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(54) GLOW PLUG

(57) A glow plug (10) comprising:
a heat-generating element (820) formed of an iron-based alloy;
a sheath tube (810) formed of a nickel-based alloy, disposed around the heat-generating element (820) and extending in an axial line (O) direction;
a fusion zone (850) formed through welding of the sheath tube (810) and the heat-generating element (820), and closing a forward end of the sheath tube (810),
wherein in a cross section including the axial line (O), the fusion zone (850) has an iron content of 20 mass% to 60 mass% at a measurement point of maximum iron content in a region having a depth of 0.5 mm or less from an outer surface of the fusion zone (850).
The measurement point is determined through EPMA analysis (WDS: wavelength-dispersive X-ray spectrometer) of the region at an acceleration voltage of 20 kV, a probe current of 2.5 x 10-8 A, a beam irradiation diameter of 10 µm, and a measurement interval of 10 µm.

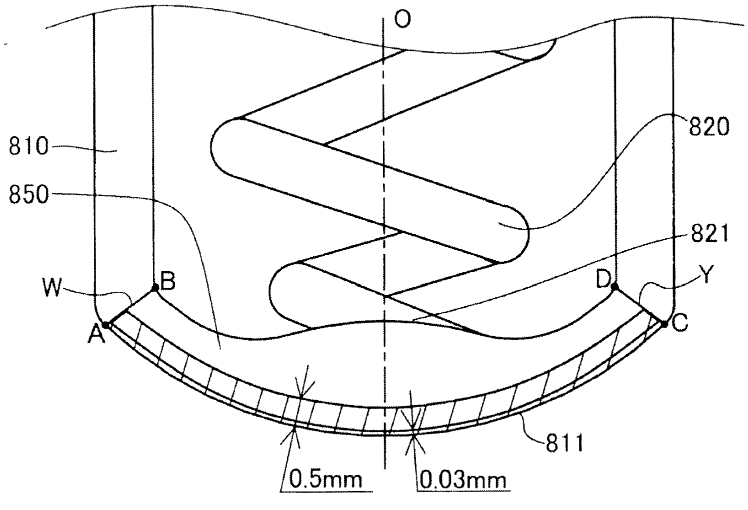

FIG. 5

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Description

[Technical Field]

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

[Background Art]

[0002] Glow plugs are used as auxiliary heat sources (heaters) in compression-ignition-type internal combustion engines (e.g., diesel engines). A glow plug generally has a structure including a sheath tube, and a coil-shaped heat-generating element accommodated therein. The forward end of the sheath tube is closed with a fusion zone. The fusion zone is formed through welding between the sheath tube and the heat-generating element. The fusion zone, which is formed through welding, has a composition which varies depending on the composition of the sheath tube or the heat-generating element (see, for example, Patent Document 1).

[Prior Art Document]

[Patent Document]

[0003]

[Patent Document 1] Japanese Patent No. 4288850

[Summary of the Invention]

[Problems to be Solved by the Invention]

[0004] When chromium or aluminum is contained in the surface of the glow plug, a Cr_2O_3 or Al_2O_3 film is formed, respectively, at the outer surface of the fusion zone through application of electricity to the glow plug. Such an oxide film protects a bulk from oxidation, to thereby improve the durability of the glow plug. As used herein, the term "bulk" refers to a portion located inward in relation to the oxide film.

[0005] Since the oxide film is present at the outer surface of the fusion zone, thermal stress arises at the oxide film in association with combustion in a combustion chamber using the glow plug. This thermal stress may cause removal of the oxide film from the bulk. Removal of the oxide film results in exposure of the bulk. The thus-exposed surface layer of the bulk is then transformed into an oxide film. The newly formed oxide film may be removed as a result of thermal stress. Thus, repeated removal of the oxide film thins the fusion zone. This phenomenon will herein be referred to as "oxidative erosion."

[0006] When at least one of the heat-generating element and the sheath tube contains iron, the fusion zone also contains iron. When an iron-localized portion is exposed through the aforementioned oxidative erosion of the fusion zone, a chromium or aluminum oxide film may be insufficiently formed at the exposed portion, resulting in failure to protect the bulk from oxidation. That is, oxidation of the bulk proceeds within a short period of time.

[0007] Thermal stress also occurs at the boundary between portions of the glow plug having different thermal expansion coefficients, in association with combustion in the aforementioned combustion chamber. The fusion zone has a composition different from that of the sheath tube or the heat-generating element, and thus the fusion zone has a thermal expansion coefficient different from that of the sheath tube or the heat-generating element. Therefore, thermal stress arises at the boundary between the fusion zone and the sheath tube, or at the boundary between the fusion zone and the heat-generating element. This thermal stress may cause cracking.

[0008] In view of the foregoing, an object of the present invention is to improve the oxidation resistance of a glow plug, and to reduce occurrence of cracking in the glow plug, to thereby improve the durability of the glow plug.

[Means for Solving the Problems]

[0009] The present invention has been conceived to solve the above-described problems and can be embodied in the following modes.

(1) A mode of the present invention provides a glow plug comprising a heat-generating element which is formed of an iron-based alloy and which generates heat through application of electricity thereto; a sheath tube which is formed of a nickel-based alloy, which is disposed around the heat-generating element, and which extends in a direction of an axial line; and a fusion zone which is formed through welding of the sheath tube and the heat-generating element, and with which a forward end of the sheath tube is closed. The glow plug is characterized in that, in a cross section of the fusion zone, the cross section including the axial line, the fusion zone has an iron content of 20 mass% to 60 mass% at a measurement point of maximum iron content in a region having a depth of 0.5 mm or less from an outer surface of the fusion zone, wherein the measurement point is determined from points of measurements through EPMA (WDS: wavelength-dispersive X-ray spectrometer) analysis of the region at an acceleration voltage of 20 kV, a probe current of 2.5×10^{-8} A, a beam irradiation diameter of 10 μm, and a measurement interval of 10 μm. According to this mode, the glow plug exhibits improved oxidation resistance, since the region to be analyzed has a maximum iron content of 60 mass% or less, and uneven distribution of iron is suppressed in the fusion zone. In addition, since the maximum iron content is 60 mass% or less, there is reduced a difference in iron content between the fusion zone and the sheath tube formed of a nickel-based alloy. Thus, a difference in thermal expansion between the fusion zone and the sheath tube is reduced, and occurrence of cracking is sup-

pressed at the boundary between the fusion zone and the sheath tube. Furthermore, since the maximum iron content is 20 mass% or more, there is reduced a difference in iron content between the fusion zone and the heat-generating element formed of an iron-based alloy. Thus, a difference in thermal expansion between the fusion zone and the heat-generating element is reduced, and occurrence of cracking is suppressed at the boundary between the fusion zone and the heat-generating element.

(2) In the aforementioned glow plug, the measurement point of maximum iron content may be located 0.03 mm or more inward from the outer surface of the fusion zone. According to this mode, a region of the fusion zone having a depth of less than 0.03 mm from the outer surface exhibits improved oxidation resistance, since the measurement point of maximum iron content is located 0.03 mm or more inward from the outer surface of the fusion zone. This region is located near the outer surface, and thus oxygen contained in the atmosphere around the glow plug easily enters the region. Therefore, improvement of the oxidation resistance of this region is particularly important.

[0010] The present invention can be embodied in various forms other than the aforementioned glow plug. For example, the present invention can be embodied in a method of manufacturing the glow plug, and in a sheath heater other than a sheath heater for the glow plug.

[Brief Description of the Drawings]

[0011]

[FIG. 1] External view and cross-sectional view of a glow plug.
[FIG. 2] Cross-sectional view of a sheath heater.
[FIG. 3] Cross-sectional view of forward end portions of a sheath tube and a heat-generating coil before welding.
[FIG. 4] Cross-sectional view of a fusion zone.
[FIG. 5] View showing a region for component analysis.
[FIG. 6] Flowchart showing component analysis procedure.
[FIG. 7] View showing a beam irradiation diameter and a step in quantitative analysis.
[FIG. 8] Table showing the relationship between maximum iron content, oxidative erosion, and cracking.
[FIG. 9] Cross-sectional view of a portion in the vicinity of the forward end before welding (modification).
[FIG. 10] Cross-sectional view of a portion in the vicinity of the forward end before welding (modification).

[Modes for Carrying out the Invention]

[0012] FIG. 1 shows a glow plug 10. FIG. 1 shows the external appearance of the glow plug 10 on the right side with respect to an axial line O, and the section of the glow plug 10 on the left side. The glow plug 10 functions as a heat source for assisting ignition at start-up of a diesel engine.

[0013] The glow plug 10 includes a center rod member 200, a metallic shell 500, and a sheath heater 800 which generates heat through application of electricity. These members are assembled to extend in the direction of the axial line O of the glow plug 10. As used herein, the sheath heater 800 side of the glow plug 10 is referred to as the "forward end side," and the opposite side is referred to as the "rear end side."

[0014] The metallic shell 500 is a tubular member formed of carbon steel. The metallic shell 500 holds, at a forward end thereof, the sheath heater 800. The metallic shell 500 holds, at a rear end thereof, the center rod member 200 via an insulating member 410 and an O-ring 460. A ring 300 which is in contact with the rear end of the insulating member 410 is crimped to the center rod member 200, whereby the insulating member 410 is fixed at a specific position in the direction of the axial line O. A rear end portion of the metallic shell 500 is electrically insulated from the center rod member 200 by the insulating member 410. The metallic shell 500 includes therein a portion of the center rod member 200 extending between the insulating member 410 and the sheath heater 800. The metallic shell 500 has an axial hole 510, a tool engagement portion 520, and an externally threaded portion 540.

[0015] The axial hole 510 is a through hole extending in the direction of the axial line O, and has a diameter larger than that of the center rod member 200. The center rod member 200 is positioned in the axial hole 510 such that a clearance is provided between the axial hole 510 and the center rod member 200 for electrically insulating them from each other. The sheath heater 800 is press-fitted into a forward end portion of the axial hole 510 to thereby be joined to the metallic shell 500. The externally threaded portion 540 is engaged with an internally threaded portion formed on an internal combustion engine (not shown). The tool engagement portion 520 is engaged with a tool (not shown) used to attach or remove the glow plug 10.

[0016] The center rod member 200, which has a cylindrical shape, is formed of an electrically conductive material. The center rod member 200 is assembled to extend in the direction of the axial line O while being inserted in the axial hole 510 of the metallic shell 500. The center rod member 200 has a forward end portion 210 on the forward end side, and a connection portion 290 on the rear end side. The forward end portion 210 is inserted into the sheath heater 800. The connection portion 290, which is an externally threaded portion, projects from the metallic shell 500. The connection portion 290 is engaged with an engagement member 100.

[0017] FIG. 2 is a cross-sectional view of the detailed configuration of the sheath heater 800. The sheath heater 800 includes a sheath tube 810, a heat-generating coil 820 (i.e., a heat-generating element), a control coil 830, insulating powder 840, and a fusion zone 850.

[0018] The forward end of the sheath tube 810 is closed with the fusion zone 850. The fusion zone 850 has a rounded outer surface 811. As described below, the fusion zone 850 is formed through welding between the heat-generating coil 820 and the sheath tube 810, and subsequent solidification of the weld portion. Thus, the fusion zone 850 has a composition which varies depending on the below-described composition of the heat-generating coil 820 or the sheath tube 810.

[0019] The sheath tube 810 is formed of a nickel-based alloy. In the present embodiment, the nickel-based alloy employed for forming the sheath tube 810 is INCONEL (registered trademark) 601. INCONEL 601 contains, for example, aluminum (1.3 mass%), chromium (23.8 mass%), iron (15.1 mass%), and nickel (60 mass%). The sheath tube 810, which is a tubular member, extends in the direction of the axial line O, and includes therein the heat-generating coil 820, the control coil 830, and the insulating powder 840.

[0020] The sheath tube 810 has, on the rear end side, an open rear end portion 819. The forward end portion 210 of the center rod member 200 is inserted through the rear end portion 819 into the sheath tube 810. The sheath tube 810 is electrically insulated from the center rod member 200 by a packing 600 and the insulating powder 840. The packing 600 is an insulating member sandwiched between the center rod member 200 and the sheath tube 810. The sheath tube 810 is electrically connected to the metallic shell 500.

[0021] The control coil 830 is formed of an electrically conductive material having a temperature coefficient of electrical resistivity larger than that of the material of the heat-generating coil 820. The electrically conductive material is preferably nickel, but may be, for example, an alloy containing cobalt or nickel as a main component. The control coil 830 is provided within the sheath tube 810, and controls the amount of electricity supplied to the heat-generating coil 820. The control coil 830 has a forward end portion 831 and a rear end portion 839. The control coil 830 is electrically connected to the heat-generating coil 820 through welding of the forward end portion 831 to the rear end portion 829 of the heat-generating coil 820. The control coil 830 is electrically connected to the center rod member 200 through bonding of the rear end portion 839 to the forward end portion 210 of the center rod member 200.

[0022] The insulating powder 840 has electrical insulation property. The insulating powder 840 is, for example, magnesium oxide (MgO) powder. The insulating powder 840 is filled into the sheath tube 810 to fill clearances between the sheath tube 810, the heat-generating coil 820, the control coil 840, and the center rod member 200 for providing electrical insulation.

[0023] The heat-generating coil 820 is formed of an iron-based alloy. In the present embodiment, the iron-based alloy employed for forming the heat-generating coil 820 is PYROMAX (registered trademark). PYROMAX contains, for example, aluminum (7.5 mass%), chromium (26 mass%), and iron (66.5 mass%). The heat-generating coil 820 is disposed within the sheath tube 810 to extend in the direction of the axial line O, and generates heat through application of electricity thereto. The heat-generating coil 820 has a forward end portion 821 and a rear end portion 829. The heat-generating coil 820 is electrically connected to the sheath tube 810 through bonding of the forward end portion 821 to the fusion zone 850.

[0024] FIG. 3 is a cross-sectional view of a portion in the vicinity of the forward end of the glow plug before welding between the sheath tube 810 and the heat-generating coil 820. The forward end of the sheath tube 810 is open before welding of the sheath tube 810 to the heat-generating coil 820. Before being welded, the heat-generating coil 820 is disposed so that the forward end thereof projects from the open end of the sheath tube. A portion of the heat-generating coil 820 projecting from the open end of the sheath tube is densely wound as in the case of another portion. Welding of the thus-disposed sheath tube 810 and heat-generating coil 820 forms a forward end portion having a shape as shown in FIG. 2. The present embodiment employs arc welding.

[0025] The maximum iron content (described below) of the fusion zone 850 can be controlled by adjusting the wall thickness T of the sheath tube 810, the wire diameter ϕC of the heat-generating coil 820, and the projection length P of the heat-generating coil 820 shown in FIG. 3. As shown in FIG. 3, the projection length P corresponds to the distance, in the direction of the axial line O, between the forward end surface of the sheath tube 810 before welding and the forward end surface of the heat-generating coil 820 before welding. In the present embodiment, the wall thickness T may be adjusted to fall within a range of 0.4 mm to 0.8 mm, and the wire diameter ϕC may be adjusted to fall within a range of 0.2 mm to 0.5 mm. For example, the wall thickness T is adjusted to 0.5 mm, and the wire diameter ϕC is adjusted to 0.4 mm. In order to control the maximum iron content of the fusion zone 850, the electric power for arc welding is adjusted, in addition to adjustment of the aforementioned values.

[0026] FIG. 4 is a cross-sectional view of a portion in the vicinity of the fusion zone 850 formed through welding between the sheath tube 810 and the heat-generating coil 820. The cross section shown in FIG. 4 includes the axial line O, and the boundary between the forward end portion 821 of the heat-generating coil and the fusion zone 850.

[0027] The fusion zone 850 is hatched in FIG. 4. The boundary between the sheath tube 810 and the fusion zone 850 is determined as follows. On the left side with respect to the axial line O in FIG. 4, a straight line W is drawn by connecting points A and B, which are respectively located at the forward end and rear end of the interface between the sheath tube 810 and the fusion zone 850. The left side with respect to the axial line O corresponds to the negative direction of X-axis under the assumption that the axial line O is Y-axis of XY plane, the forward end side corresponds to the positive direction of Y-axis, and the rear end side corresponds to the negative direction of Y-axis. The interface between the sheath tube 810 and the fusion zone 850 is determined through, for example, visual observation of an enlarged image of the cross section which has been subjected to mirror polishing and subsequent electrolytic etching with oxalic acid dihydrate.

[0028] Similarly, on the right side with respect to the axial line O in FIG. 4, a straight line Y is drawn by connecting points C and D, which are respectively located at the forward end and rear end of the interface between the sheath tube 810 and the fusion zone 850. Each of the thus-drawn straight lines W and Y is regarded as the boundary between the sheath tube 810 and the fusion zone 850.

[0029] FIG. 5 is a cross-sectional view of a portion in the vicinity of the fusion zone 850, and shows a region for component analysis of the fusion zone 850. This region is hatched in FIG. 5. The cross section shown in FIG. 5, similar to that shown in FIG. 4, includes the axial line O, and the boundary between the forward end portion 821 of the heat-generating coil and the fusion zone 850.

[0030] The region for component analysis, which is hatched in FIG. 5, is located near the outer surface 811 of the fusion zone 850. Specifically, the region for component analysis (hereinafter may be referred to as the "analysis region") corresponds to a region having a depth of 0.5 mm or less from the outer surface 811. As used herein, the term "depth" refers to a length toward the inside of the fusion zone 850. The depth direction is perpendicular to the outer surface 811.

[0031] In the aforementioned component analysis, the analysis region is divided into two regions, and the maximum iron content of each of the two regions is determined. The two regions correspond to a region having a depth of 0 mm or more and less than 0.03 mm from the outer surface 811 (hereinafter may be referred to as an "outer region"), and a region having a depth of 0.03 mm or more and 0.5 mm or less from the outer surface 811 (hereinafter may be referred to as an "inner region").

[0032] FIG. 6 is a flowchart showing the procedure of component analysis. The component analysis procedure is roughly divided into mapping (steps S710 to S730) and quantitative analysis (steps S740 to S770).

[0033] Firstly, the analysis region is analyzed through wavelength-dispersive X-ray spectroscopy by means of an EPMA (WDS: wavelength-dispersive X-ray spectrometer) (step S710). Specifically, a dispersive crystal is set at a position corresponding to iron peak intensity, and the following conditions are employed: acceleration voltage: 20 kV, probe current: 2.5×10^{-8} A, beam irradiation diameter: 10 μm, step (measurement interval): 10 μm, points: 400 × 400, and main peak acquisition time: 10 ms or longer. As used herein, EPMA refers to an electron probe micro analyzer, and WDS is an abbreviation of wavelength dispersive X-ray spectrometer.

[0034] Next, iron intensity is measured at different points in the analysis region, and the thus-measured intensity data are converted into a two-dimensional map (step S720).

[0035] Subsequently, a point of maximum iron content is determined in each of the inner and outer regions on the basis of the two-dimensional map (step S730). Hereinafter, a point of maximum iron content in the inner region may be referred to as "maximum point M-in," and a point of maximum iron content in the outer region may be referred to as "maximum point M-out."

[0036] Thereafter, qualitative analysis of the fusion zone 850 is carried out by means of an EPMA (WDS) (step S740). This analysis identifies elements contained in the fusion zone 850, and also identifies an element contained therein in a maximum amount (mass%) (hereinafter, the element may be referred to as a "first component").

[0037] Subsequently, EPMA (WDS) measurement conditions are determined (step S750). This determination is carried out for improving analytical precision. These conditions are determined to meet the requirement that, in identification of the first component in step S740, 10,000 or more counts can be measured at such a beam current that counting loss due to a large amount of incident X-rays does not occur.

[0038] Next, the elements identified in step S740 are quantitatively analyzed under the conditions determined in step S750, to thereby determine the iron content of each point (step S760). Specifically, the following conditions are employed: acceleration voltage: 20 kV, probe current: 2.5×10^{-8} A, beam irradiation diameter: 10 μm, main peak acquisition time: 10 seconds, high-angle background acquisition time: 5 seconds, and low-angle background acquisition time: 5 seconds. The CPS (count per second) of each element is determined from the net intensity, and quantitative determination is carried out through the ZAF method by use of the CPS of a comparative sample (standard sample manufactured by ASTIMEX) analyzed under the same conditions as described above. The iron content of the comparative sample has been determined in advance. "ZAF" is an acronym for Z effect (atomic number effect), absorption effect, and fluorescence excitation effect. Upon this quantitative determination, normalization is performed so that the total element content becomes 100%.

[0039] In step S760, as shown in FIG. 7, quantitative determination is carried out on 5 × 5 points including the maximum point M-in at the center (step: 10 μm), and also on 5 × 5 points including the maximum point M-out (not shown) at the center (step: 10 μm) Among the 25 (5 × 5) points, a point located outside the analysis region is omitted from analysis. For example, when the maximum point M-in of the inner region is located in the vicinity of the boundary between the inner region and the outer region, some of the 25 points may be included in the outer region. In such a case, the points included in the outer region are omitted from analysis of the inner region. The same shall apply to the case where the outer region is analyzed.

[0040] Finally, the maximum iron content of each of the inner region and the outer region is determined (step S770). Specifically, the maximum value of the iron contents of the 5 × 5 points including the maximum point M-in at the center is determined as the maximum iron content of the inner region (hereinafter may be referred to as the "inner-region maximum iron content"). Meanwhile, the maximum value of the iron contents of the 5 × 5 points including the maximum point M-out at the center is determined as the maximum iron content of the outer region (hereinafter may be referred to as the "outer-region maximum iron content").

[0041] FIG. 8 is a table showing the results of a test for examining the relationship between inner-region maximum iron content, oxidative erosion, and cracking. The inner-region maximum iron contents (20 mass% to 60 mass%) of samples Nos. 2 to 6 were achieved through the aforementioned adjustment in the welding process.

[0042] The inner-region maximum iron content of sample No. 1 (10 mass%), which is lower than the iron content of the sheath tube 810 (15.1 mass%), is difficult to achieve through the aforementioned adjustment. Therefore, the inner-region maximum iron content was adjusted to be 10 mass% by forming the sheath tube 810 from a material having an iron content of less than 10%.

[0043] The inner-region maximum iron content of sample No. 7 (70 mass%), which is higher than the iron content of the heat-generating coil 820 (66.5 mass%), is difficult to achieve through the aforementioned adjustment. Therefore, the inner-region maximum iron content was adjusted to be 70 mass% by forming the heat-generating coil 820 from a material having an iron content of more than 70%.

[0044] The aforementioned test is a durability test involving repeated application of thermal shock. As used herein, the term "oxidative erosion" refers to the case where repeated application of thermal shock causes removal of the outer surface 811, resulting in thinning of the fusion zone 850. As used herein, the term "cracking" refers to occurrence of cracking at the interface between the fusion zone 850 and the heat-generating coil 820, or at the interface between the fusion zone 850 and the sheath tube 810.

[0045] For application of thermal shock, the glow plug 10 was subjected to 8,000 cycles of heating and cooling. Heating was carried out for 20 seconds so that the surface of the glow plug 10 became 1,150°C. Cooling was carried out for 60 seconds so that the temperature was lowered by 149°C one second after initiation of cooling. These test conditions (numerical values) are only an example, and may be optionally varied for reproducibility tests. For example, cooling may be carried out so that the temperature is lowered by 139 to 159°C one second after initiation of cooling, and heating may be carried out so that the surface temperature of the glow plug 10 becomes 1,140 to 1,160°C.

[0046] When the thickness of the fusion zone corresponding to oxidative erosion was represented by x, rating "A" was assigned in the case of $0 \text{ mm} < x \leq 0.1 \text{ mm}$, rating "B" was assigned in the case of $0.1 \text{ mm} < x \leq 0.15 \text{ mm}$, and rating "C" was assigned in the case of $0.15 \text{ mm} < x \leq 0.2 \text{ mm}$.

[0047] As shown in FIG. 8, samples Nos. 2 to 6 were found to have an inner-region maximum iron content of 20 mass% or more. In each of samples Nos. 2 to 6, the inner-region maximum iron content was higher than the outer-region maximum iron content. That is, in each of samples Nos. 2 to 6, the inner-region maximum iron content corresponded to the maximum iron content of the analysis region. Since oxidative erosion proceeds from the outer surface 811, when a portion having a higher iron content is located in the outer region, the portion of higher iron content is easily exposed to the outside in association with progress of oxidative erosion, whereby further oxidative erosion is likely to proceed. Therefore, when the outer-region maximum iron content is lower than the inner-region maximum iron content, oxidative erosion is advantageously reduced.

[0048] As shown in FIG. 8, rating "C" for oxidative erosion was assigned to a sample having an inner-region maximum iron content of 70 mass%, whereas rating "B" or "A" for oxidative erosion was assigned to a sample having an inner-region maximum iron content of 60 mass% or less. Therefore, the inner-region maximum iron content is preferably 60 mass% or less. That is, the maximum iron content of the analysis region is preferably 60 mass% or less. Rating "A" for oxidative erosion was assigned to a sample having an inner-region maximum iron content of 20 mass% or less. Therefore, the inner-region maximum iron content is more preferably 20 mass% or less. That is, the maximum iron content of the analysis region is more preferably 20 mass% or less.

[0049] As shown in FIG. 8, cracking occurred in sample No. 1 (inner-region maximum iron content: 10 mass%) and sample No. 7 (inner-region maximum iron content: 70 mass%), whereas no cracking occurred in samples Nos. 2 to 6 (inner-region maximum iron content: 20 mass% to 60 mass%). Therefore, the inner-region maximum iron content is preferably 20 mass% to 60 mass%. That is, the maximum iron content of the analysis region is preferably 20 mass% to 60 mass%.

[0050] When the inner-region maximum iron content was 10 mass%, cracking occurred at the boundary between the fusion zone 850 and the heat-generating coil 820. Conceivably, this is attributed to a large difference in thermal expansion coefficient between the fusion zone 850 and the heat-generating coil 820. Conceivably, a large difference in thermal expansion coefficient therebetween is attributed to a large difference between the inner-region maximum iron content of the fusion zone 850 and the iron content of the heat-generating coil 820, and thus a large difference in iron content between the fusion zone 850 and the heat-generating coil 820 at the vicinity of the boundary between the fusion zone 850 and the heat-generating coil 820.

[0051] When the inner-region maximum iron content was 70 mass%, cracking occurred at the boundary between the fusion zone 850 and the sheath tube 810. Conceivably, this is attributed to a large difference in thermal expansion coefficient between the fusion zone 850 and the sheath tube 810. Conceivably, a large difference in thermal expansion coefficient therebetween is attributed to a large difference between the inner-region maximum iron content of the fusion zone 850 and the iron content of the sheath tube 810, and thus a large difference in iron content between the fusion zone 850 and the sheath tube 810 at the vicinity of the boundary between the fusion zone 850 and the sheath tube 810.

[0052] The present invention is not limited to the above-described embodiment, but may be embodied in various other forms without departing from the spirit of the invention. For example, in order to solve, partially or entirely, the above-mentioned problem or yield, partially or entirely, the above-mentioned effects, technical features of the embodiment corresponding to technical features of the modes described in the section "Summary of the Invention" can be replaced or combined as appropriate. Also, the technical features can be eliminated as appropriate unless the technical features are specified as indispensable ones in the present specification. For example, other embodiments will be described below.

[0053] FIG. 9 shows a sheath tube 810 and a heat-generating coil 820a before welding in another embodiment. The heat-generating coil 820a is an alternative of the heat-generating coil 820 of the aforementioned embodiment. As shown in FIG. 9, a forward end portion of the heat-generating coil 820a extends in a direction almost parallel to the axial line O.

[0054] FIG. 10 shows a sheath tube 810 and a heat-generating coil 820b before welding in yet another embodiment. The heat-generating coil 820b is an alternative of the heat-generating coil 820 of the aforementioned embodiment. As shown in FIG. 10, a forward end portion of the heat-generating coil 820b extends in a direction inclined to the axial line O. Alternatively, the heat-generating coil may have a form different from that shown in FIG. 3, FIG. 9, or FIG. 10 before welding.

[0055] The outer-region maximum iron content may be 20 mass% or more. When the outer-region maximum iron content is 20 mass% or more, the outer-region maximum iron content may be equal to or higher than the inner-region maximum iron content. In these cases, even when the higher one of the inner-region maximum iron content and the outer-region maximum iron content is 20 mass% to 60 mass%, oxidative erosion and cracking may be effectively reduced.

[0056] When, as described above, an outer-region maximum iron content of 20 mass% or more is accepted, the inner region and the outer region are not necessarily distinguished from each other in component analysis. Specifically, only one point of maximum iron content may be determined in the analysis region in step S730 described above in the embodiment, and only one value of maximum iron content may be determined in step S770.

[0057] The cross section employed for analysis does not necessarily include the boundary between the forward end portion of the heat-generating coil and the fusion zone.

[0058] The boundary between the sheath tube and the fusion zone may be determined through an alternative technique. For example, a curved boundary may be determined through visual observation of a mirror-polished cross section as described above.

[Description of Reference Numerals]

[0059]

10:	glow plug
100:	engagement member
200:	center rod member
210:	forward end portion of center rod member
290:	connection portion
300:	ring
410:	insulating member
460:	O-ring
500:	metallic shell
510:	axial hole
520:	tool engagement portion
540:	externally threaded portion
600:	packing
800:	sheath heater
810:	sheath tube
811:	outer surface
819:	rear end portion of sheath tube
820:	heat-generating coil
820a:	heat-generating coil
820b:	heat-generating coil
821:	forward end portion of heat-generating coil
829:	rear end portion of heat-generating coil
830:	control coil
831:	forward end portion of control coil
839:	rear end portion of control coil
840:	insulating powder
850:	fusion zone
O:	axial line
M-out:	point of maximum iron content in outer region
M-in:	point of maximum iron content in inner region

Claims

1. A glow plug comprising:

a heat-generating element which is formed of

an iron-based alloy and which generates heat through application of electricity thereto;
a sheath tube which is formed of a nickel-based alloy, which is disposed around the heat-generating element, and which extends in a direction of an axial line; and
a fusion zone which is formed through welding of the sheath tube and the heat-generating element, and with which a forward end of the sheath tube is closed, the glow plug being **characterized in that**
in a cross section of the fusion zone, the cross section including the axial line, the fusion zone has an iron content of 20 mass% to 60 mass% at a measurement point of maximum iron content in a region having a depth of 0.5 mm or less from an outer surface of the fusion zone, wherein the measurement point is determined from points of measurements through EPMA (WDS: wavelength-dispersive X-ray spectrometer) analysis of the region at an acceleration voltage of 20 kV, a probe current of 2.5×10^{-8} A, a beam irradiation diameter of 10 μm, and a measurement interval of 10 μm.

2. A glow plug according to claim 1, wherein the measurement point of maximum iron content is located 0.03 mm or more inward from the outer surface of the fusion zone.

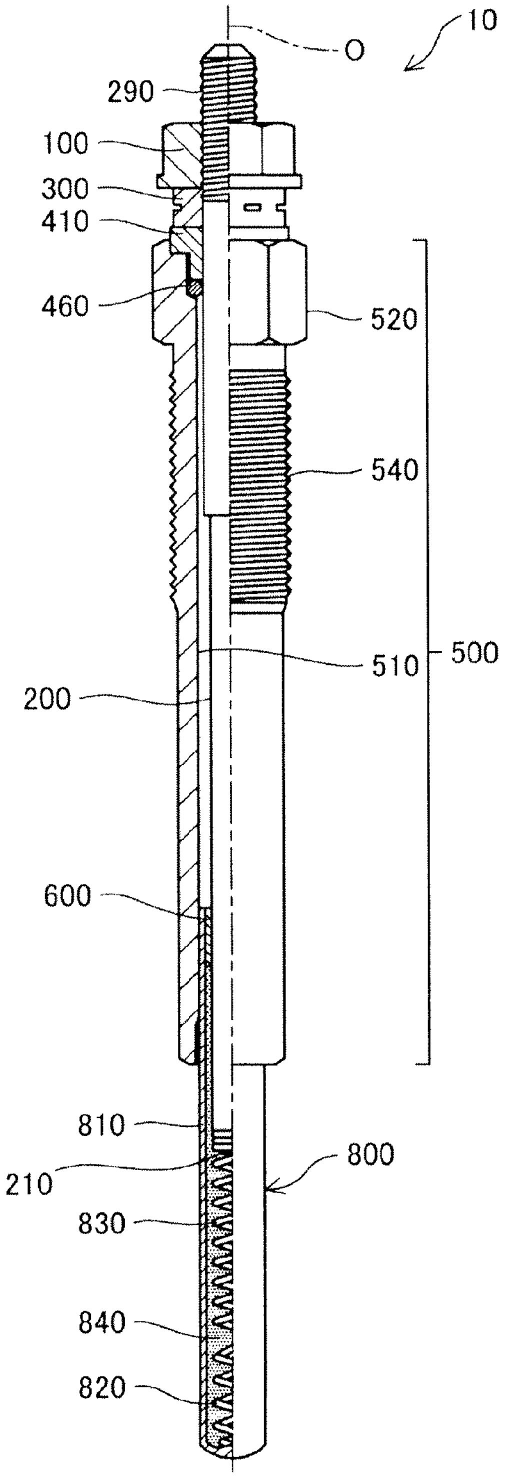
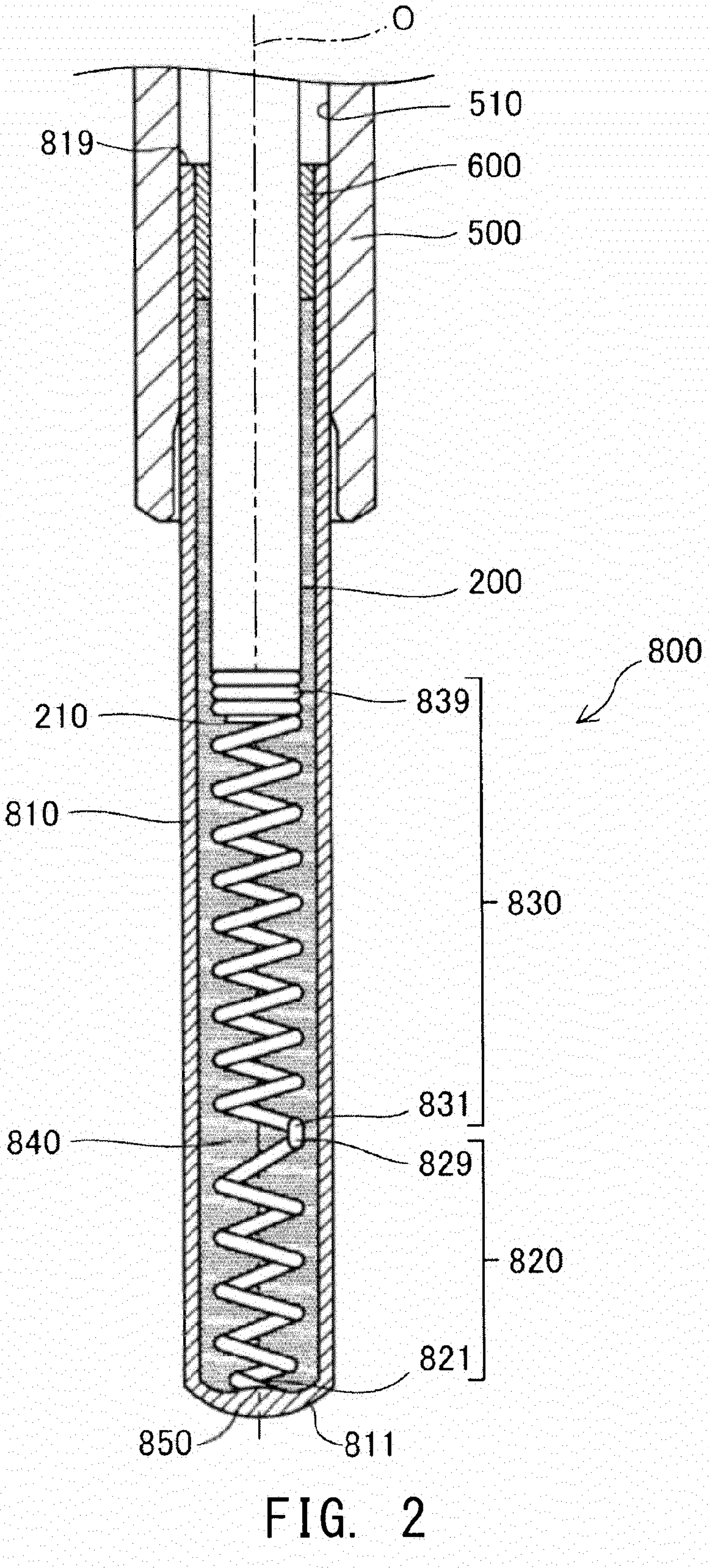

10
O
290
100
300
410
460
520
540
510
500
200
600
810
800
210
830
840
820

FIG. 1


O
510
819
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500
200
800
839
210
810
830
831
840
829
820
821
850
811

FIG. 2

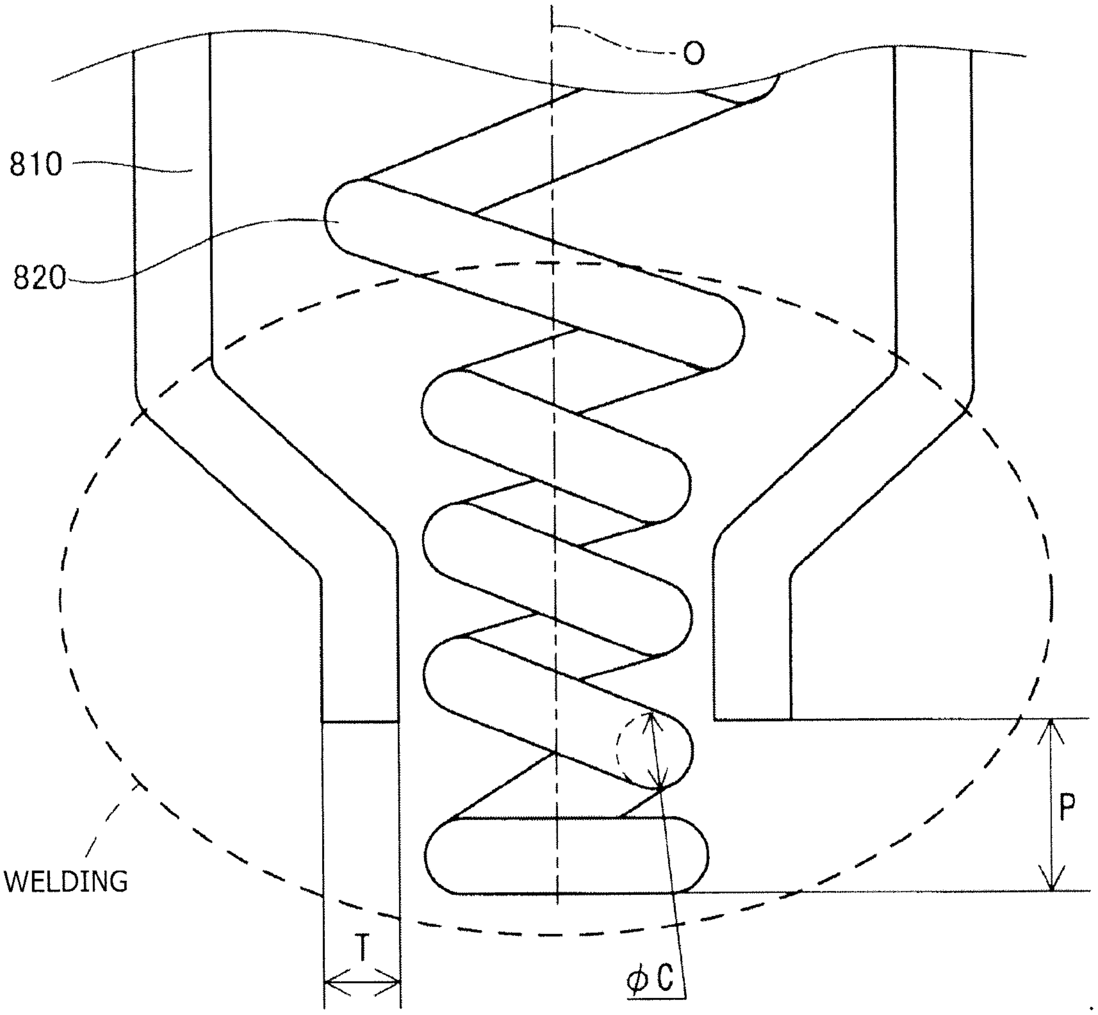

FIG. 3

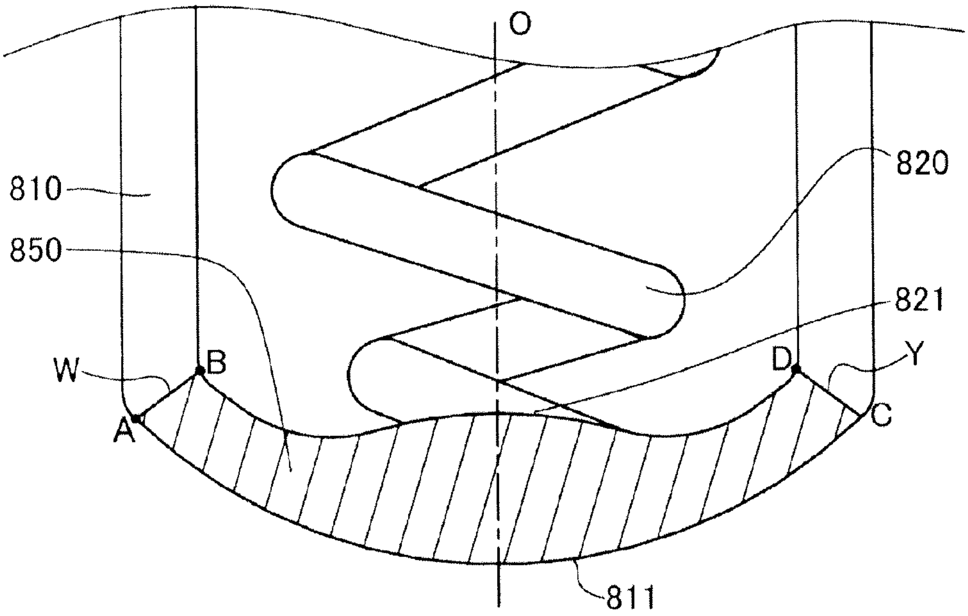
O
810
820
850
821
W
B
D
Y
A
C
811

FIG. 4

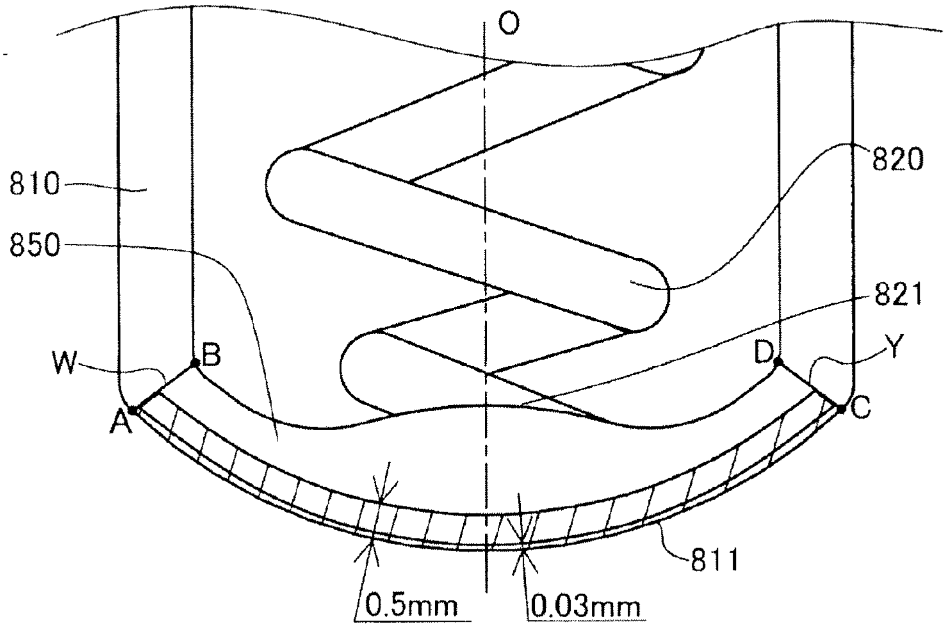
O
810
820
850
821
W
B
D
Y
A
C
811
0.5mm
0.03mm

FIG. 5

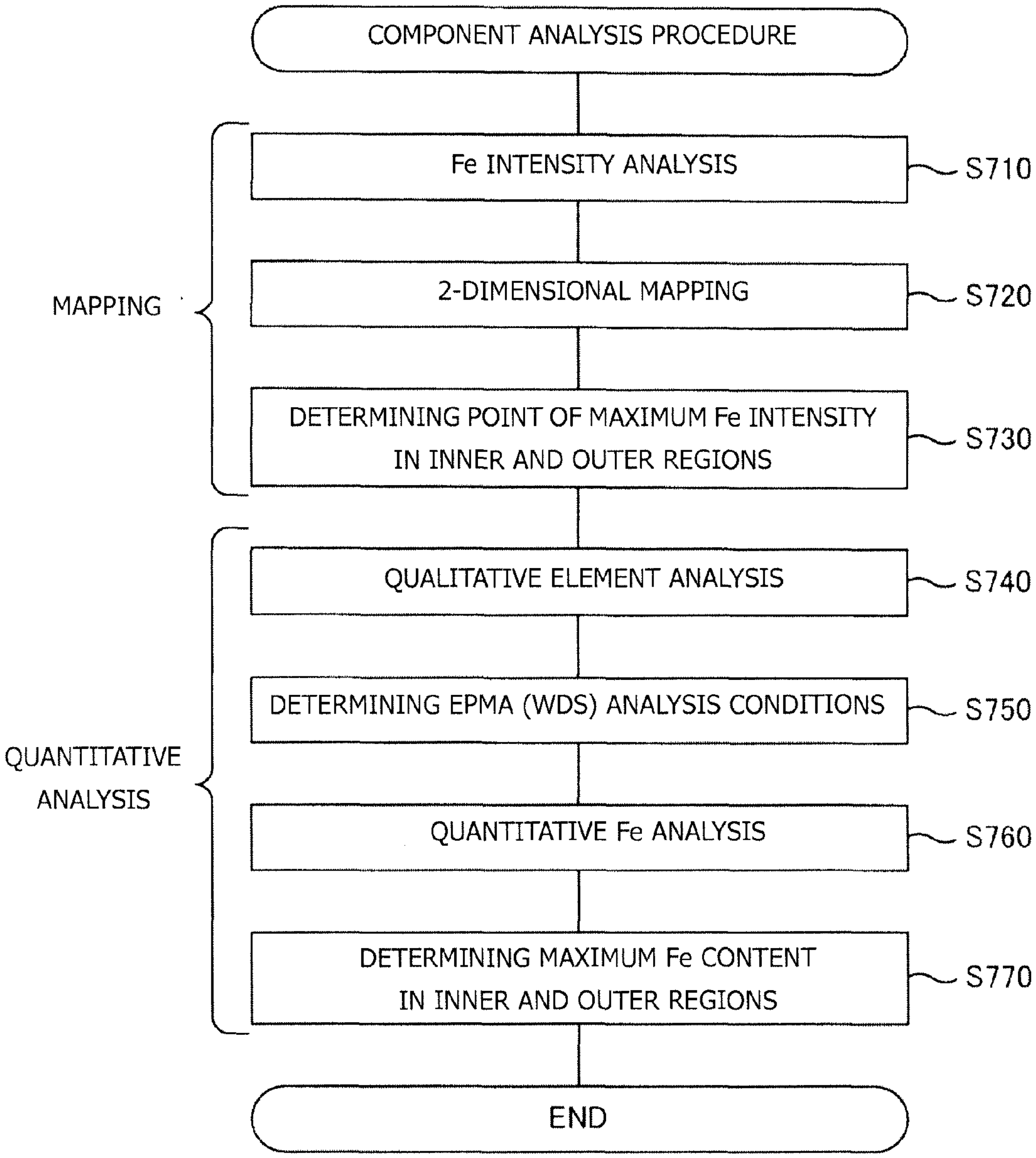
COMPONENT ANALYSIS PROCEDURE
Fe INTENSITY ANALYSIS
S710
2-DIMENSIONAL MAPPING
S720
MAPPING
DETERMINING POINT OF MAXIMUM Fe INTENSITY IN INNER AND OUTER REGIONS
S730
QUALITATIVE ELEMENT ANALYSIS
S740
DETERMINING EPMA (WDS) ANALYSIS CONDITIONS
S750
QUANTITATIVE ANALYSIS
QUANTITATIVE Fe ANALYSIS
S760
DETERMINING MAXIMUM Fe CONTENT IN INNER AND OUTER REGIONS
S770
END

FIG. 6

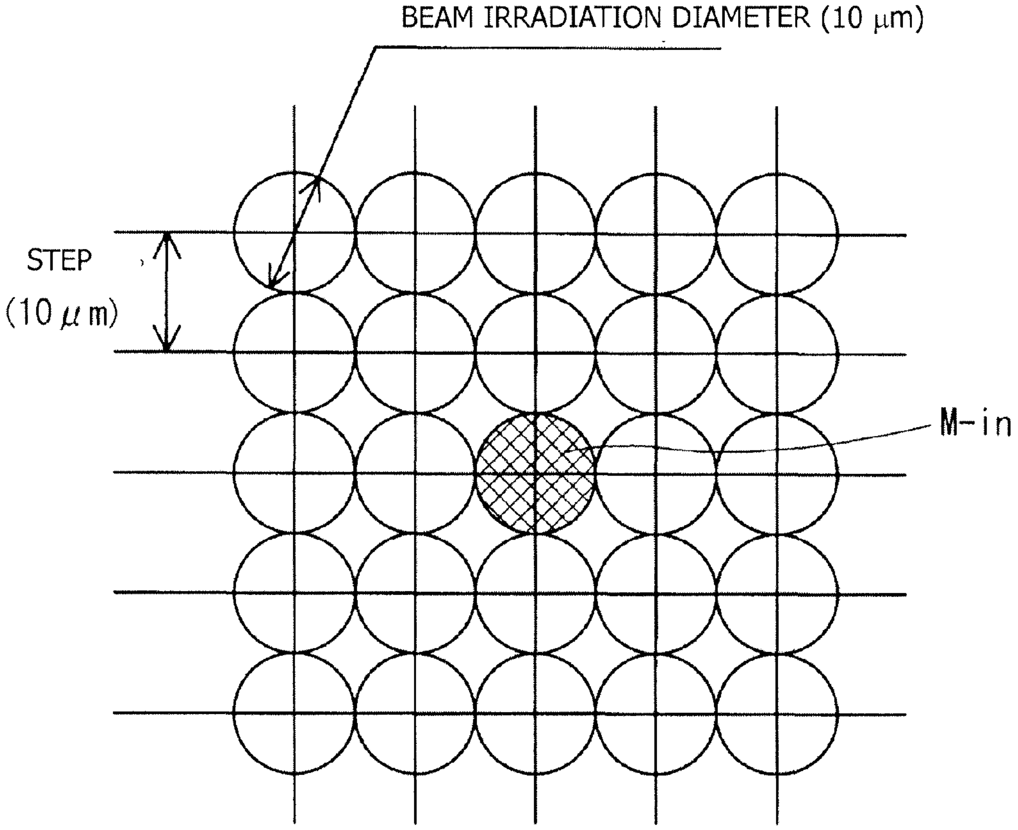

FIG. 7

No.	Inner-region maximum iron content (mass%)	Oxidative erosion	Cracking
1	10	A	Presence
2	20	A	Absence
3	30	B	Absence
4	40	B	Absence
5	50	B	Absence
6	60	B	Absence
7	70	C	Presence

FIG. 8

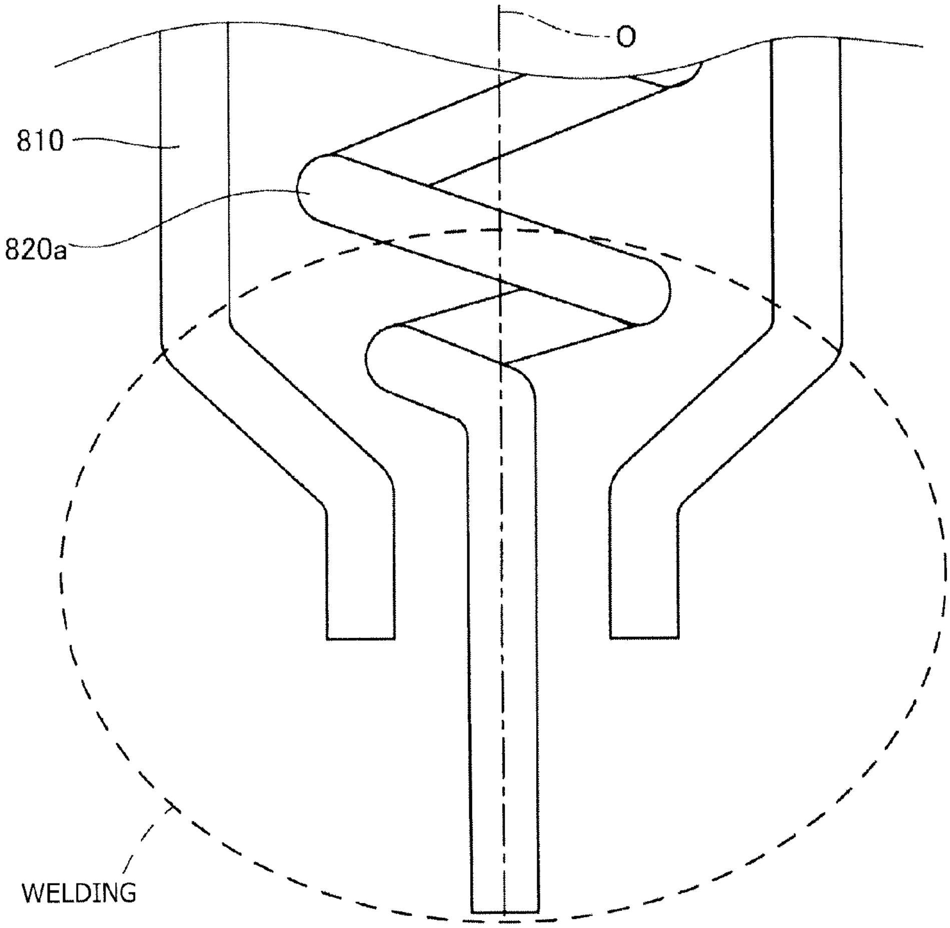

FIG. 9

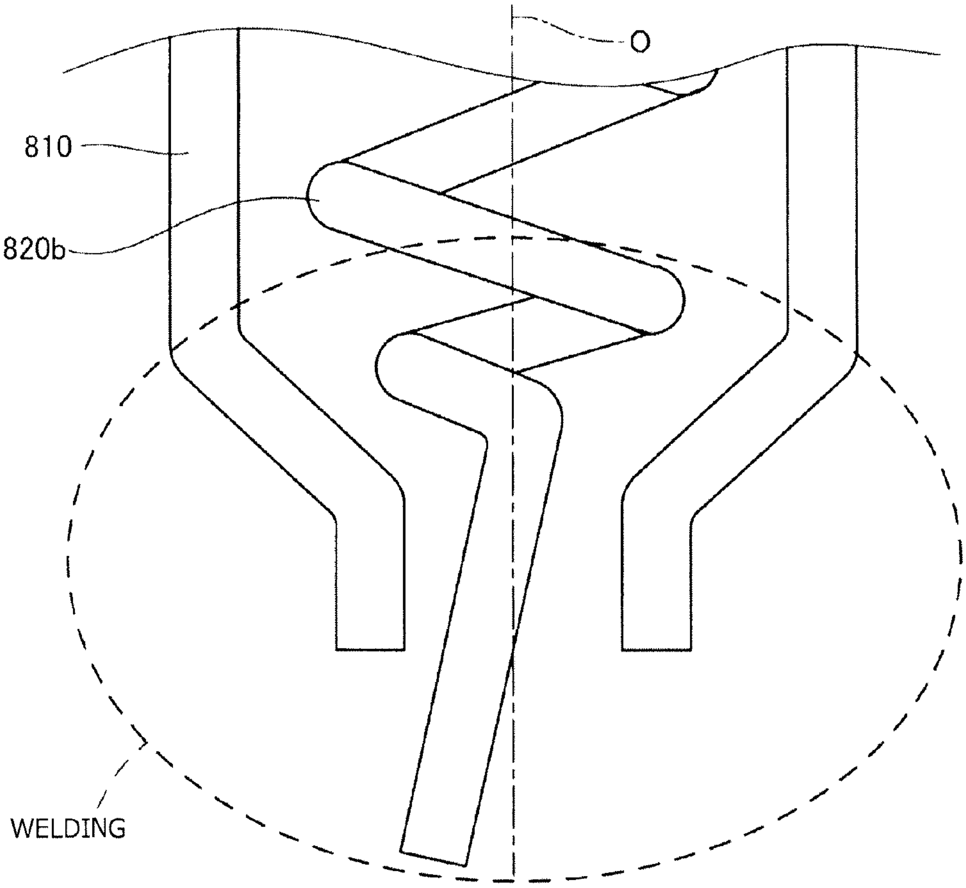

FIG. 10

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European
Patent Office
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des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 14 19 1900

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	JP 2009 156560 A (NGK SPARK PLUG CO) 16 July 2009 (2009-07-16) * paragraphs [0010], [0049], [0052], [0058], [0076] * * claim 1; figures 1-4, 9 * -----	1,2	INV. F23Q7/00
A	JP 2009 158431 A (NGK SPARK PLUG CO) 16 July 2009 (2009-07-16) * paragraphs [0010], [0045], [0049] * * figure 3 * -----	1	

TECHNICAL FIELDS SEARCHED (IPC)
F23Q

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	27 April 2015	Vogl, Paul

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
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& : 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 14 19 1900

27-04-2015

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 2009156560 A	16-07-2009	NONE	
JP 2009158431 A	16-07-2009	NONE	

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

Patent documents cited in the description

- JP 4288850 B **[0003]**