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(71) Applicant: **NGK Spark Plug Co., Ltd.**
Nagoya-shi,
Aichi 467-8525 (JP)

(72) Inventors:
- **Yatsuya, Yosuke**
Nagoya, Aichi (JP)
- **Segawa, Masayuki**
Nagoya, Aichi (JP)
- **Tanaka, Tomo-o**
Nagoya, Aichi (JP)

(74) Representative: **Grünecker Patent- und Rechtsanwälte**
PartG mbB
Leopoldstraße 4
80802 München (DE)

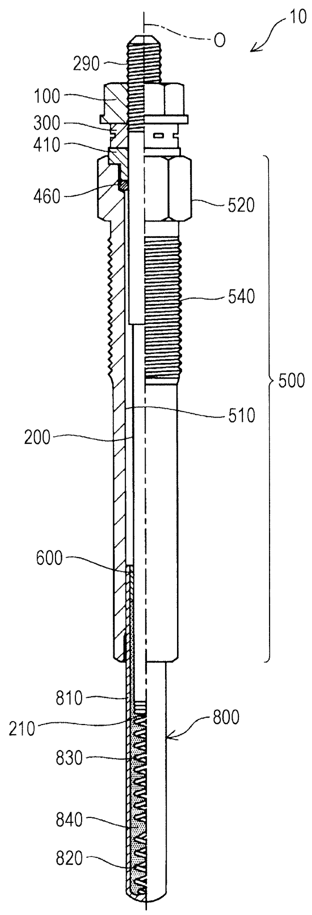
(54) **Sheated heater, glow plug**

(57) [Objective] To improve durability of a sheath heater.

[Means for Solution] A sheath heater includes a sheath tube, a heating unit, and a magnesium oxide. The sheath tube is a tubular member whose one end is closed.

The heating unit generates heat by transmission of electricity and is arranged inside the sheath tube. The magnesium oxide is arranged between the sheath tube and the heating unit and filled directly in contact with the sheath tube. The sheath tube is not thermally contracted when a temperature is increased from 20°C to 1200°C. In the sheath tube, an average thermal expansion rate is equal to or more than 13×10^{-6}/K and equal to or less than 18×10^{-6}/K when the temperature is increased from 20°C to 1200°C.

FIG. 1



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Description

[Technical Field]

[0001] The present invention relates to a sheath heater, and more particularly to a glow plug.

[Background Art]

[0002] A glow plug includes a sheath heater, and is used as an auxiliary heat source for an internal combustion engine of a compression ignition system (such as a diesel engine). The glow plug is required to have durability in usage environment within a combustion chamber or the like. To satisfy such characteristics, various combinations of materials are proposed. For example, as a material for a sheath tube which houses a heat generating coil and an insulator (for example, MgO), a nickel-based heat-resistant alloy (for example, INCONEL 601 (INCONEL is a registered trademark)), an austenitic stainless steel (Fe-Cr-Ni alloy, for example, SUS310S), or the like is used (for example, Patent Document 1).

[0003] The nickel-based heat-resistant alloy and the austenitic stainless steel have a stabilized face-centered cubic (fcc) crystal structure by containing nickel. When the crystal structure is fcc, the diffusion of oxygen into alloy becomes slow and thus the oxidation resistance becomes high. In contrast, a ferritic stainless steel (Fe-Cr alloy) that does not contain nickel has a body-centered cubic (bcc) crystal structure. Accordingly, the ferritic stainless steel is inferior in oxidation resistance under high-temperature environment and is less frequently used as the material for the sheath tube.

[Prior Art Document]

[Patent Document]

[0004] [Patent Document 1] JP-A-2007-64621

[Summary of the Invention]

[Problem to be Solved by the Invention]

[0005] The problem of the above-described prior art is that there is still room for improvement in durability. For example, when a nickel-based alloy is used as the material for the sheath tube, exposure to high temperature may cause a clearance

[0006] (hereinafter referred to as "crack") within the insulator or between the sheath tube and the insulator due to the thermal expansion difference between the sheath tube and the insulator. The occurrence of the crack locally deteriorates the heat transfer between the heat generating coil and the sheath tube. As a result, the temperature of the heat generating coil may be partially increased, which occasionally leads to meltdown of the heat generating coil. The durability to be focused on in this application refers to the properties that do not cause such meltdown of the heat generating coil.

[0007] Such a crack may occur also by thermal contraction of the sheath tube. The thermal contraction means a decrease in volume due to phase transformation caused by a temperature rise. The sheath tube compresses the insulator when thermal contraction occurs. The sheath tube after compressing the insulator may be elastically deformed to be pressed up from the inside by a reactive force against this compression. This elastic deformation causes a crack occurring between the sheath tube and the insulator when the temperature decreases.

[Means for Solving the Problems]

[0008] The present invention has been made to solve the above-mentioned problem, and can be achieved as embodiments below.

(1) According to one aspect of the present invention, the sheath heater includes: a tubular sheath tube whose one end is closed; a heating unit that is arranged inside the sheath tube and that generates heat by transmission of electricity; and a magnesium oxide that is arranged between the sheath tube and the heating unit and is filled directly in contact with the sheath tube. The sheath tube is not thermally contracted when a temperature is increased from 20°C to 1200°C, and an average thermal expansion rate is equal to or more than 13×10^{-6}/K and equal to or less than 18×10^{-6}/K when the temperature is increased from 20°C to 1200°C. According to this aspect, the durability at 20°C to 1200°C is improved. Since the sheath tube is not thermally contracted, elastic deformation of the sheath tube caused by the thermal contraction is prevented. Furthermore, since the average thermal expansion coefficient of the sheath tube is equal to or more than 13×10^{-6}/K and 18×10^{-6}/K, this average thermal expansion coefficient has a value close to the average thermal expansion coefficient of the magnesium oxide as an insulator. As a result, the occurrence of a crack caused by a temperature change is restrained.

(2) The average thermal expansion rate of the sheath tube may be equal to or less than 17×10^{-6}/K. According to this aspect, the occurrence of a crack caused by a temperature change is further restrained. This is because, according to this aspect, the average thermal expansion coefficient of the sheath tube has a value closer to the average thermal expansion coefficient of the magnesium oxide as the insulator.

(3) The average thermal expansion rate of the sheath tube may be equal to or more than 15×10^{-6}/K. According to this aspect, the occurrence of a crack

caused by a temperature change is further restrained. This is because, according to this aspect, the average thermal expansion coefficient of the sheath tube has a value closer to the average thermal expansion coefficient of the magnesium oxide as the insulator.

(4) The average thermal expansion rate of the sheath tube may be equal to or more than 16×10^{-6}/K. According to this aspect, the occurrence of a crack caused by a temperature change is further restrained.

(5) The sheath tube may contain nickel as a main component and contain chrome. According to this aspect, the numerical range of the above-described average thermal expansion rate is likely to be achieved.

(6) The sheath tube may contain at least one of aluminum, silicon, iron, and molybdenum. According to this aspect, the numerical range of the above-described average thermal expansion rate is likely to be achieved.

(7) In the sheath tube, an aluminum content rate may be equal to or more than 0.5 mass% and a silicon content rate may be equal to or more than 0.2 mass%. According to this aspect, the oxidation resistance is improved. This is because the oxide coatings of aluminum and silicon are formed on the surface of the sheath tube and suppresses the oxidation inside the sheath tube.

(8) In the sheath tube, an aluminum content rate may be equal to or less than 2.0 mass% and a silicon content rate may be equal to or less than 2.0 mass%. According to this aspect, the numerical range of the above-described average thermal expansion rate is likely to be achieved.

(9) In the sheath tube, an iron content rate may be equal to or less than 10.0 mass%. According to this aspect, the numerical range of the above-described average thermal expansion rate is likely to be achieved.

(10) In the sheath tube, an iron content rate may be equal to or less than 2.0 mass%.

(11) In the sheath tube, a molybdenum content rate may be equal to or more than 6.0 mass%. According to this aspect, the numerical range of the above-described average thermal expansion rate is likely to be achieved.

(12) In the sheath tube, a molybdenum content rate may be equal to or less than 12.0 mass%. According to this aspect, the reduction in oxidation resistance can be restrained.

(13) The sheath tube may satisfy at least one of: a chrome content rate is equal to or more than 12.0 mass%; and a chrome content rate is equal to or more than 10.0 mass% and an aluminum content rate is equal to or more than 0.3 mass%. The sheath tube may contain iron as a main component. According to this aspect, the phase transformation from bcc to fcc is restrained and thus the thermal contraction is restrained.

(14) In the sheath tube, an aluminum content rate may be equal to or more than 1.0 mass%. According to this aspect, the oxidation resistance is improved. This is because the oxide coating of aluminum is formed on the surface of the sheath tube and suppresses the oxidation inside the sheath tube.

(15) In the sheath tube, an aluminum content rate may be equal to or less than 7.0 mass%. According to this aspect, the deterioration in workability of the sheath tube is restrained. This is because, for example, forming by swaging processing becomes difficult when the aluminum content rate is more than 7.0 mass%.

(16) In the sheath tube, a chrome content rate may be equal to or less than 30.0 mass%. According to this aspect, the deterioration in workability of the sheath tube is restrained. This is because a σ phase is easily deposited when the chrome content rate is more than 30.0 mass%. The σ phase is an intermetallic compound between iron and chrome, and is brittle.

[0009] The present invention can be embodied by various aspects other than the above-described aspect. For example, the present invention can be embodied as a glow plug that includes the above-described sheath heater and a metal shell holding the sheath heater.

[Brief Description of the Drawings]

[0010]

[FIG. 1] FIG. 1 is a sectional view and an external view of a glow plug.
[FIG. 2] FIG. 2 is a sectional view of a sheath heater.
[FIG. 3] FIG. 3 is a table showing test conditions and test results of a durability test of a heat generating coil.
[FIG. 4] FIG. 4 is a table showing test conditions and test results of the durability test of the heat generating coil.
[FIG. 5] FIG. 5 is a table showing test conditions and test results of the durability test of the heat generating

coil.

[Description of Embodiments]

[0011] FIG. 1 illustrates a glow plug 10. FIG. 1 illustrates the external configuration on the right side of an axial line O on the paper and illustrates the cross-sectional configuration on the left side of the axial line O on the paper. The glow plug 10 functions as a heat source that assists ignition at the start of a diesel engine.

[0012] The glow plug 10 includes a center rod member 200, a metal shell 500, and a sheath heater 800 that generates heat by transmission of electricity. These members are assembled along the axial line O of the glow plug 10. In this description, the sheath heater 800 side in the glow plug 10 is referred to as a "front end side" while the opposite side is referred to as a "rear end side."

[0013] The metal shell 500 is formed into a tubular shape and made of carbon steel. The metal shell 500 holds the sheath heater 800 at an end portion on the front end side. The metal shell 500 holds the center rod member 200 at an end portion on the rear end side via an insulating member 410 and an O-ring 460. A position of the insulating member 410 in the axial line O direction is secured by crimping a ring 300 that is in contact with a rear end of the insulating member 410 to the center rod member 200. The insulating member 410 insulates the rear end side of the metal shell 500. The metal shell 500 incorporates a part of the center rod member 200 from the insulating member 410 to the sheath heater 800. The metal shell 500 includes an axial hole 510, a tool engagement portion 520, and an external thread portion 540.

[0014] The axial hole 510 is a through hole formed along the axial line O, and has a diameter larger than the center rod member 200. In a state where the center rod member 200 is arranged in the axial hole 510, a space is formed between the axial hole 510 and the center rod member 200 so as to provide an electrical insulation therebetween. The sheath heater 800 is press-fitted and joined to the front end side of the axial hole 510. The external thread portion 540 fits an internal thread formed at an internal combustion engine (not illustrated). The tool engagement portion 520 engages a tool (not illustrated) used for installation and removal of the glow plug 10.

[0015] The center rod member 200 is made of a conductive material in a cylindrical shape. The center rod member 200 is assembled along the axial line O while being inserted into the axial hole 510 of the metal shell 500. The center rod member 200 includes a center rod member front end portion 210 formed at the front end side and a connecting portion 290 disposed at the rear end side. The center rod member front end portion 210 is inserted to the inside of the sheath heater 800. The connecting portion 290 is an external thread projected from the metal shell 500. The engaging member 100 is fitted to the connecting portion 290.

[0016] FIG. 2 is a sectional view illustrating a detailed configuration of the sheath heater 800. The sheath heater 800 includes a sheath tube 810, a heat generating coil 820 as a heating unit, a control coil 830, and insulating powder 840.

[0017] The sheath tube 810 is a tubular member that extends in the axial line O direction and has a closed front end. The sheath tube 810 is made of metal, whose composition will be described in detail with reference to FIG. 3. The heat generating coil 820, the control coil 830, and the insulating powder 840 are arranged inside the sheath tube 810. The sheath tube 810 includes a sheath tube front end portion 811 and a sheath tube rear end portion 819. The sheath tube front end portion 811 is an end portion formed to a rounded shape toward the outside at the front end side of the sheath tube 810. The sheath tube rear end portion 819 is an end portion open at the rear end side of the sheath tube 810. The center rod member front end portion 210 of the center rod member 200 is arranged at the inside from the sheath tube rear end portion 819 to the sheath tube 810. A packing 600 and the insulating powder 840 electrically insulate the sheath tube 810 from the center rod member 200. 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 metal shell 500.

[0018] The control coil 830 is a coil made of a conductive material that has a temperature coefficient of specific electric resistance larger than a material forming the heat generating coil 820. As the conductive material, nickel is preferable. Other than this, for example, the conductive material may be an alloy containing cobalt or nickel as a main component. The main component according to this embodiment is a component having the highest content rate (mass%).

[0019] The control coil 830 is disposed inside of the sheath tube 810. The control coil 830 controls electric power supplied to the heat generating coil 820 according to the temperature. The control coil 830 includes a control coil front end portion 831 at the end portion on the front end side, and a control coil rear end portion 839 at the end portion on the rear end side. The control coil front end portion 831 is electrically connected to the heat generating coil 820 by being welded to a heat generating coil rear end portion 829 of the heat generating coil 820. The control coil rear end portion 839 is electrically connected to the center rod member 200 by being bonded to the center rod member front end portion 210 of the center rod member 200.

[0020] The insulating powder 840 is powder having electrical insulating properties. As the insulating powder 840, for example, powder of magnesium oxide (MgO) is used. In this embodiment, the magnesium oxide content rate in the insulating powder 840 is equal to or more than 85.0 mass%. Other than magnesium oxide, calcium oxide (CaO), zirconia (zirconium dioxide, ZrO_2), or the like is contained in the insulating powder 840, for example. The insulating powder 840 is filled inside the sheath tube

810. The insulating powder 840 electrically insulates respective clearances of the sheath tube 810, the heat generating coil 820, the control coil 830, and the center rod member 200. After filling up with the insulating powder 840, the outer diameter of the sheath tube 810 is adjusted by swaging processing. The insulating powder 840 is compressed due to the use of the glow plug 10, and then loses fluidity. As a result, the above-mentioned crack (the clearance inside the insulating powder 840 or the clearance between the insulating powder 840 and the sheath tube 810) may occur at the insulating powder 840.

[0021] The heat generating coil 820 contains, for example, iron or nickel as a main component, and may contain at least any of aluminum, chrome, and tungsten (see FIG. 3). The heat generating coil 820 is disposed along the axial line O direction on the inner side of the sheath tube 810, and generates heat by transmission of electricity.

[0022] The heat generation by the heat generating coil 820 allows a rapid temperature rise. The rapid temperature rise means that the surface temperature of a predetermined portion of the sheath tube 810 reaches 1000°C from a normal temperature within 2 seconds. The above-described predetermined portion is at the position moved by 2 mm from the front end of the sheath tube 810 to the rear end side in the axial line O direction. The front end of the sheath tube 810 is identical to the front end of the sheath tube front end portion 811. For the rapid temperature rise, the electric power equal to or more than a predetermined value is supplied to the heat generating coil 820.

[0023] The heat generating coil 820 includes a heat generating coil front end portion 821 at the end portion on the front end side, and the heat generating coil rear end portion 829 at the end portion on the rear end side. The heat generating coil front end portion 821 is electrically connected to the sheath tube 810 by being welded to a part in the vicinity of the front end of the sheath tube 810.

[0024] FIGS. 3, 4, and 5 show test conditions and test results of durability tests of the heat generating coil 820 as tables. FIG. 3 shows the case where the main component of the sheath tube 810 is iron, and FIGS. 4 and 5 show the cases where the main component of the sheath tube 810 is nickel. However, the main component of the test piece No. 1 shown in FIG. 3 is platinum.

[0025] The sign "-" shown in FIGS. 3, 4, and 5 means that the content rate is zero or a value within an error range. The content rates of the sheath tube 810 and the heat generating coil 820 have values in a region except for a region where the constituent changes due to welding with the above-mentioned sheath tube 810.

[0026] As shown in FIG. 3, the sheath tubes 810 (the test pieces Nos. 2 to 16) that contain iron as the main component contain chrome. The sheath tubes 810 of the test pieces Nos. 3, 4, 6, and 8 to 16 contain aluminum.

[0027] As shown in FIGS. 4 and 5, the sheath tubes 810 (the test pieces Nos.17 to 73) that contain nickel as the main component contain chrome. Furthermore, the sheath tubes 810 that contain nickel as the main component contain at least one of silicon, aluminum, molybdenum, and iron. Furthermore, some of the sheath tubes 810 that contain nickel as the main component contain at least one of manganese, cobalt, titanium, niobium, tantalum, and yttrium. The value shown in "OTHER" in FIG. 4 is indicated by mass% of the subsequent chemical symbol. For example, "0.2Ti, 4Nb+Ta" of the test piece No. 18 means that the titanium content rate is 0.2 mass% and the sum of the niobium content rate and the tantalum content rate is 4.0 mass%. The sheath tubes 810 of the test pieces Nos. 1 to 73 may contain other impurities.

[0028] The compositions of the heat generating coils 820 shown in FIGS. 3, 4, and 5 show chemical symbols of the main components and the other components. The other components are shown by mass%. For example, "Fe20Cr5Al" in the test piece No. 1 means that the main component is iron, the chrome content rate is 20.0 mass%, and the aluminum content rate is 5.0 mass%.

[0029] The parameters changed as the test condition are the composition and thermal expansion rate of the sheath tube 810, the composition of the heat generating coil 820, the temperature, and the atmosphere gas.

[0030] The thermal expansion rate of the sheath tube 810 (hereinafter simply referred to as "thermal expansion rate") is an average value of the thermal expansion rate during the temperature rise from 20°C to 1200°C. The method for obtaining the thermal expansion rate is as follows. After a length L_{20} of a test piece at room temperature is measured, the temperature of the test piece is increased and a length L_{1200} of the test piece at 1200°C is measured. The thermal expansion rate is calculated by $(L_{1200} - L_{20})/(L_{20} \times 1180\ K)$. In this embodiment, the length of the test piece was measured using a thermomechanical analyzer (TMA) while the temperature was gradually increased. Accordingly, the length at a medium temperature between 20°C and 1200°C was also measured. Thus, whether or not thermal contraction occurs during the temperature rise from 20°C to 1200°C in the above-described test can be also determined. In this embodiment, however, the length at the medium temperature was not used for calculating the thermal expansion rate as described above.

[0031] The durability test was carried out by repeating heating and cooling of the heat generating coil 820 while energizing the heat generating coil 820 in the air and by counting repetitions (breaking cycles) until the wire breaking of the heat generating coil 820 occurred. The heating was performed for 10 minutes to reach 900°C, 1100°C, or 1150°C. These temperatures are the surface temperatures of the glow plug 10, and the conditions of measurement are as follows. When a monochromatic radiation thermometer was used, an emissivity $\varepsilon = 1.0$ at the time of measurement, and a measurement spot diameter was 2 mm, a measuring position was set to the position by 2 mm from the sheath tube front end portion 811 of the sheath tube 810 to the rear end side in the axial line O direction. The cooling was performed for 2 minutes by air cooling in the atmosphere.

[0032] Regarding the test pieces Nos. 2 and 3, the tests were also carried out in nitrogen, in addition to the atmosphere, in accordance with the above-described procedure. In the case where the heating temperature was 900°C or 1100°C, an evaluation A was determined when the count of breaking cycles was equal to or more than 20 thousand, an evaluation B was determined when the count of breaking cycles was equal to or more than 10 thousand and less than 20 thousand, and an evaluation C was determined when the count of breaking cycles was less than 10 thousand. In the case where the heating temperature was 1150°C, an evaluation A was determined when the count of breaking cycles was equal to or more than 10 thousand, an evaluation B was determined when the count of breaking cycles was equal to or more than 7 thousand and less than 10 thousand, and an evaluation C was determined when the count of breaking cycles was less than 7 thousand. However, it was impossible to assemble the test piece No. 15, and therefore the durability test was not able to be carried out for the test piece No. 15 (details will be described later).

[0033] Based on the above-described count of breaking cycles, the comprehensive evaluations of the respective test pieces were determined. The comprehensive evaluation was determined by six levels from a comprehensive evaluation 1 to a comprehensive evaluation 6 while the comprehensive evaluation 1 was ranked as the most preferable evaluation. The specific determination method of the comprehensive evaluation is as follows. In the following description of the determination method, the test was carried out in the atmosphere unless otherwise stated.

[0034] Under the condition at 1150°C, the test pieces 30 to 33, and 36 with the evaluation A were determined as the comprehensive evaluation 1. For the test pieces Nos. 28 and 29, the test under the condition at 1150°C was not carried out but the composition of the sheath tube 810 was identical to that of the test piece No. 30. Accordingly, the test pieces Nos. 28 and 29 were determined as the comprehensive evaluation 1. For the test pieces Nos. 34 and 35, the test under the condition at 1150°C was not carried out but the composition of the sheath tube 810 was identical to that of the test piece No. 36. Accordingly, the test pieces Nos. 34 and 35 were determined as the comprehensive evaluation 1.

[0035] After the test pieces with the comprehensive evaluation 1 were excluded, the test pieces 17 to 26 and 37 to 39 with the evaluation A under the condition at 1100°C were determined as the comprehensive evaluation 2. For the test piece No. 27, the composition of the sheath tube 810 was identical to that of the test piece No. 26. Accordingly, the test piece No. 27 was determined as the comprehensive evaluation 2.

[0036] After the test pieces with the comprehensive evaluations 1 and 2 were excluded, the test pieces 4, 6, 8 to 12, 16, and 40 to 67 were determined as the comprehensive evaluation 3. The test pieces 4, 6, 8 to 12, 16, and 40 to 67, which satisfied at least any of: the evaluation B under the condition at 1100°C; and the evaluation B under the condition at 1150°C, were determined as the comprehensive evaluation 3. The test pieces Nos. 13 and 14 did not satisfy any of the above-described two conditions but the composition of the sheath tube 810 was identical to that of the test piece No. 12. Accordingly, the test pieces Nos. 13 and 14 were determined as the comprehensive evaluation 3.

[0037] The test piece No. 7 with the evaluation B under the condition at 900°C was determined as the comprehensive evaluation 4. Furthermore, the test piece No. 3 with the evaluation B under the condition in nitrogen and at 1100°C was also determined as the comprehensive evaluation 4.

[0038] The test piece No. 15 was determined as the comprehensive evaluation 5. The test piece No. 15 was not able to undergo the test as described later in detail, but the thermal expansion rate was 18×10^{-6}/K. Accordingly, the test piece No. 15 was determined to be more preferable than the following comprehensive evaluation 6.

[0039] The test pieces except for the above-described pieces were determined as the comprehensive evaluation 6. That is, the test pieces Nos. 1, 5, and 68 to 73 determined only as the evaluation C were determined as the comprehensive evaluation 6.

[0040] Both in the case where the thermal expansion rate was 11×10^{-6}/K (in the test piece No. 1) and in the case where the thermal expansion rate was 19×10^{-6}/K (in the test pieces Nos. 68 to 73), a large crack occurred and the comprehensive evaluation 6 was determined. In contrast, in the case where the thermal expansion rate was equal to or more than 13×10^{-6}/K and equal to or less than 18×10^{-6}/K, the comprehensive evaluation 5 or a higher rank was determined. Accordingly, the thermal expansion rate is preferred to be equal to or more than 13×10^{-6}/K and equal to or less than 18×10^{-6}/K.

[0041] The thermal expansion rate of the sheath tube 810 is preferred to be equal to or more than 13×10^{-6}/K and equal to or less than 18×10^{-6}/K because this thermal expansion rate is close to 15.7×10^{-6}/K that is the thermal expansion rate of the insulating powder 840 according to this embodiment. This causes reduction in the size or suppression in occurrence of the above-mentioned crack even when heating and cooling are repeated.

[0042] The test piece No. 5 had a thermal expansion rate of a value (15×10^{-6}/K) within the above-described preferred range, but was determined as the comprehensive evaluation 6. This is considered to be because the sheath tube 810 was thermally contracted. This thermal contraction is considered to occur at, for example, 840 to 890°C. As described above, the thermal contraction of the sheath tube 810 may cause a crack of the insulating powder 840 and meltdown of the heat generating coil 820. It is considered from the comparison with the test pieces Nos. 3 and 7 that the thermal contraction occurred in the test piece No. 5 because any of the following (a) and (b) was not satisfied.

(a) the chrome content rate in the sheath tube 810 is equal to or more than 10.0 mass% and the aluminum content rate in the sheath tube 810 is equal to or more than 0.3 mass%
(b) the chrome content rate in the sheath tube 810 is equal to or more than 12.0 mass%

[0043] Accordingly, when the main component is iron, the numerical ranges shown as (a) and (b) are preferred. When any of (a) and (b) is satisfied, the occurrence of thermal contraction is restrained. This is considered to be because the phase transformation from bcc to fcc for iron contained as the main component is restricted.

[0044] The test piece No. 3 had a thermal expansion rate of a value (14×10^{-6}/K) within the above-described preferred range, but was determined as the comprehensive evaluation 4. This is considered to be because the sheath tube 810 had a hole due to the durability test in the case where the atmosphere was the air. Since the evaluation on breaking of wire in the test piece No. 3 in the case where the atmosphere was nitrogen was the evaluation B, the cause of the hole of the sheath tube 810 in the test piece No. 3 is considered to be the oxidation of the sheath tube 810.

[0045] On the other hand, the test piece No. 6 was determined as the evaluation B in the case of 1100°C in the test in the air. Compared with the sheath tube 810 of the test piece No. 3, the sheath tube 810 of the test piece No. 6 contained the same element as the main component and had the same chrome content rate while having a higher content rate (1.0 mass%) of aluminum. Accordingly, the condition where the aluminum content rate in the sheath tube 810 is equal to or more than 1.0 mass% is considered to suppress the occurrence of the hole due to the oxidation of the sheath tube 810 and thus is preferred.

[0046] Incidentally, the test piece No. 2 was determined as the evaluation B in the test at 900°C. Accordingly, it is considered that, under the usage environment up to 900°C, the hole is not generated due to the oxidation and the test piece No. 2 is durable in use, even if aluminum is not contained.

[0047] The test pieces where the main component of the sheath tube 810 was iron and the thermal expansion rate was equal to or more than 15×10^{-6}/K and equal to or less than 17×10^{-6}/K (the test pieces Nos. 4, 6, and 8 to 14) were determined as the comprehensive evaluation 3, except the test piece No. 5 where thermal contraction occurred and the test piece No. 7. When the main component of the sheath tube 810 is iron, the thermal expansion rate is preferred to be equal to or more than 15×10^{-6}/K and equal to or less than 17×10^{-6}/K. The thermal expansion rate is preferred to be equal to or more than 15×10^{-6}/K and equal to or less than 17×10^{-6}/K because it is considered that the thermal expansion rate is closer to the thermal expansion rate (15.7×10^{-6}/K) of magnesium oxide and therefore the occurrence of a crack is further restrained.

[0048] The test piece No. 7 had the thermal expansion rate of 15×10^{-6}/K, but was determined as the comprehensive evaluation 4 because it is considered that the oxidation resistance of the sheath tube 810 in the test piece No. 7 is inferior to those of the other test pieces. The oxidation resistance of the sheath tube 810 in the test piece No. 7 is inferior because the aluminum content rate in the sheath tube 810 is approximately zero. When the main component of the sheath tube 810 is iron and the thermal expansion rate is equal to or more than 15×10^{-6}/K and equal to or less than 17×10^{-6}/K, the aluminum content rate in the sheath tube 810 is preferred to be equal to or more than 1.0 mass%, for example, like the test pieces Nos. 4, 6, 8 to 14, and 16.

[0049] For the test piece No. 15, the durability test was not able to be carried out as mentioned above. This is because, in the case of the test piece No. 15, the workability of the sheath tube 810 was poor and swaging processing of the sheath tube 810 was not able to be properly carried out. It is considered that the workability was poor because the aluminum content rate was 10.0 mass%. In the test pieces except the test piece No. 15, there was no problem with the workability of the sheath tube 810 and the aluminum content rate was equal to or less than 7.0 mass%. Accordingly, when the main component of the sheath tube 810 is iron, the aluminum content rate in the sheath tube 810 is preferred to be equal to or less than 7.0 mass%.

[0050] When the main component of the sheath tube 810 is iron, the chrome content rate in the sheath tube 810 is preferred to be equal to or less than 30.0 mass%. This is because a σ phase is deposited when the chrome content rate in the sheath tube 810 exceeds 30.0 mass%. The σ phase is an intermetallic compound between iron and chrome, and is brittle. Accordingly, the deposition of the σ phase makes the production of the sheath tube 810 difficult.

[0051] In the test pieces in which the main component of the sheath tube 810 was iron and which were determined as the comprehensive evaluations 3 and 4, the content rate of iron was equal to or more than 61.0 mass%. In addition, in the test pieces in which the main component of the sheath tube 810 was iron and which were determined as the comprehensive evaluations 3 and 4, thermal contraction did not occur in the above-described tests where the temperature was increased from 20°C to 1200°C.

[0052] As shown in FIGS. 4 and 5, the test pieces Nos. 17 to 67 where the main component of the sheath tube 810 was nickel and the thermal expansion rate was equal to or more than 16×10^{-6}/K and equal to or less than 18×10^{-6}/K were determined as the comprehensive evaluation 3 or a higher rank. Accordingly, when the main component of the sheath tube 810 is nickel, the thermal expansion rate is preferred to be equal to or more than 16 $\times$ 10^{-6}/K and equal to or less than 18 $\times$ 10^{-6}/K.

[0053] The test pieces Nos. 17 to 39 where the main component of the sheath tube 810 was nickel and the thermal expansion rate was equal to or more than 16 $\times$ 10^{-6}/K and equal to or less than 17 $\times$ 10^{-6}/K were determined as the comprehensive evaluation 2 or a higher rank. Accordingly, when the main component of the sheath tube 810 is nickel, the thermal expansion rate is preferred to be equal to or more than 16 $\times$ 10^{-6}/K and equal to or less than 17 $\times$ 10^{-6}/K.

[0054] As mentioned above, when the main component of the sheath tube 810 was iron, all the test pieces (the test pieces Nos. 2 to 16) were determined as the comprehensive evaluation 3 or a lower rank. On the other hand, when the main component of the sheath tube 810 was nickel, some test pieces were determined as the comprehensive evaluation 2 or a higher rank as described above. Such a difference occurs because the crystal structure is bcc when the main component of the sheath tube 810 is iron, while the crystal structure is fcc when the main component of the sheath tube 810 is nickel. The crystal structure of fcc is more excellent in high-temperature strength compared with the case where the crystal structure is bcc.

[0055] In all of the test pieces Nos. 17 to 73 where the main component of the sheath tube 810 was nickel, the sheath tube 810 contained chrome. When the main component of the sheath tube 810 is nickel, it is considered that the chrome content rate in the sheath tube 810 facilitates obtainment of a desired thermal expansion rate. Accordingly, when the main component of the sheath tube 810 is nickel, the sheath tube 810 is preferred to contain chrome.

[0056] When the main component of the sheath tube 810 was nickel and the thermal expansion rate was equal to or more than 16 $\times$ 10^{-6}/K and equal to or less than 18 $\times$ 10^{-6}/K, the test pieces Nos. 18, 26, and 40 were determined as the evaluation C in the test at 1150°C. The test pieces Nos. 18, 26, and 40 were determined as the evaluation B or a higher rank at 1100°C. Thus, the cause of the evaluation C is considered that the test pieces Nos. 18, 26, and 40 are inferior to the other test pieces in oxidation resistance under a high-temperature condition.

[0057] The oxidation resistance under the high-temperature condition depends on the content rates of silicon and aluminum. It is understood that, from the comparison between the test piece No. 40 and the test piece No. 41, the evaluation at 1150°C improves from the evaluation C to the evaluation B when the silicon content rate is increased from 0.1 mass% to 0.2 mass%. Accordingly, the silicon content rate is preferred to be equal to or more than 0.2 mass%.

[0058] On the other hand, the test piece No. 18 where the silicon content rate was 0.2 mass% was determined as the evaluation C at 1150°C. This is considered to be because the aluminum content rate is 0.2 mass% from the comparison with the test piece No. 41 where the aluminum content rate is 0.5 mass%. Accordingly, the aluminum content rate is preferred to be equal to or more than 0.5 mass%.

[0059] As discussed above, when the main component of the sheath tube 810 is nickel, the oxidation resistance is preferably suppressed in the case where the silicon content rate is equal to or more than 0.2 mass% and the aluminum content rate is equal to or more than 0.5 mass%.

[0060] As shown in FIG. 4, in all the test pieces Nos. 28 to 36 determined as the comprehensive evaluation 1, the silicon content rate was 0.2 mass% and the aluminum content rate was equal to or more than 0.5 mass% as described above. Also for this reason, when the main component of the sheath tube 810 is nickel, it is preferred that the silicon content rate be 0.2 mass% and the aluminum content rate be equal to or more than 0.5 mass%.

[0061] On the other hand, the test pieces Nos. 37 to 39 were determined as the comprehensive evaluation 2 even when the main component of the sheath tube 810 was nickel, the thermal expansion rate was equal to or more than 16 $\times$ 10^{-6}/K and equal to or less than 17 $\times$ 10^{-6}/K, the silicon content rate was 0.2 mass%, and the aluminum content rate was equal to or more than 0.5 mass%, similarly to the test pieces Nos. 28 to 36. This is considered to be because the molybdenum content rate was 13.0 mass% from the comparison with the test pieces Nos. 28 to 36. On the other hand, the test pieces Nos. 28 to 36 were determined as the comprehensive evaluation 1, in which the molybdenum content rate was equal to or less than 12.0 mass%. Accordingly, when the main component of the sheath tube 810 is nickel, the molybdenum content rate is preferred to be equal to or less than 12.0 mass%. The cause of the comprehensive evaluation 2 when the molybdenum content rate was 13.0 mass% is considered to be because a large content of molybdenum was oxidized.

[0062] When the main component of the sheath tube 810 was nickel, in all the test pieces Nos. 17 to 39 with the comprehensive evaluation 2 or a higher rank, the thermal expansion rate was equal to or more than 16 $\times$ 10^{-6} and equal to or less than 17 $\times$ 10^{-6} and the molybdenum content rate was equal to or more than 6.0 mass%. In contrast, when the main component of the sheath tube 810 was nickel, in all the test pieces Nos. 40 to 73 with the comprehensive evaluation 3 or a lower rank, the thermal expansion rate was equal to or more than 18 $\times$ 10^{-6} and equal to or less than 19 $\times$ 10^{-6} and the molybdenum content rate was equal to or less than 3.0 mass%. Accordingly, when the main component of the sheath tube 810 is nickel, the molybdenum content rate is preferred to be equal to or more than 6.0 mass%. It is considered that the above-described test results are caused by the phenomenon where the thermal expansion rate is reduced when the molybdenum content rate is high.

[0063] As shown in FIGS. 4 and 5, in the test pieces Nos. 18 to 67 in which the main component of the sheath tube 810 was nickel and which were determined as the comprehensive evaluation 3 or a higher rank, the thermal expansion rate was equal to or more than 16 × 10^{-6}/K and equal to or less than 18 × 10^{-6}/K and the iron content rate was equal to or less than 10.0 mass%. In contrast, in the test pieces Nos. 68 to 71 determined as the comprehensive evaluation 6, the thermal expansion rate was 19 × 10^{-6}, and the iron content rate was equal to or more than 11.0 mass%. Accordingly, when the main component of the sheath tube 810 is nickel, the iron content rate is preferred to be equal to or less than 10.0 mass%. It is considered that the above-described test results are caused by the phenomenon where the thermal expansion rate is reduced when the iron content rate is low. Even if the iron content rate is 18.0 mass%, however, the comprehensive evaluation 2 can be obtained when a thermal expansion rate of 17 × 10^{-6}/K, like the test piece No. 17.

[0064] As shown in FIGS. 4 and 5, in the test pieces Nos. 23 to 44, 46 to 52, and 62 to 67, the main component of the sheath tube 810 was nickel, the comprehensive evaluation 3 or a higher rank was determined, and the iron content rate was equal to or less than 2.0 mass%.

[0065] Although the main component of the sheath tube 810 was nickel and the iron content rate was approximately zero, the test piece No. 72 was determined as the comprehensive evaluation 6 and had a thermal expansion rate of 19 × 10^{-6}. This is considered to be because the aluminum content rate was 2.1 mass%. In contrast, in all the test pieces Nos. 17 to 67 that were determined as the comprehensive evaluation 3 or a higher rank, the aluminum content rate was equal to or less than 2.0 mass%. Accordingly, when the main component of the sheath tube 810 is nickel, the aluminum content rate is preferred to be equal to or less than 2.0 mass%.

[0066] Although the main component of the sheath tube 810 was nickel and the iron content rate was approximately zero, the test piece No. 73 was determined as the comprehensive evaluation 6 and had a thermal expansion rate of 19 × 10^{-6}. This is considered to be because the silicon content rate was 2.1 mass%. In contrast, in all the test pieces Nos. 17 to 67 that were determined as the comprehensive evaluation 3 or a higher rank, the silicon content rate was equal to or less than 2.0 mass%. Accordingly, when the main component of the sheath tube 810 is nickel, the silicon content rate is preferred to be equal to or less than 2.0 mass%.

[0067] In all the test pieces Nos. 17 to 73, thermal contraction did not occur. In the test piece No. 17, inconel HX was used as a material for the sheath tube 810. In the test pieces Nos. 18 to 22, inconel 625 was used as the material for the sheath tube 810. In the test pieces Nos. 26 and 27, inconel 617 was used as the material for the sheath tube 810. In the test pieces Nos. 69 to 71, inconel 601 was used as the material for the sheath tube 810.

[0068] The present invention is not limited to the above-described embodiment, and may be practiced in various forms without departing from the scope of the invention. For example, the technical features in the embodiment corresponding to the technical features in the respective aspects described in Summary of the Invention may be, as necessary, replaced or combined to solve a part or all of the above-described problems or to achieve a part or all of the above-described advantageous effects. The technical features may be, as necessary, omitted unless the technical features are explained as necessary features in this description. The following describes examples.

[0069] The above-described sheath heater may be used for, for example, a heater, a cooker, or the like, other than the glow plug. The length of a test piece at a medium temperature may be taken into consideration in calculating an average thermal expansion rate. For example, the least squares method or integration may be used. When integration is used, for example, an area value in a strain-temperature relationship may be obtained and the tangent of the approximated rectangular triangle may be obtained as a value of the thermal expansion rate. The approximated rectangular triangle is the rectangular triangle that has the area identical to the above-described area value and uses the temperature range of the measurement target as a length of the base. The sheath tube may contain nickel as impurities even when iron is contained as the main component.

[0070] The sheath heater may not include the control coil. When the control coil is not included, the heat generation of the glow plug may be controlled by a glow controller.

[0071] The magnesium oxide content rate in the insulating powder may be high than 85.0 mass%. For example, the magnesium oxide content rate may be higher to the extent that the thermal expansion rate of the insulating powder has the value approximately identical to the thermal expansion rate of pure magnesium oxide. The approximately identical value is, for example, equal to or more than 13.0 × 10^{-6}/K and equal to or less than 18.0 × 10^{-6}/K. The lower limit value is more preferably equal to or more than 15.0 × 10^{-6}/K. The upper limit value is more preferably equal to or less than 17.0 × 10^{-6}/K, and even more preferably equal to or less than 16.0 × 10^{-6}/K. To obtain such a thermal expansion rate, for example, the magnesium oxide content rate in the insulating powder may be set to be equal to or more than 98.0 mass%.

[Description of Reference Numerals]

[0072]

- 10: Glow plug
- 100: Engaging member
- 200: Center rod
- 210: Center rod member front end portion
- 290: Connecting portion
- 300: Ring
- 410: Insulating member

460: O-ring
500: Metal shell
510: Axial hole
520: Tool engagement portion
540: External thread portion
600: Packing
800: Sheath heater
810: Sheath tube
811: Sheath tube front end portion
819: Sheath tube rear end portion
820: Heat generating coil
821: Heat generating coil front end portion
829: Heat generating coil rear end portion
830: Control coil
831: Control coil front end portion
839: Control coil rear end portion
840: Insulating powder
O: Axial line

Claims

1. A sheath heater comprising:

a tubular sheath tube whose one end is closed;
a heating unit arranged inside the sheath tube, the heating unit generating heat by transmission of electricity; and
a magnesium oxide arranged between the sheath tube and the heating unit, the magnesium oxide being filled directly in contact with the sheath tube, wherein
the sheath tube is not thermally contracted when a temperature is increased from 20°C to 1200°C, and an average thermal expansion rate is equal to or more than 13×10^{-6}/K and equal to or less than 18×10^{-6}/K when the temperature is increased from 20°C to 1200°C.

2. The sheath heater according to claim 1, wherein the average thermal expansion rate of the sheath tube is equal to or less than 17×10^{-6}/K.

3. The sheath heater according to claim 1 or 2, wherein the average thermal expansion rate of the sheath tube is equal to or more than 15×10^{-6}/K.

4. The sheath heater according to claim 3, wherein the average thermal expansion rate of the sheath tube is equal to or more than 16×10^{-6}/K.

5. The sheath heater according to any one of claims 1 to 4, wherein
the sheath tube contains nickel as a main component and contains chrome.

6. The sheath heater according to claim 5, wherein the sheath tube contains at least one of silicon, aluminum, molybdenum, and iron.

7. The sheath heater according to claim 5 or 6, wherein the sheath tube has an aluminum content rate of equal to or more than 0.5 mass% and a silicon content rate of equal to or more than 0.2 mass%.

8. The sheath heater according to any one of claims 5 to 7, wherein
the sheath tube has an aluminum content rate of equal to or less than 2.0 mass% and a silicon content rate of equal to or less than 2.0 mass%.

9. The sheath heater according to any one of claims 5 to 8, wherein
the sheath tube has an iron content rate of equal to or less than 10.0 mass%.

10. The sheath heater according to claim 9, wherein the sheath tube has an iron content rate of equal to or less than 2.0 mass%.

11. The sheath heater according to any one of claims 5 to 10, wherein
the sheath tube has a molybdenum content rate of equal to or more than 6.0 mass%.

12. The sheath heater according to any one of claims 5 to 11, wherein
the sheath tube has a molybdenum content rate of equal to or less than 12.0 mass%.

13. The sheath heater according to any one of claims 1 to 4, wherein
the sheath tube satisfies at least one of:

a chrome content rate is equal to or more than 12.0 mass%; and
a chrome content rate is equal to or more than 10.0 mass% and an aluminum content rate is equal to or more than 0.3 mass%, and

the sheath tube contains iron as a main component.

14. The sheath heater according to claim 13, wherein the sheath tube has an aluminum content rate of equal to or more than 1.0 mass%.

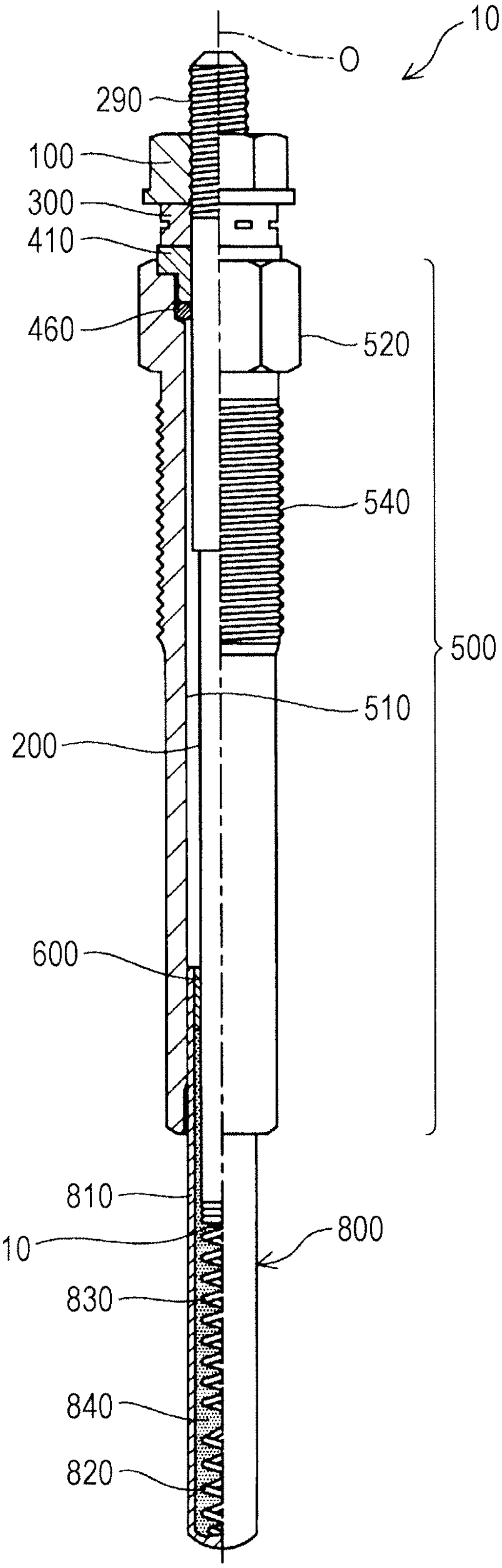
15. The sheath heater according to claim 13 or 14, wherein
the sheath tube has an aluminum content rate of equal to or less than 7.0 mass%.

16. The sheath heater according to any one of claims 13 to 15, wherein
the sheath tube has a chrome content rate of equal to or less than 30.0 mass%.

17. A glow plug, comprising:

a sheath heater; and
a metal shell that holds the sheath heater, wherein
the glow plug includes the sheath heater according to any one of claims 1 to 16.

FIG. 1


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

FIG. 2

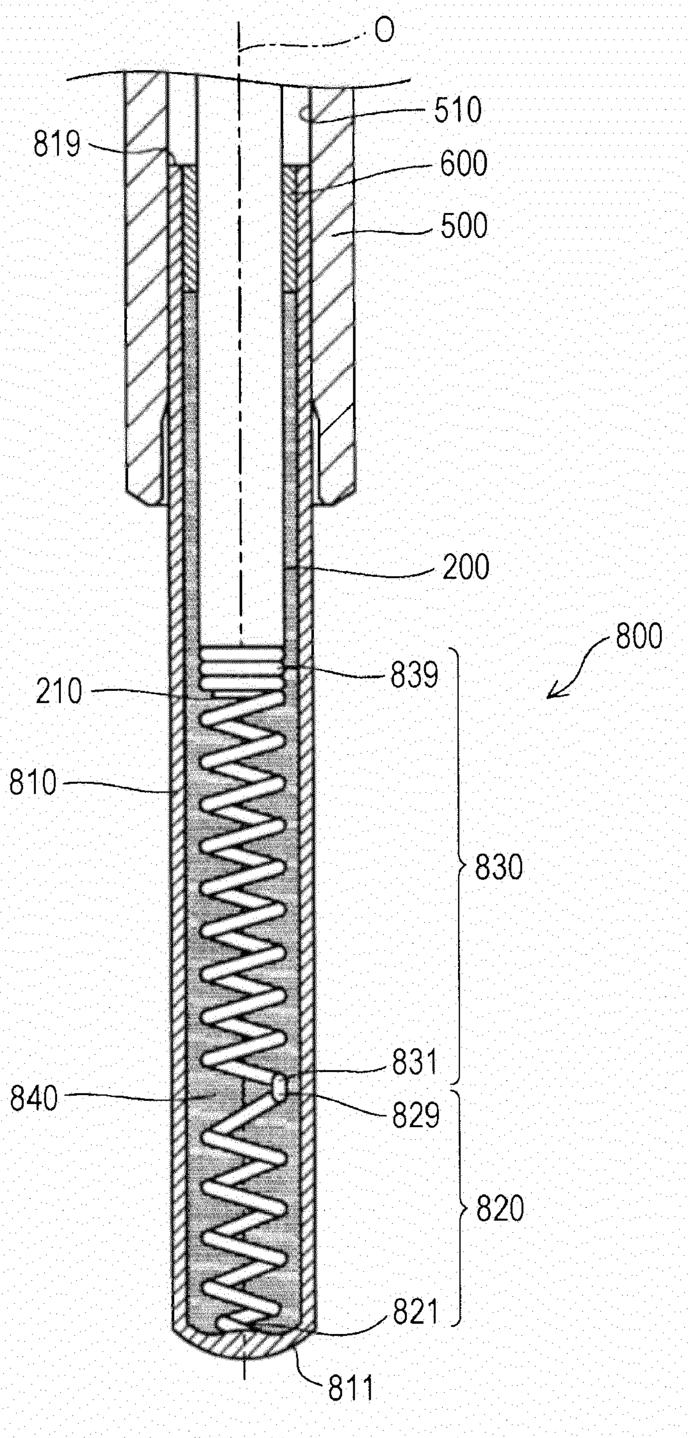

FIG. 3

No.	SHEATH TUBE (Fe IS MAIN COMPONENT)			COMPOSITION OF HEAT GENERATING COIL	TEST				REMARKS
	COMPOSITION (mass%)		THERMAL EXPANSION RATE (10^{-6}/K)		TEMPERATURE (°C)	COUNT OF BREAKING CYCLES	EVALUATION	COMPREHENSIVE EVALUATION	
	Cr	Al							
1	–	–	11	Fe20Cr5Al	1100	8217	C	6	Pt IS MAIN COMPONENT
2	26.0	–	13	Fe20Cr5Al	900	18230	B	4	
					1100	1922	C		
					1100	10883	B		IN NITROGEN
3	10.0	0.3	14	Fe20Cr5Al	1100	4399	C	4	
					1100	12999	B		IN NITROGEN
4	30.0	1.0	14	Ni33W	1100	11929	B	3	
5	10.0	–	15	Fe20Cr5Al	900	8821	C	6	THERMAL CONTRACTION
6	10.0	1.0	15	Ni20Cr	1100	11982	B	3	
7	12.0	–	15	Fe20Cr5Al	900	17298	B	4	
8	18.0	3.0	15	Fe20Cr5Al	900	25147	A	3	
					1100	10975	B		
9	18.0	3.0	15	Ni20Cr	900	21853	A	3	
					1100	13220	B		
10	18.0	3.0	15	Fe25Cr7.5Al	1100	12113	B	3	
11	18.0	3.0	15	Ni33W	900	29872	A	3	
					1100	14239	B		
12	25.0	5.0	17	Ni33W	1100	15821	B	3	
					1150	4025	C		
13	25.0	5.0	17	Ni20Cr	1150	3295	C	3	
14	25.0	5.0	17	Fe20Cr5Al	900	28545	A	3	
					1150	3895	C		
15	10.0	10.0	18	Ni33W	TEST IMPOSSIBLE			5	
16	25.0	7.0	18	Ni33W	1100	13925	B	3	

FIG. 4

No.	SHEATH TUBE (Ni IS MAIN COMPONENT)								COMPOSITION OF HEAT GENERATING COIL	TEST			
	COMPOSITION (mass%)							THERMAL EXPANSION RATE (10^{-6}/K)		TEMPERATURE (°C)	COUNT OF BREAKING CYCLES	EVALUATION	COMPREHENSIVE EVALUATION
	Cr	Si	Al	Mo	Fe	Mn	OTHER						
17	22.0	1.0	–	9.0	18.0	1.0	1.5Co	17	Ni33W	1100	25888	A	2
18	21.5	0.2	0.2	9.0	2.5	0.2	0.2Ti, 4.0Nb+Ta	17	Ni33W	1100 1150	24555 4899	A C	2
19	21.5	0.2	0.2	9.0	2.5	0.2	0.2Ti, 4.0Nb+Ta	17	Ni25W	1100	20899	A	2
20	21.5	0.2	0.2	9.0	2.5	0.2	0.2Ti, 4.0Nb+Ta	17	Ni20W	1100	28968	A	2
21	21.5	0.2	0.2	9.0	2.5	0.2	0.2Ti, 4.0Nb+Ta	17	Fe25Cr7.5Al	900 1100	35882 21788	A A	2
22	21.5	0.2	0.2	9.0	2.5	0.2	0.2Ti, 4.0Nb+Ta	17	Ni20Cr	1100	26877	A	2
23	21.5	0.2	0.2	9.0	2.0	0.2	–	17	Ni33W	1100 1150	27541 6854	A C	2
24	21.5	0.2	0.2	9.0	2.0	0.2	–	17	Fe25Cr7.5Al	1100 1150	25145 6155	A C	2
25	21.5	0.2	0.2	9.0	2.0	0.2	–	17	Ni20Cr	1100 1150	22698 6274	A C	2
26	22.0	–	1.0	9.0	–	–	0.3Ti, 12.5Co	17	Ni33W	1100 1150	24882 6821	A C	2
27	22.0	–	1.0	9.0	–	–	0.3Ti, 12.5Co	17	Fe25Cr7.5Al	900	32788	A	2
28	23.0	0.2	1.0	6.0	–	0.5	–	17	Fe25Cr7.5Al	1100	20954	A	1
29	23.0	0.2	1.0	6.0	–	0.5	–	17	Ni20Cr	1100	21893	A	1
30	23.0	0.2	1.0	6.0	–	0.5	–	17	Ni33W	1100 1150	22266 12889	A A	1
31	23.0	0.2	1.0	9.0	–	0.5	–	17	Fe25Cr7.5Al	900 1100 1150	35244 24855 16741	A A A	1
32	23.0	0.2	1.0	9.0	–	0.5	–	17	Ni20Cr	1100 1150	22364 13857	A A	1
33	23.0	0.2	1.0	9.0	–	0.5	–	17	Ni33W	1100 1150	25814 12854	A A	1
34	23.0	0.2	1.0	12.0	–	0.5	–	16	Fe25Cr7.5Al	1100	21997	A	1
35	23.0	0.2	1.0	12.0	–	0.5	–	16	Ni20Cr	1100	21845	A	1
36	23.0	0.2	1.0	12.0	–	0.5	–	16	Ni33W	1100 1150	24699 10852	A A	1
37	23.0	0.2	1.0	13.0	–	0.5	–	16	Fe25Cr7.5Al	900 1100	38441 20589	A A	2
38	23.0	0.2	1.0	13.0	–	0.5	–	16	Ni20Cr	1100	21885	A	2
39	23.0	0.2	1.0	13.0	–	0.5	–	16	Ni33W	1100 1150	22914 9711	A B	2

FIG. 5

No.	SHEATH TUBE (Ni IS MAIN COMPONENT)								COMPOSITION OF HEAT GENERATING COIL	TEST			
	COMPOSITION (mass%)							THERMAL EXPANSION RATE (10^{-6}/K)		TEMPERATURE (°C)	COUNT OF BREAKING CYCLES	EVALUATION	COMPREHENSIVE EVALUATION
	Cr	Si	Al	Mo	Fe	Mn	Y						
40	21.0	0.1	0.5	–	–	–	–	18	Ni33W	1100	10587	B	3
										1150	4758	C	
41	21.0	0.2	0.5	–	–	–	–	18	Ni33W	1150	7985	B	3
42	23.0	0.2	1.0	3.0	–	0.5	–	18	Fe25Cr7.5Al	1100	15669	B	3
43	23.0	0.2	1.0	3.0	–	0.5	–	18	Ni20Cr	1100	18965	B	3
44	23.0	0.2	1.0	3.0	–	0.5	–	18	Ni33W	1100	17544	B	3
										1150	8514	B	
45	21.0	0.2	1.0	–	10.0	–	–	18	Ni33W	1150	7514	B	3
46	23.0	0.2	1.0	–	–	0.5	–	18	Fe25Cr7.5Al	1100	13542	B	3
47	23.0	0.2	1.0	–	–	0.5	–	18	Ni20Cr	1100	15752	B	3
48	23.0	0.2	1.0	–	–	0.5	–	18	Ni33W	1100	11862	B	3
49	23.0	0.2	1.0	–	–	0.5	–	18	Ni33W	1150	7587	B	3
50	23.0	0.2	1.0	–	2.0	0.5	–	18	Fe25Cr7.5Al	1100	10411	B	3
										1150	7099	B	3
51	23.0	0.2	1.0	–	2.0	0.5	–	18	Ni20Cr	1100	13411	B	3
										1150	7124	B	3
52	23.0	0.2	1.0	–	2.0	0.5	–	18	Ni33W	1100	11025	B	3
										1150	7058	B	3
53	23.0	0.5	0.9	–	9.0	0.5	0.1	18	Fe25Cr7.5Al	1100	11251	B	3
54	23.0	0.5	0.9	–	9.0	0.5	0.1	18	Ni20Cr	1100	13105	B	3
55	23.0	0.5	0.9	–	9.0	0.5	0.1	18	Ni33W	1100	11892	B	3
56	23.0	0.5	0.9	–	9.0	0.5	0.1	18	Fe25Cr7.5Al	1150	7158	B	3
57	23.0	0.5	0.9	–	9.0	0.5	0.1	18	Ni20Cr	1150	7112	B	3
58	23.0	0.5	0.9	–	9.0	0.5	0.1	18	Ni33W	1150	7096	B	3
59	23.0	1.2	0.5	–	9.0	0.5	0.1	18	Fe25Cr7.5Al	1150	7189	B	3
60	23.0	1.2	0.5	–	9.0	0.5	0.1	18	Ni20Cr	1150	7009	B	3
61	23.0	1.2	0.5	–	9.0	0.5	0.1	18	Ni33W	1150	7215	B	3
62	23.0	0.5	0.9	–	–	0.5	0.1	18	Fe25Cr7.5Al	1150	7264	B	3
63	23.0	0.5	0.9	–	–	0.5	0.1	18	Ni20Cr	1150	7031	B	3
64	23.0	0.5	0.9	–	–	0.5	0.1	18	Ni33W	1150	7589	B	3
65	21.0	1.0	2.0	–	–	–	–	18	Ni33W	1150	8631	B	3
66	21.0	1.0	2.0	–	–	–	–	18	Ni33W	1150	8766	B	3
67	21.0	2.0	2.0	–	–	–	–	18	Ni33W	1150	7985	B	3
68	21.0	0.2	1.0	–	11.0	–	–	19	Ni33W	1150	6874	C	6
69	23.0	0.2	1.4	–	14.0	0.5	–	19	Ni20Cr	1100	8739	C	6
70	23.0	0.2	1.4	–	14.0	0.5	–	19	Ni33W	1100	9021	C	6
										1150	5864	C	
71	23.0	0.2	1.4	–	14.0	0.5	–	19	Fe25Cr7.5Al	900	8739	C	6
										1100	6023	C	
72	21.0	1.5	2.1	–	–	–	–	19	Ni33W	1150	5777	C	6
73	21.0	2.1	1.5	–	–	–	–	19	Ni33W	1150	5982	C	6

REFERENCES CITED IN THE DESCRIPTION

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