and the axial hole 31. The thread portion 32 is an external thread fitted to an internal combustion engine (not shown). The tool engagement portion 33 is a portion having a shape (e.g., a hexagonal shape) engageable with a tool (not shown) used to fit or remove the thread portion 32 to or from a threaded hole (not shown) of the internal combustion engine.
[0016] The metal shell 30 holds the center rod 20 via the O-ring 22 and the insulator 23 on the rear side of the axial hole 31. As a result of the ring 24 being crimped to the center rod 20 with the ring 24 being in contact with the insulator 23, the position, in the axial direction, of the insulator 23 is fixed. The rear side of the metal shell 30 and the ring 24 are insulated from each other by the insulator 23. A tube 40 is fixed to the front side of the axial hole 31 of the metal shell 30.
[0017] The tube 40 is a tubular body made of metal having a closed front end 41. The tube 40 is fixed to the metal shell 30 by being press-fitted into the axial hole 31. Examples of the material of the tube 40 include heat resistant alloys such as a nickel-based alloy and stainless steel.
[0018] The front side of the center rod 20 is inserted in the tube 40. The inner diameter of the tube 40 is larger than the outer diameter of the center rod 20, so that a gap is formed between the center rod 20 and the tube 40. The sealing member 42 is a cylindrical insulating member sandwiched between the front side of the center rod 20 and the rear end of the tube 40. The sealing member 42 maintains an interval between the center rod 20 and the tube 40, and seals the space between the center rod 20 and the tube 40.
[0019] As shown in FIG. 2, the heating element 50 (heating coil) is housed in the tube 40 along the center axis O, and the front end thereof is joined by welding to the front end 41 of the tube 40. The heating element 50 is a spiral coil that generates heat by energization. Examples of the material of the heating element 50 include metals such as Fe, Ni, Mo, W and Co, and alloys containing any of these elements as a main component. The rear end of the heating element 50 is joined to the control coil 51 by welding. A melt portion 52 that has been solidified after being melted by welding is formed between the heating element 50 and the control coil 51.
[0020] The control coil 51 is a member that is connected in series with the heating element 50 via the melt portion 52. The control coil 51 controls the electric power supplied to the heating element 50 so as to prevent excessive temperature rise of the heating element 50. The control coil 51 is formed from a conductive material having a temperature coefficient of resistivity larger than the temperature coefficient of resistivity of the material forming the heating element 50. Examples of the material of the control coil 51 include pure Ni, a Ni alloy, and a Co alloy. The control coil 51 is housed in the tube 40 along the center axis O, and the rear end thereof is joined to the front end of the center rod 20 by welding. The center rod 20 is electrically connected to the tube 40 via the control coil 51 and the heating element 50.
[0021] The insulating powder 60 is a powder having electrical insulation and having thermal conductivity under a high temperature, and is filled between the heating element 50 and the tube 40, between the control coil 51 and the tube 40,

between the center rod 20 and the tube 40, and inside the control coil 51 and the heating element 50. The insulating powder 60 causes heat to transfer from the heating element 50 to the tube 40, prevents short circuit between the heating element 50 or the control coil 51 and the tube 40, and prevents disconnection of the heating element 50 and the control coil 51 by making the heating element 50 and the control coil 51 less liable to vibrate.

[0022] Examples of the insulating powder 60 include oxide powder such as MgO powder and Al_2O_3 powder. Preferably, the insulating powder 60 contains at least one of these oxide powders. More preferably, the insulating powder 60 contains MgO powder from among these oxide powders since the desired thermal conductivity can be maintained. The insulating powder 60 contains MgO powder, preferably by 85 mass% or greater and 100 mass% or less of, more preferably by 99 mass% or greater and less than 100 mass%, relative to the total mass of the insulating powder 60, and may contain Al_2O_3 powder or other substances as the remainder. Examples of the other substances include powders of CaO, ZrO_2, and SiO_2.

[0023] The components contained in the insulating powder 60 (first particle group 61) and the content thereof can be determined in the following manner. First, the first particle group 61 is subjected to qualitative analysis by a powder X-ray diffraction method or the like, to grasp the components contained in the first particle group 61. Then, the elements contained in the first particle group 61 are subjected to quantitative analysis by ICP emission spectrometry. When the components contained in the first particle group 61 have been identified as oxides by the qualitative analysis, the contents of the elements determined by the quantitative analysis are calculated as oxides so as to be determined as the contents of oxides. When the main component of the first particle group 61 has been identified as MgO by the qualitative analysis, the components other than MgO are analyzed by ICP emission spectrometry, and the MgO content can be determined as the remainder.

[0024] The insulating powder 60 consists of the first particle group 61 and a second particle group 62. The first particle group 61 is a plurality of particles disposed at a position corresponding to the heating element 50. Specifically, the first particle group 61 is a plurality of particles filled between the heating element 50 and the tube 40, and inside the heating element 50 (the particles located below the dashed line D in FIG. 2). The second particle group 62 is a plurality of particles filled between the control coil 51 and the tube 40, between the center rod 20 and the tube 40, and inside the control coil 51 (the particles located above the dashed line D in FIG. 2).

[0025] The first particle group 61 (group of particles) is for transferring heat from the heating element 50 to the tube 40. The volume-based particle size distribution measured by a laser diffraction method is defined for the first particle group 61. The particle size distribution of the first particle group 61 will be described with reference to FIG. 3. FIG. 3 shows an example of the volume-based particle size distribution of the insulating powder 60 (first particle group 61), measured by a laser diffraction particle size distribution measurement device (HORIBA LA-750, manufactured by Horiba, Ltd.). FIG. 3 plots the particle size (μm) on the horizontal axis, and the frequency (%) on the vertical axis.

[0026] As shown in FIG. 3, in the volume-based particle size distribution measured by a laser diffraction method, the first particle group 61 has at least one maximum value 72 of frequency of 6% or greater in a range 71 of particle sizes of 12 μm or greater. Further, the first particle group 61 has only frequencies of 2.5 to 6% in a range 73 of particle sizes of 4 to 8 μm. This can increase the filling density of the first particle group 61 and reduce the porosity. Since the thermal conductivity on the front side (the portion corresponding to the heating element 50) of the tube 40 can be increased, it is possible to facilitate transfer of heat from the heating element 50 to the tube 40 by heat conduction and heat transmission. Since the calorific value on the front side of the tube 40 can be increased, it is possible to achieve increase in heating temperature while ensuring the rapid temperature rising property. The surface temperature of the tube 40 can be rapidly raised to a high temperature without applying a large current through the heating element 50. Therefore, it is particularly suitable for an internal combustion engine for which enhanced startability is desired.

[0027] Here, when the first particle group does not have a maximum value of frequency of 6% or greater in the range 71 of particle sizes of 12 μm or greater, the percentage of particles having a particle size of less than 12 μm (relative amount of particles based on the total amount of particles taken as 100%) is large, so that the number of particles present between the heating element 50 and the tube 40 is increased. The boundary surface between the particles that are in contact with each other works as a barrier against heat conduction. Accordingly, with an increase in the number of particles present between the heating element 50 and the tube 40, heat tends to be more difficult to be transferred by heat conduction compared to the case when the number of such particles is small (less barriers). This can be prevented by defining the particle size distribution of the first particle group 61, thus facilitating transfer of heat.

[0028] The maximum value 72 may not be a sharp peak as shown in FIG. 3, and may be a broad peak. It is sufficient that at least one maximum value 72 is in the range 71, and therefore, a plurality of broad peaks may be in the range 71. This is because in either case, a percentage of the particles having a particle size of 12 μm or greater can be ensured.

[0029] The range 71 is preferably set such that the upper limit of the particle size is 40 μm (i.e., a particle size of 12 to 40 μm). When a maximum value of frequency of 6% or greater is in a range of particle sizes exceeding 40 μm, the percentage of the particles having a larger particle size is high, so that gaps between the filled particles are increased, which may result in a reduced filling density of the first particle group 61. When the filling density of the first particle group 61 is reduced, the heating element 50 becomes liable to vibrate, so that the heating element 50 may become liable to be disconnected. The presence of the maximum value 72 of frequency of 6% or greater in the range of particle sizes of 12 to 40 μm makes it possible to prevent disconnection of the heating element 50, while facilitating transfer of heat.

[0030] The range 71 is preferably set such that the upper limit of the frequency is 9% (i.e., frequency of 6 to 9%). When a maximum value of frequency exceeding 9% is in a range of particle sizes of 12 μm or greater, the percentage of the particles having a large particle size is also high, so that gaps between the filled particles are increased, which may result in a reduced filling density of the first particle group 61. In this case as well, the heating element 50 may become liable to vibrate, so that the heating element 50 may become liable to be disconnected. The presence of the maximum value 72 of frequency of 6 to 9% in a range of particle sizes of 12 μm or greater makes it possible to prevent disconnection of the heating element 50, while facilitating transfer of heat.

[0031] Even if it is assumed that at least one maximum value 72 of frequency of 6% or greater is in the range 71, when the first group has at least a part of the frequencies of less than 2.5% in the range 73, the percentage of small sized particles having a particle size less than the range 73 is increased, or the percentage of large sized particles having a particle size of 12 μm or greater is increased. In the former case, the particle size of the particles filling the gap, formed as a result of filling particles having a particle size of 12 μm or greater, is decreased so that the number of the particles present between the heating element 50 and the tube 40 is increased, which makes it difficult for heat to be transferred by heat conduction. In the latter case, the percentage of large size particles is increased, so that gaps between the filled particles are increased, which may result in a reduced filling density of the first particle group 61. When the filling density of the first particle group 61 is reduced, the heating element 50 becomes liable to vibrate, so that the heating element 50 may become liable to be disconnected.

[0032] Even if it is assumed that at least one maximum value 72 of frequency of 6% or greater is in the range 71, -when the first group has at least a part of the frequencies exceeding 6% in the range 73, the percentage of small sized particles having a particle size less than the range 73 is decreased, or the percentage of large sized particles having a particle size of 12 μm or greater is decreased. In the former case, gaps between the particles that have been formed as a result of the particles having a particle size of 12 μm or greater being filled become difficult to be filled, so that the filling density of the first particle group 61 may be decreased. When the filling density of the first particle group 61 is decreased, the heating element 50 becomes liable to vibrate, so that the heating element 50 may become liable to be disconnected. In the latter case, the number of particles present between the heating element 50 and the tube 40 is increased, which makes it difficult for heat to be transferred by heat conduction.

[0033] Thus, by setting the only frequencies to 2.5 to 6%in the range 73, it is possible to prevent disconnection of the heating element 50 while facilitating transfer of heat.

[0034] Furthermore, the first particle group 61 has a cumulative frequency 74 of 4 to 26% in a range of particle sizes of 34 μm or greater. By setting the percentage of large sized particles to such a predetermined amount, it is possible to prevent an excessive increase or decrease in the number of the particles present between the heating element 50 and the tube 40. Thus, the number of heat barriers can be decreased by decreasing the number of the particles present between the heating element 50 and the tube 40, making it possible to prevent heat from becoming difficult to be transferred from the heating element 50 to the tube 40. Furthermore, the porosity (gap ratio) of the first particle group 61 can be decreased, so that it is possible to prevent disconnection of the heating element 50.

[0035] The first particle group has a cumulative frequency 75 of 0.1 to 5% in a range of particle sizes of 1.0 μm or less. By setting the percentage of the particles having a particle size of 1.0 μm or less to such a predetermined amount, the porosity of the first particle group 61 can be decreased, making it possible to prevent disconnection of the heating element 50. Furthermore, the heat barriers can be decreased by decreasing the number of the particles present between the heating element 50 and the tube 40, making it possible to prevent heat from becoming difficult to be transferred from the heating element 50 to the tube 40.

[0036] The D50 (50% particle size or median size) of the first particle group 61 is preferably 10 to 20 μm. When D50 of the first particle group 61 is 10 to 20 μm and when the maximum value 72, the range 73, and the cumulative values 74, 75 of the first particle group 61 have the predetermined values, it is possible to facilitate transfer of heat from the heating element 50 to the tube 40. The first particle group 61 preferably has the only frequencies of 2.5% or greater in a range of particle sizes of 8 μm to a maximum value. The reason is that this facilitates transfer of heat from the heating element 50 to the tube 40.

[0037] The second particle group 62 may be a group of particles having the same particle size distribution as the particle size distribution of the first particle group 61. Further, the second particle group 62 may be a group of particles having a particle size distribution different from the particle size distribution of the first particle group 61. This is because the second particle group 62 is a group of particles filled around the control coil 51, and is less required to achieve the function of causing heat to transfer to the tube 50.

[0038] The particle size distribution of the first particle group 61 can be measured by a laser diffraction particle size distribution measurement device (HORIBA LA-750) in the following manner. First, the insulating powder 60 (first particle group 61) is taken out from the glow plug 10, and a measurement sample is prepared. Specifically, first, the tube 40 is cut on a plane that is orthogonal to the center axis O and includes the vicinity of the melt portion 52. After the tube 40 has been cut, the heating element 50 located inside the tube 40 on the front end 41 side is pulled out from the tube 40, and impact is applied to the heating element 50 so as to take out the particles (first particle group 61) packed inside the heating element 50 (heating coil). Likewise, impact is applied to the tube 40 so as to take out the particles (first particle group 61) inside the tube 40.

[0039] The taken out particles (first particle group 61) have agglomerated in the form of a mass, and thus are ground in a mortar to crash the mass. It has been confirmed that since particles are hard, grinding the first particle group 61 by the mortar and a muller held in a hand does not crush the particles (primary particles) and has no effect on the measurement results. Any impurity is removed from the particles (first particle group 61) that have been ground in the mortar, while the particles are being observed with a magnifying glass. In this manner, 0.35 g or greater of a sample of the first particle group 61 is prepared for each measurement.

[0040] Then, the prepared sample (e.g., 2 to 4 spatula scoops) of the first particle group 61 is dispersed in a dispersing medium (e.g., 150 cc of a 0.2 mass% solution of sodium hexametaphosphate). Examples of the method for dispersing the sample include a method in which the sample is stirred with an external homogenizer for three minutes, followed by stirring for two minutes with an ultrasonic probe included in the laser diffraction particle size distribution measurement device. The particle size distribution of the sample dispersed in the dispersing medium is measured by the laser diffraction particle size distribution measurement device, and the frequency distribution of a particle size of 0.1 to 100 μm, the cumulative distribution of a particle size of 34 μm or greater (for particles remaining on the sieve), and the cumulative distribution of a particle size of 1 μm or less (for particles passing the sieve) are determined. The measurement of the particle size distribution is carried out three times, and the average of the three measurements is determined.

[0041] The first particle group 61 may be present as primary particles, or may be present as secondary particles. The first particle group 61 may be present in the form of either primary particles or secondary particles, but are preferably present in the form of primary particles. When the particles contained in the first particle group 61 are present as secondary particles, a large number of voids are present in the secondary particles. Accordingly, the voids may work as a heat-insulating layer (barrier) to reduce the heat transfer of the first particle group 61. Usually, MgO does not form secondary particles, and is present in the form of primary particles. Therefore, in this respect as well, the particles constituting the first particle group 61 are preferably formed of MgO powder.

[0042] The glow plug 10 can be produced, for example, in the following manner. First, a resistance heating wire having a predetermined composition is processed into a coil, from which a heating element (heating coil) 50 and a control coil 51 are produced. Then, end portions of the heating element 50 and the control coil 51 are joined together by arc welding or the like so as to form a coil member. Then, the control coil 51 of the coil member is joined to the front end of a center rod 20.

[0043] Meanwhile, a metal steel pipe having a predetermined composition is formed so as to have a diameter larger than the final dimension of the tube 40, and to have a front end thereof having a diameter smaller than the diameters of the other portions, thereby producing a tapered-off tube precursor having an open front end. The coil member integrated with the center rod 20 is inserted into the tube precursor, and the front end of the heating element 50 is disposed in the tapered-off opening portion of the tube precursor. The opening portion of the tube precursor and the front end portion of the heating element 50 are melted by arc welding or the like to close the front end portion of the tube precursor, to form a heater precursor having the coil member housed therein.

[0044] Then, after insulating powder 60 is filled in the tube 40 of the heater precursor, a sealing member 42 is inserted between the opening portion of the tube 40 at the rear end and the center rod 20 so as to seal the tube 40. Next, swaging is performed on the tube 40 until the tube 40 has a predetermined outer diameter. The insulating powder 60 filled in the tube 40 is crushed as a result of swaging, and undergoes change in particle size. Accordingly, with a decrease in the outer diameter of the tube 40 at the time of performing swaging taken into consideration, for example, the insulating powder 60 is filled into the tube 40 such that the first particle group 61 disposed around the heating element 50 has a predetermined particle size distribution after swaging (after crushing of particles by swaging).

[0045] Next, the tube 40 that has undergone swaging is fixed by being press-fitted into an axial hole 31 of a metal shell 30, and an 0-ring 22 and an insulator 23 are fitted 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, to obtain a glow plug 10.

[Examples]

<Production of glow plug and analysis of first particle group>

[0046] Glow plugs having the same configuration as that of the glow plug 10 shown in FIG. 1 were produced in the above-described manner, to obtain glow plugs according to Experimental Examples 1 to 16. The glow plugs according to Experimental Examples 1 to 16 each include MgO powder as the insulating powder 60. The particle size of the first particles 61 (after being filled) of each of the experimental examples was prepared by adjusting the particle size distribution of the insulating powder 60 (before being filled) to be filled into the tube 40, and adjusting the decrease in the outer diameter of the tube 40 before and after swaging in the production process of the glow plug 10.

[0047] The volume-based particle size distribution of the first particle group 61 filled in the tube 40 of each of the experimental examples was measured in the above-described manner by a laser diffraction particle size distribution measurement device (HORIBA LA-750) to determine the maximum frequency, the frequency in a range of particle sizes of 4 to 8 μm, the cumulative frequency in a range of particle sizes of 1.0 μm or less, and the cumulative frequency in a range of particle sizes of 34 μm or greater. Here, as a dispersing medium for analyzing each sample of the first particle group 61, 150 cc of a 0.2 mass% solution of sodium hexametaphosphate was used. The dispersion of the sample was performed by stirring the sample for three minutes with an external homogenizer, followed by stirring for two minutes with an ultrasonic probe included in the laser diffraction particle size distribution measurement device. The measurement of the particle size distribution of the sample was carried out three times, and the average of the obtained three measurements was determined.

[0048] It should be noted that the components contained in the first particle group 61 and the contents thereof of each of the glow plugs according to Experimental Examples 1 to 16 were measured in the above-described manner by a powder X-ray diffraction method and ICP emission spectrometry. Each of the samples contained 99.4 mass% of MgO as a main component, and contained a total of 0.6 mass% of CaO, ZrO_2, and SiO_2. As a result of observing the first particle group 61 with a scanning microscope (1000X), it was confirmed that primary particles were present as the particles.

<Energization test>

[0049] The heat transfer (ease of transfer of heat) of the first particle group 61 was evaluated on the basis of the difference (T1-T2) between a temperature (hereinafter referred to as "T1") of the heating element 50 and a surface temperature (hereinafter referred to as "T2") of the tube 40. Specifically, a voltage was applied between the center rod 20 and the metal shell 30 such that T2 reached 1000°C two seconds after energization. The experimental examples in which the temperature difference between the T1 and T2 two seconds after energization was 100°C or less were evaluated as "excellent", the experimental examples in which the temperature difference between T1 and T2 was greater than 100°C but not greater than 120°C were evaluated as "good", and the experimental examples in which the temperature difference between T1 and T2 was greater than 120°C were evaluated as "poor".

[0050] The temperature (T1) of the heating element 50 was measured with a thermocouple disposed at a position corresponding to the heating element 50. The thermocouple was disposed inside the heating element 50 at the time of producing each of the glow plugs according to the experimental examples (before inserting the heating element 50 into the tube 40). The position at which the thermocouple was disposed was a position of the heating element 50 that is located on the center axis O and 2.0 mm away from the front end 41 in the direction of the center axis O. The surface temperature (T2) of the tube 40 was measured with a thermocouple attached to the tube 40. The thermocouple was attached to the tube 40 after production of each of the glow plugs according to the experimental examples. The position at which the thermocouple was attached was a position located 2.0 mm away from the front end 41 of the tube 40 in the direction of the center axis O.

[0051] The results of the analysis and the energization test for the glow plugs according to Experimental Examples 1 to 16 are shown in Table 1. Table 1 shows, as the results of the analysis of the first particle group 61, "particle size, frequency, and determination results for the maximum value", "frequency of particle size of 4 μm, frequency of particle size of 8 μm, and determination results for frequencies in a range of particle sizes of 4 to 8 μm", "determination results for cumulative frequency in a range of particle sizes of 1.0 μm or less", and " determination results for cumulative frequency in a range of particle sizes of 34 μm or greater".

[Table 1]

	Maximum value			Frequency (%) of 4 to 8 μm			Cumulative frequency of 1μm or less	Cumulative frequency of 34μm or greater	Energization test
	Particle size (μm)	Frequency (%)	Determination	4 μm	8 μm	Determination			
Experimental Example 1	20	8.0	OK	3.0	3.8	OK	OK	OK	Excellent
Experimental Example 2	15	7.2	OK	3.2	5.1	OK	OK	OK	Excellent
Experimental Example 3	15	7.2	OK	2.6 6	3.0	OK	OK	OK	Excellent
Experimental Example 4	15	7.2	OK	5.8	6.0	OK	OK	OK	Excellent
Experimental Example 5	15	7.2	OK	3.7	5.6	OK	OK	<4%	Good
Experimental Example 6	20	6.7	OK	3.0	3.2	OK	>5%	OK	Good
Experimental Example 7	26	6.4	OK	2.6	3.0	OK	OK	>26%	Good
Experimental Example 8	13	6.9	OK	4.2	5.5	OK	<0.1%	<4%	Good
Experimental Example 9	20	5.9	NG	2.6 6	4.0	OK	OK	OK	Poor
Experimental Example 10	11	7.5	NG	4.2	5.8	OK	OK	OK	Poor
Experimental Example 11	15	7.2	OK	2.1	2.3	NG	OK	<4%	Poor
Experimental Example 12	15	7.2	OK	1.1	1.0	NG	<0.1%	OK	Poor
Experimental Example 13	15	7.2	OK	6.1	6.3	NG	OK	<4%	Poor

(continued)

	Maximum value			Frequency (%) of 4 to 8 μm			Cumulative frequency of 1μm or less	Cumulative frequency of 34μm or greater	Energization test
	Particle size (μm)	Frequency (%)	Determination	4 μm	8 μm	Determination			
Experimental Example 14	15	7.2	OK	6.2	6.2	NG	<0.1%	OK	Poor
Experimental Example 15	15	7.2	OK	2.3	3.7	NG	OK	OK	Poor
Experimental Example 16	15	7.2	OK	4.7	6.3	NG	OK	OK	Poor

[0052] In Table 1, each of the determination results for the maximum value was indicated by OK when a maximum value of frequency of 6% or greater is in the range of particle sizes of 12 μm or greater, or indicated by NG when the maximum value falls outside the aforementioned range. Each of the determination results for the frequencies in the range of particle sizes of 4 to 8 μm was indicated by OK when the particle group 61 has only frequencies of 2.5 to 6% in the range of particle sizes of 4 to 8 μm, or indicated by NG when the frequency falls outside the aforementioned range. Each of the determination results for the cumulative frequency in the range of particle sizes of 1.0 μm or less was indicated by OK when the cumulative frequency falls in the range of 0.1 to 5%. When the cumulative frequency falls outside the above-described range, the side on which the cumulative frequency is located (<0.1%, or >5%) is shown. Each of the determination results for the cumulative frequency in the range of particle sizes of 34 μm or greater is indicated by OK when the cumulative frequency is in the range of 4 to 26%. When the cumulative value falls outside the aforementioned range, the side on which the cumulative frequency is located (<4%, or >26%) is shown.

[0053] As shown in Table 1, the results of energization tests were "excellent" or "good" (the temperature difference (T1-T2) was 120°C or lower) for Experimental Examples 1 to 8, in which the maximum value of frequency of 6% or greater is in the range of particle sizes of 12 μm or greater, and the first particle group 61 has only frequencies of 2.5 to 6% in the range of particle sizes of 4 to 8 μm, in the particle size distribution of the first particle group 61. In particular, of Experimental Examples 1 to 8, the results of the energization test were "excellent" (the temperature difference (T1-T2) was 100°C or lower) for Experimental Examples 1 to 4, in which the cumulative frequency in the rage of particle sizes of 1.0 μm or less falls within the range of 0.1 to 5% and the cumulative frequency in the range of particle sizes of 34 μm or greater falls within the range of 4 to 26%.

[0054] On the other hand, the results of the energization test were "poor" (the temperature difference (T1-T2) was greater than 120°C) for Experimental Examples 9 and 10, in which no maximum value of frequency of 6% or greater presents in the range of particle sizes of 12 μm or greater , and Experimental Examples 11 to 16, in which the particle group has only frequencies of 2.5 to 6% in the range of particle sizes of 4 to 8 μm.

[0055] According to the examples, it can be understood that when the maximum value of frequency of 6% or greater is in the range of particle sizes of 12 μm or greater and the particle group has only frequencies of 2.5 to 6% in the range of particle sizes of 4 to 8 μm, in the volume-based particle size distribution of the first particle group 61, the first particle group 61 has a favorable heat transfer, thus making it possible to rapidly raise the surface temperature of the tube 40 to a high temperature, without applying a large current through the heating element 50.

[0056] When the maximum value of frequency of 6% or greater is in the range of particle sizes of 12 μm or greater and the particle group has only frequencies in the range of particle sizes of 4 to 8 μm, and when the cumulative frequency in the range of particle sizes of 1.0 μm or less falls within the range of 0.1 to 5% and the cumulative frequency in the range of particle sizes of 34 μm or greater is 4 to 26%, in the volume-based particle size distribution of the first particle group 61, the first particle group 61 has a more favorable heat transfer, thus making it possible to rapidly raise the surface temperature of the tube 40 to a higher temperature, without applying a large current through the heating element 50.

[0057] Although the present invention has been described by way of embodiments and examples, the present invention is by no means limited by the above-described embodiments and examples. It would be readily surmised that various improvements and modifications may be made thereto without departing from the scope and spirit of the present invention. For example, the shape of the tube 40 is not particularly limited as long as it is tubular, and the cross section orthogonal to the center axis O may be circular, elliptical, polygonal, or the like.

[0058] Although the above embodiment has described the heating element 50 as being formed of a spiral coil, the present invention is not necessarily limited thereto. The shape of the heating element 50 is not particularly limited, as long as the heating element 50 is a resistor that generates heat by application of electricity.

[0059] In the above embodiment, the control coil 51 for preventing excessive temperature rise of the heating element 50 is interposed between the heating element 50 and the center rod 20. However, the present invention is not necessarily limited thereto, and it is of course possible to omit the control coil 51, and directly join the heating element 50 to the center rod 20. It is of course possible to connect a rear end coil in series between the heating element 50 and the center rod 20, instead of using the control coil 51. As the material of the rear end coil, Fe-Cr-A, Ni-Cr or the like may be used. In this case as well, the first particle group 61 is disposed at a position opposing the heating element 50.

[Description of Reference Numerals]

[0060]

10: glow plug; 20: center rod; 40: tube; 42: sealing member; 50: heating element; 60: insulating powder; 61: first group of particles (group of particles); 71: range; 72: maximum value; 74, 75: cumulative value

Claims

1. A glow plug (10) comprising:

a metal central rod (20);
a heating element (50) electrically connected to a front end of the central rod (20);
a metal tube (40) to which the heating element (50) is electrically connected, the metal tube (40) having a closed front end (41) and housing a front side of each of the heating element (50) and the central rod (20);
a sealant (42) interposed between the tube (40) and the central rod (20); and
insulating powder (60) charged in the tube (40), a space between the tube (40) and the central rod (20) being sealed by the sealant (42), wherein
a group of particles (61), that are included in the insulating powder (60) and disposed at a position opposing the heating element (50), have at least one maximum value of frequency of 6% or greater in a range of a particle size of 12 μm or greater, and a frequency of a particle size of 4 to 8 μm is in a range of 2.5 to 6% in a volume-based particle size distribution measured by a laser diffraction method.

2. The glow plug (10) according to claim 1, wherein
a cumulative value of frequency of a particle size of 34 μm or greater of the group of particles (61) is in a range of 4 to 26% in the particle size distribution.

3. The glow plug (10) according to claim 1 or 2, wherein
a cumulative value of frequency of a particle size of 1.0 μm or less of the group of particles (61) is in a range of 0.1 to 5% in the particle size distribution.

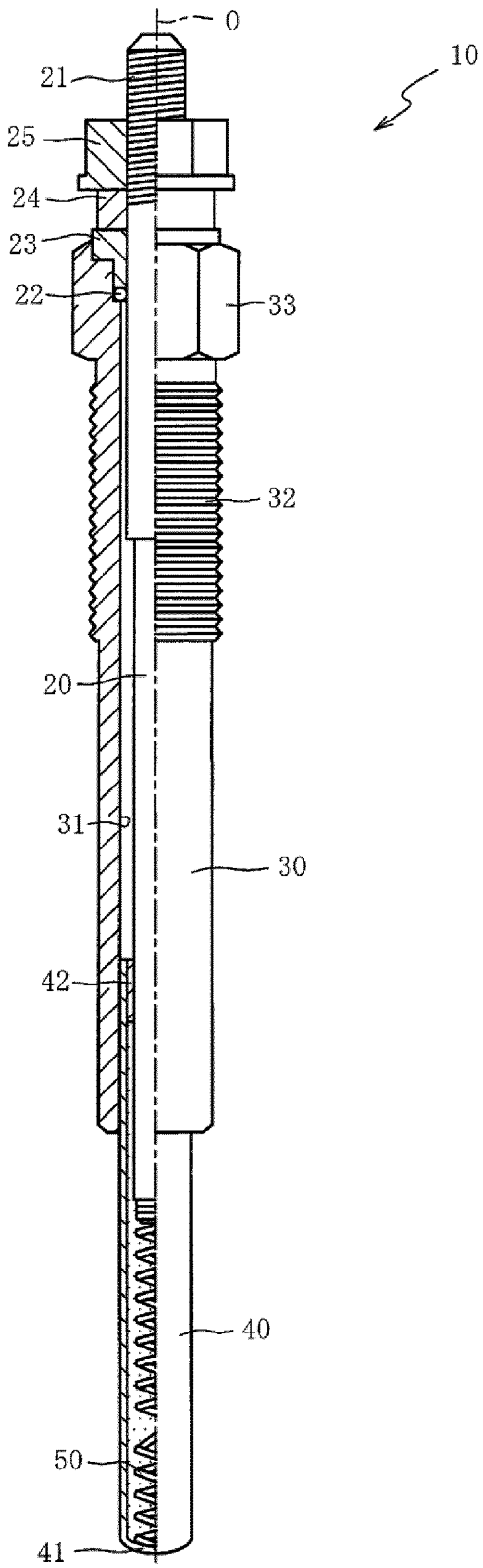

FIG. 1

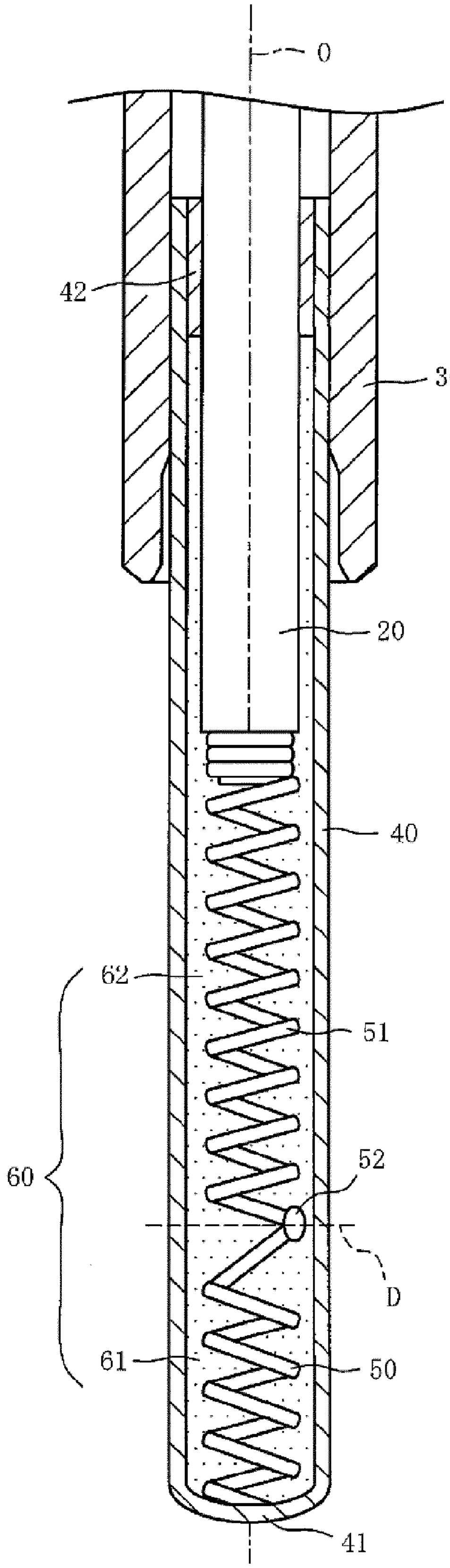

FIG. 2

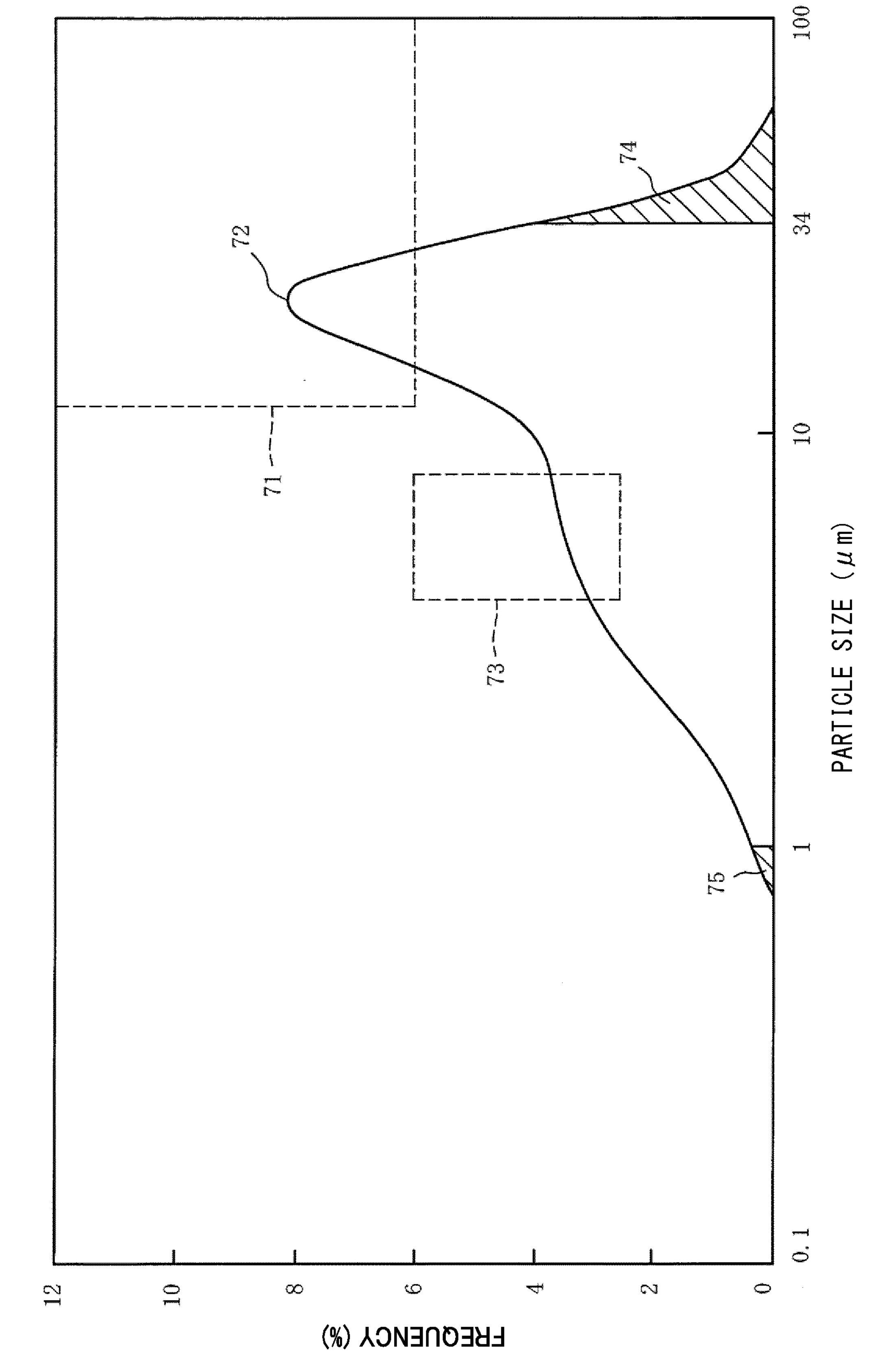
FREQUENCY (%)
0
2
4
6
8
10
12
PARTICLE SIZE (μm)
0.1
1
10
34
100
71
72
73
74
75

FIG. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 17 15 3358

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	14 June 2017	Theis, Gilbert

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