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(54) GLOW PLUG

(57) [Objective] To mitigate force transmitted from a center rod to a ceramic heater.

[Means for Solution] Aglow plug includes a metallic shell, a sleeve, a ceramic heater, a center rod, and a packing. The center rod includes one or more neck portions which extend in the direction of the axial line and in which a plurality of grooves each extending on the outer circumferential surface of the center rod in the circumferential direction thereof are successively arranged in the direction of the axial line.

The following relational expression is satisfied:

$$Lb > \frac{19.7}{Da^3} \times La$$

where La is a distance between a first position and a second position in the direction of the axial line, the first position being a position of an axial center of a contact area between the packing and the outer circumferential surface of the center rod, the second position being a position of a rearmost end of a contact area between the ceramic heater and the sleeve; Lb is a distance in the direction of the axial line between the first position and a forward end of a forwardmost neck portion of the one or more neck portions; and Da is an outer diameter of the ceramic heater at the second position.

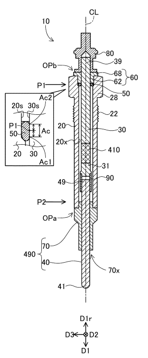

FIG. 1(A)

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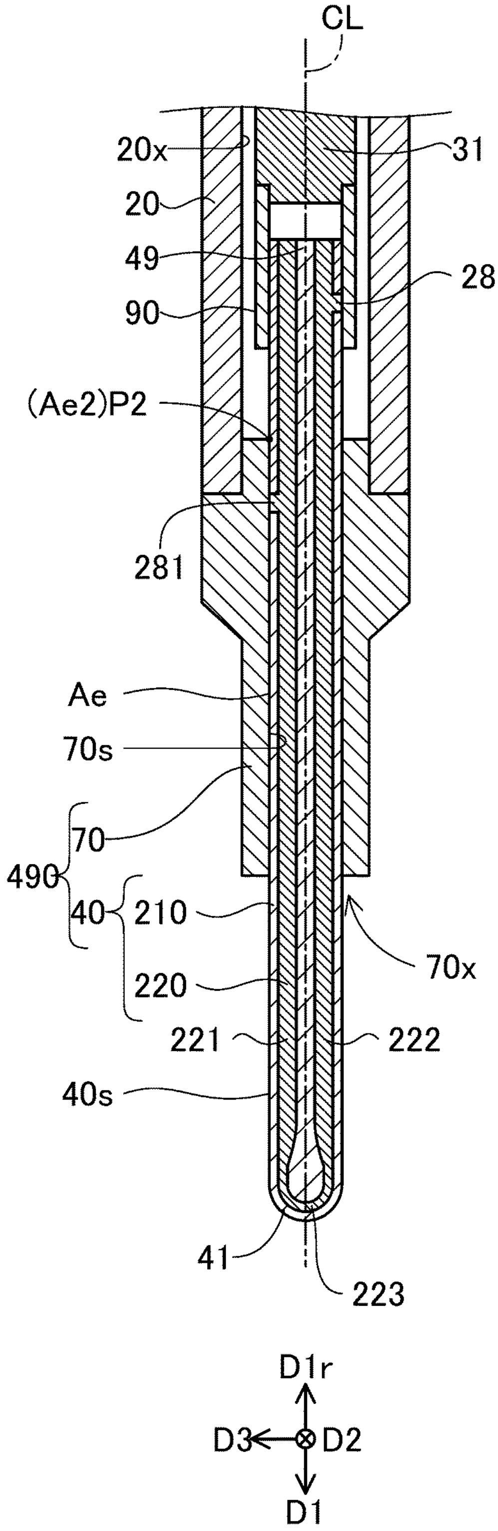

CL
20x
31
20
49
282
90
(Ae2)P2
281
Ae
70s
70
490
40
210
70x
220
221
222
40s
41
223
D1r
D3
D2
D1

FIG. 1(B)

Description

[0001] The present specification relates to a ceramic glow plug used for an internal combustion engine or the like.

[0002] Conventionally, a ceramic glow plug which generates heat upon energization has been utilized, for example, for assisting the startup of an internal combustion engine. Such a conventionally used ceramic glow plug includes a ceramic heater and a center rod connected to the ceramic heater. Incidentally, when the ceramic glow plug is manufactured, the center rod may be fixed to the ceramic heater in a state in which the center rod is inclined in relation to the ceramic heater. When the metallic shell, the ceramic heater, and the center rod of the ceramic glow plug are combined for assembly, in order for these members to be disposed coaxially, a force for reducing the inclination of the center rod may be applied to the center rod, and as a result, the ceramic heater may be broken. In view of the forgoing, there has been proposed a technique for preventing breakage of the ceramic heater as a result of transmission of such force to the ceramic heater. According to the proposed technique, a smaller diameter portion for mitigating stress is provided on the center rod.

[Patent Document 1] Japanese Patent Application Laid-Open (*kokai*) No. 2006-207988
[Patent Document 2] Japanese Patent Application Laid-Open (*kokai*) No. 2002-359060
[Patent Document 3] US Patent No. 4252091
[Patent Document 4] Japanese Patent Application Laid-Open (*kokai*) No. 2014-109434
[Patent Document 5] Japanese Patent Application Laid-Open (*kokai*) No. 2015-78825

[0003] However, there has not yet been conceived a way of properly mitigating the force transmitted from the center rod to the ceramic heater.

[0004] The present specification discloses a technique for properly mitigating the force transmitted from the center rod to the ceramic heater.

[0005] The present specification discloses the following application examples, for example.

[Application example 1]

[0006] A glow plug comprising:

a metallic shell having a through hole extending in the direction of an axial line;
a sleeve inserted into the through hole of the metallic shell and fixed to the metallic shell;
a ceramic heater inserted into the sleeve and fixed to the sleeve;
a center rod formed of a metal, inserted into the through hole of the metallic shell, and electrically connected to the ceramic heater; and
a packing sandwiched between an inner circumferential surface of the metallic shell and an outer circumferential surface of the center rod, wherein
the center rod includes one or more neck portions which extend in the direction of the axial line and in which a plurality of grooves each extending on the outer circumferential surface of the center rod in the circumferential direction thereof are successively arranged in the direction of the axial line; and
the following relational expression is satisfied:

$$Lb > \frac{19.7}{Da^3} \times La$$

where

La is a distance between a first position and a second position in the direction of the axial line, the first position being a position of a center, in the direction of the axial line, of a contact area between the packing and the outer circumferential surface of the center rod, the second position being a position of a rearmost end of a contact area between the ceramic heater and the sleeve,
Lb is a distance in the direction of the axial line between the first position and a forward end of a forwardmost neck portion of the one or more neck portions, and
Da is an outer diameter of the ceramic heater at the second position.

[0007] According to this configuration, when a force is applied to the center rod, for example, during manufacture, the force transmitted from the center rod to the ceramic heater can be mitigated properly.

[Application example 2]

[0008] A glow plug according to application example 1, wherein the one or more neck portions include a first neck portion whose forward end is located forward of a middle position between the first position and the second position in the direction of the axial line, and a second neck portion whose forward end is located rearward of the middle position.

[0009] According to this configuration, when the center rod vibrates, for example, during operation of an internal combustion engine, the force transmitted from the center rod to the ceramic heater can be mitigated properly.

[Application example 3]

[0010] A glow plug according to application example 1 or 2, wherein a length of the forwardmost neck portion in the direction of the axial line is 5 mm or more.

[0011] According to this configuration, the force transmitted from the center rod to the ceramic heater can be mitigated properly.

[Application example 4]

[0012] A glow plug according to any one of application examples 1 to 3, wherein the forwardmost neck portion is formed by closed loop grooves each extending, on the outer circumferential surface of the center rod, completely around the center rod in the circumferential direction thereof; and
the following relational expression is satisfied:

$$Db < \sqrt[3]{\frac{Lb}{La}} \times Da$$

where Db is a smallest outer diameter of a portion of the center rod where the forwardmost neck portion is formed.
[0013] According to this configuration, the force transmitted from the center rod to the ceramic heater can be mitigated properly.

[Application example 5]

[0014] A glow plug according to any one of application examples 1 to 4, wherein the center rod includes
a first transition portion which is connected to a forward end of at least one neck portion of the one or more neck portions and which includes a groove extending on the outer circumferential surface of the center rod in the circumferential direction thereof, and
a first trunk portion which is connected to a forward end of the first transition portion and which has an approximately constant outer diameter,
wherein a distance between a bottom portion of the groove of the first transition portion and the center axis of the center rod is larger than a distance between a bottom portion of each of the grooves of the neck portion and the center axis, and is smaller than a distance between an outer circumferential surface of the first trunk portion and the center axis.
[0015] According to this configuration, when a force is applied to the center rod, the concentration of stress on the forward end of the neck portion can be mitigated through bending of the bottom portion of the groove of the first transition portion. As a result, excessive bending of the center rod can be prevented.

[Application example 6]

[0016] A glow plug according to application example 5, wherein
the first transition portion has a plurality of closed loop grooves each extending, on the outer circumferential surface of the center rod, completely around the center rod in the circumferential direction thereof; and
the plurality of grooves of the first transition portion are formed such that the bottom portion of a groove on a forward side has an outer diameter larger than that of the bottom portion of a groove on a rear side.
[0017] According to this configuration, the plurality of grooves of the first transition portion gradually change the groove outer diameter between the neck portion and the first trunk portion. Accordingly, it is possible to mitigate the concentration of stress on a portion of the first transition portion. As a result, excessive bending of the center rod can be prevented.

[Application example 7]

[0018] A glow plug according to application example 5, wherein
the first transition portion has a plurality of closed loop grooves each extending, on the outer circumferential surface of the center rod, completely around the center rod in the circumferential direction thereof; and
of N pairs (N is an integer of 2 or greater) which are formed by the plurality of grooves of the first transition portion and each of which includes two adjacent grooves, L pairs (L is an integer of 1 or greater but not greater than N-1) are configured such that the outer diameter of the bottom portion of the groove on the forward side is larger than that of the bottom portion of the groove on the rear side, and (N-L) pairs are configured such that the outer diameter of the bottom portion of the groove on the forward side is the same as that of the bottom portion of the groove on the rear side.
[0019] According to this configuration, the plurality of grooves of the first transition portion change the groove outer diameter in a plurality of steps between the neck portion and the first trunk portion. Accordingly, it is possible to mitigate the concentration of stress on a portion of the first transition portion. As a result, excessive bending of the center rod can be prevented.

[Application example 8]

[0020] A glow plug according to any one of application examples 1 to 7, wherein the center rod includes
a second transition portion which is connected to a rear end of at least one neck portion of the one or more neck portions and which includes a groove extending on the outer circumferential surface of the center rod in the circumferential direction thereof, and
a second trunk portion which is connected to a rear end of the second transition portion and which has an approximately constant outer diameter,
wherein a distance between a bottom portion of the groove of the second transition portion and the center axis of the center rod is larger than a distance between a bottom portion of each of the grooves of the neck portion and the center axis, and is smaller than a distance between an outer circumferential surface of the second trunk portion and the center axis.

[0021] According to this configuration, when a force is applied to the center rod, the concentration of stress on the rear end of the neck portion can be mitigated through bending of the bottom portion of the groove of the second transition portion. As a result, excessive bending of the center rod can be prevented.

[Application example 9]

[0022] A glow plug according to application example 8, wherein
the second transition portion has a plurality of closed loop grooves each extending, on the outer circumferential surface of the center rod, completely around the center rod in the circumferential direction thereof; and
the plurality of grooves of the second transition portion are formed such that the bottom portion of a groove on a rear side has an outer diameter larger than that of the bottom portion of a groove on a forward side.

[0023] According to this configuration, the plurality of grooves of the second transition portion gradually change the groove outer diameter between the neck portion and the second trunk portion. Accordingly, it is possible to mitigate the concentration of stress on a portion of the second transition portion. As a result, excessive bending of the center rod can be prevented.

[Application example 10]

[0024] A glow plug according to application example 8, wherein
the second transition portion has a plurality of closed loop grooves each extending, on the outer circumferential surface of the center rod, completely around the center rod in the circumferential direction thereof; and
of P pairs (P is an integer of 2 or greater) which are formed by the plurality of grooves of the second transition portion and each of which includes two adjacent grooves, Q pairs (Q is an integer of 1 or greater but not greater than P-1) are configured such that the outer diameter of the bottom portion of the groove on the rear side is larger than that of the bottom portion of the groove on the forward side, and (P-Q) pairs are configured such that the outer diameter of the bottom portion of the groove on the rear side is the same as that of the bottom portion of the groove on the forward side.

[0025] According to this configuration, the plurality of grooves of the second transition portion change the groove outer diameter in a plurality of steps between the neck portion and the second trunk portion. Accordingly, it is possible to mitigate the concentration of stress on a portion of the second transition portion. As a result, excessive bending of the center rod can be prevented.

[0026] Notably, the technique disclosed in the present specification can be realized in various forms. For example, the technique can be realized as a center rod for a ceramic glow plug, a ceramic glow plug including the center rod, a startup assist apparatus including the ceramic glow plug, an internal combustion engine on which the ceramic glow plug is mounted, or an internal combustion engine on which the startup assist apparatus including the ceramic glow plug is mounted.

[Brief Description of the Drawings]

[0027]

[FIGS. 1(A) and 1(B)] Schematic views of one example of a ceramic glow plug of an embodiment.
[FIGS. 2(A), 2(B), and 2(C)] Explanatory views of a center rod 30.
[FIG. 3] Schematic sectional view of an assembly 200 used in an evaluation test.
[FIGS. 4(A), 4(B), and 4(C)] Graphs showing the results of the evaluation test.
[FIGS. 5(A) and 5(B)] Schematic views of a second embodiment of the center rod.
[FIGS. 6(A), 6(B), and 6(C)] Schematic views of another embodiment of the center rod.
[FIGS. 7(A) and 7(B)] Schematic views of still another embodiment of the center rod.
[FIGS. 8(A) and 8(B)] Schematic views of yet another embodiment of the center rod.
[FIGS. 9(A) and 9(B)] Schematic views of a modification of the center rod.

[Mode for Carrying out the Invention]

A. First embodiment:

A1. Structure of ceramic glow plug:

[0028] FIGS. 1 (A) and 1 (B) are schematic views of one example of a ceramic glow plug of an embodiment. FIG. 1 (A) is a sectional view of a ceramic glow plug 10 (hereinafter also referred to as the "glow plug 10" for simplicity), and FIG. 1(B) is an enlarged sectional view showing a portion of the glow plug 10 (a portion including a ceramic heater element 40). A line CL shown in these drawings shows a center axis of the glow plug 10. The section shown in these drawings a flat section including the center axis CL. In the following description, the center axis CL is also referred to as the "axial line CL," and a direction parallel to the center axis CL is also referred to as the "axial direction." The radial direction of a circle which is centered at the center axis CL is also referred to as the "radial direction" for simplicity, and the circumferential direction of a circle which is centered at the center axis CL is also referred to as the "circumferential direction." Of the directions parallel to the center axis CL, the downward direction in FIGS. 1(A) and 1(B) is referred to as the first direction D1. The first direction D1 is the direction from a terminal member 80 (which will be described later) toward the ceramic heater element 40. A second direction D2 and a third direction D3 in the drawings are directions which are orthogonal to each other and are orthogonal to the first direction D1. In the following description, the first direction D1 is also referred to as the forward direction D1, and the direction opposite the first direction D1 is also referred to as the rearward direction D1r. Also, the forward direction D1 side in FIGS. 1(A) and 1(B) is referred to as the forward side of the glow plug 10, and the rearward direction D1r side in FIGS. 1(A) and 1(B) is referred to as the rear side of the glow plug 10.

[0029] The glow plug 10 includes a metallic shell 20, a center rod 30, a ceramic heater element 40 (hereinafter also referred to as the "heater element 40" for simplicity), an O-ring 50 (hereinafter also referred to as the "packing 50"), an insulating member 60, a metal sleeve 70 (hereinafter also referred to as the "sleeve 70" for simplicity), a terminal member 80, and a connection member 90. The metallic shell 20 is a tubular member having a through hole 20x extending along the center axis CL. The metallic shell 20 has a tool engagement portion 28 formed on an end portion thereof on the rearward direction D1r side, and a male screw portion 22 provided on the forward direction D1 side of the tool engagement portion 28. The tool engagement portion 28 is a portion with which an unillustrated tool is engaged when the glow plug 10 is attached or detached. The male screw portion 22 includes a screw thread for screw engagement with a female screw of a mounting hole of an unillustrated internal combustion engine. The metallic shell 20 is formed of an electrically conductive material (e.g., metal such as carbon steel).

[0030] The center rod 30 is accommodated in the through hole 20x of the metallic shell 20. The center rod 30 is a rod-like member and extends along the axial line CL. The center rod 30 is formed of an electrically conductive material (for example, metal such as stainless steel). A rear end portion 39 (an end portion on the rearward direction D1 r side) of the center rod 30 projects in the rearward direction D1 r from an opening OPb of the metallic shell 20 on the rearward direction D1 r side. The center rod 30 has a neck portion 410 which is provided between an end portion 31 (an end portion on the forward direction D1 side) of the center rod 30 and the end portion 39 on the rearward direction D1r side. The neck portion 410 will be described in detail later.

[0031] In the vicinity of the opening OPb, the ring-shaped packing 50 is provided between the outer surface of the center rod 30 and the wall surface of the through hole 20x of the metallic shell 20. The packing 50 is formed of elastic material (for example, rubber). A ring-shaped insulating member 60 is attached to the opening OPb of the metallic shell 20. The insulating member 60 includes a tubular portion 62 and a flange portion 68 provided on the rearward direction D1 r side of the tubular portion 62. The tubular portion 62 is sandwiched between the outer surface of the center rod 30 and the inner surface of a portion of the metallic shell 20 which forms the opening OPb. The insulating member 60 is formed of, for example, resin. The metallic shell 20 supports the center rod 30 through these members 50 and 60.

[0032] A left portion of FIG. 1 (A) shows a partial enlarged view of portions of the metallic shell 20 and the center rod 30 between which the packing 50 is sandwiched. The packing 50 is in contact with an inner circumferential surface 20s of the metallic shell 20 and an outer circumferential surface 30s of the center rod 30 and establishes a seal between the inner circumferential surface 20s of the metallic shell 20 and the outer circumferential surface 30s of the center rod 30. The packing 50 is crushed between these surfaces 20s and 30s. An area Ac in FIG. 1(A) shows a portion of the outer circumferential surface 30s of the center rod 30, which portion is in contact with the packing 50 (hereinafter this area is also referred to as the contact area Ac). Afirst positon P1 is the position of the center of the contact area Ac in the direction parallel to the axial line CL. Namely, the first position P1 is a position at which an area extending from the end Ac1 of the contact area Ac on the forward direction D1 side to the end Ac2 of the contact area Ac on the rearward direction D1r side is bisected in the direction parallel to the axial line CL.

[0033] The terminal member 80 is disposed on the rearward direction D1r side of the insulating member 60. The terminal member 80 is a cap-shaped member, and is formed of an electrically conductive material (for example, metal such as carbon steel). The flange portion 68 of the insulating member 60 is sandwiched between the terminal member 80 and the metallic shell 20. The rear end portion 39 of the center rod 30 is inserted into the terminal member 80. As a result of the terminal member 80 being crimped, the terminal member 80 is fixed to the rear end portion 39. Thus, the terminal member 80 is electrically connected to the center rod 30.

[0034] A portion of the sleeve 70 on the rearward direction D1 r side is inserted into an opening Opa of the metallic shell 20 on the forward direction D1 side, and the sleeve 70 is fixed (for example, press-fitted or welded) to the metallic shell 20. The sleeve 70 is a tubular member having a through hole 70x extending along the center axis CL. The sleeve 70 is formed of an electrically conductive material (for example, metal such as stainless steel).

[0035] The heater element 40, which generates heat upon energization, is inserted into the through hole 70x of the sleeve 70. The heater element 40 is a rod-shaped member disposed to extend along the center axis CL. The sleeve 70 holds the outer circumferential surface of a central portion of the heater element 40. A forward end portion 41 and a rear end portion 49 of the heater element 40 are exposed to the outside of the sleeve 70. The rear end portion 49 of the heater element 40 is accommodated in the through hole 20x of the metallic shell 20. In the following description, the combination of the heater element 40 and the metal sleeve 70 is also referred to as a "heater module 490."

[0036] The connection member 90 is fixed to the rear end portion 49 of the heater element 40. The connection member 90 is a cylindrical tubular member having a through hole extending along the center axis CL, and is formed of an electrically conductive material (for example, metal such as stainless steel). The rear end portion 49 of the heater element 40 is press-fitted into a portion of the connection member 90 on the forward direction D1 side. The forward end portion 31 (the end portion on the forward direction D1 side) of the center rod 30 is press-fitted into a portion of the connection member 90 on the rearward direction D1 r side. Thus, the center rod 30 is fixed to the heater element 40 through the connection member 90. Also, the center rod 30 is electrically connected to the connection member 90. Notably, the forward end portion 31 of the center rod 30 and the connection member 90 may be welded together.

[0037] Next, the details of the heater module 490 will be described. FIG. 1(B) shows a more specific sectional view of the metal sleeve 70, the connection member 90, and the heater element 40. The heater element 40 includes a round-rod-shaped base member 210 extending along the axial line CL, and a generally U-shaped heat generation resistor 220 (hereinafter simply referred to as the "resistor 220") embedded in the base member 210. The base member 210 is formed of an insulating ceramic material (for example, a material containing silicon nitride). The resistor 220 is formed of an electrically conductive ceramic material (for example, a material containing silicon nitride and an electrical conductive substance (e.g., tungsten carbide). The base member 210 supports the resistor 220 in a state in which the base member 210 covers the resistor 220. The heater element 40 is formed by firing the material thereof. A forward end portion of the base member 210 (namely, the forward end portion 41 of the heater element 40) is rounded. The electrical conductivity of the resistor 220 is higher than that of the base member 210. The resistor 220 generates heat upon energization.

[0038] The resistor 220 includes two lead portions 221 and 222, a heat generation portion 223 connected to the lead portions 221 and 222, and electrode connection portions 281 and 282. Each of the lead portions 221 and 222 extends, along the direction in which the axial line CL extends (parallel to the axial line CL in the present embodiment), from the rear end portion 49 of the heater element 40 to a position near the forward end portion 41. The first lead portion 221 and the second lead portion 222 are disposed at positions which are approximately symmetric with respect to the center axis CL. The third direction D3 is a direction from the second lead portion 222 toward the first lead portion 221.

[0039] The heat generation portion 223 is embedded in the forward end portion 41 of the heater element 40, and connects together the end of the first lead portion 221 on the forward direction D1 side and the end of the second lead portion 222 on the forward direction D1 side. Namely, the lead portions 221 and 222 are connected to the ends of the heat generation portion 223 on the rearward direction D1 r side. The shape of the heat generation portion 223 is a generally U-like shape; i.e., the heat generation portion 223 curves to follow the round shape of the forward end portion 41 of the heater element 40. The cross-sectional area of the heat generation portion 223 is smaller than those of the lead portions 221 and 222. Also, the electrical resistance of the heat generation portion 223 per unit length is larger than those of the lead portions 221 and 222. As a result, when the heater element is energized, the temperature of the heat generation portion 223 increases quickly as compared with the temperatures of the lead portions 221 and 222.

[0040] The first electrode connection portion 281 is connected to a portion of the first lead portion 221 on the rearward direction D1r side. The first electrode connection portion 281 extends along the radial direction. An inner end portion of the first electrode connection portion 281 is connected to the first lead portion 221, and an outer end portion thereof is exposed on the outer surface of the heater element 40. The exposed portion of the first electrode connection portion 281 is in contact with the inner circumferential surface of the sleeve 70. Thus, the sleeve 70 and the first lead portion 221 are electrically connected together.

[0041] The second electrode connection portion 282 is connected to a portion of the second lead portion 222 on the rearward direction D1r side. The second electrode connection portion 282 extends along the radial direction, and is disposed on the rearward direction D1r side in relation to the first electrode connection portion 281. An inner end portion of the second electrode connection portion 282 is connected to the second lead portion 222, and an outer end portion thereof is exposed on the outer surface of the heater element 40. The exposed portion of the second electrode connection portion 282 is in contact with the inner circumferential surface of the connection member 90. Thus, the connection member 90 and the second lead portion 222 are electrically connected together.

[0042] A second position P2 in the drawings is the position of a rearmost end Ae2 (an end at the rearmost position in the rearward direction D1 r) of a contact area Ae where the heater element 40 comes into contact with the sleeve 70. Namely, the area Ae of the outer circumferential surface 40s of the heater element 40 which comes into contact with the inner circumferential surface 70s of the sleeve 70 extends from the second position P2 toward the forward direction D1 side.

[0043] When the glow plug 10 is used, a voltage is applied between the metallic shell 20 and the terminal member 80. As described above, the first lead portion 221 is electrically connected to the metallic shell 20 through the first electrode connection portion 281 and the metal sleeve 70. The second lead portion 222 is electrically connected to the terminal member 80 through the second electrode connection portion 282, the connection member 90, and the center rod 30. Accordingly, the electric power supplied through the metallic shell 20 and the terminal member 80 is supplied to the heat generation portion 223 through the lead portions 221 and 222. As a result, the heat generation portion 223 generates heat.

[0044] FIGS. 2(A), 2(B) and 2(C) are explanatory views of the center rod 30. FIG. 2(A) schematically shows the external appearance of the center rod 30, and FIG. 2(B) shows a cross section of the neck portion 410 of the center rod 30. The cross section of FIG. 2(B) is a flat cross section containing the axial line CL. As shown in these drawings, a plurality of grooves (radially inward recesses) 300 are formed on the outer circumferential surface of the neck portion 410. Each groove 300 is a closed loop groove which extends, on the outer circumferential surface 30s of the center rod 30, completely around the center rod 30 in the circumferential direction thereof. Namely, each groove 300 extends completely around the center line CL.

[0045] On the cross section of FIG. 2(B), each groove 300 is defined by a bottom portion 310 and two sloping surfaces 320 and 330 which are located on opposite sides of the bottom portion 310. The bottom portion 310 has an outer circumferential surface approximately parallel to the axial line CL. A first length L1 in FIG. 2(B) is the length of each bottom portion 310 in the direction parallel to the axial line CL. The first sloping surface 320 is a sloping surface which slopes toward the forward direction D1 side to be oblique to the axial line CL when the sloping surface is followed from the inner side toward the outer side in the radial direction. The first sloping surface 320 is connected to the end of the bottom portion 310 on the forward direction D1 side. The sloping surface 320 on the forward direction D1 side of the groove 300 is also referred to as the forward side sloping surface 320. The second sloping surface 330 is a sloping surface which slopes toward the rearward direction D1 r side to be oblique to the axial line CL when the sloping surface is followed from the inner side toward the outer side in the radial direction. The second sloping surface 330 is connected to the end of the bottom portion 310 on the rearward direction D1 r side. The sloping surface 330 on the rearward direction D1 r side of the groove 300 is also referred to as the rear side sloping surface 330.

[0046] The radially outer end of the first sloping surface 320 and the radially outer end of the second sloping surface 330 are connected to corresponding crest portions 340. Each crest portion 340 has an outer circumferential surface approximately parallel to the axial line CL. A second length L2 in FIG. 2(B) is the length of each crest portion 340 in the direction parallel to the axial line CL. Each first sloping surface 320 is connected to the end of the corresponding crest portion 340 on the rearward direction D1r side, and each second sloping surface 330 is connected to the end of the corresponding crest portion 340 on the forward direction D1 side.

[0047] As shown in FIG. 2(B), the neck portion 410 forms a wavy portion where the bottom portions 310 and the crest portions 340 are alternatingly arranged toward the forward direction D1 side. As described above, the neck portion 410 extends in the direction parallel to the axial line CL.

[0048] A pitch Pt in FIG. 2(B) is the pitch of the grooves 300 in the direction parallel to the axial line CL. In the embodiment shown in FIG. 2(B), the pitch Pt is determined with the end of each bottom portion 310 on the rearward direction D1r side used as a reference. The plurality of grooves 300 are arranged toward the forward direction D1 side at the same pitch Pt.

[0049] A forward end 410f in FIG. 2(B) shows the forward end of the neck portion 410, and a rear end 410r in FIG. 2(B) shows the rear end of the neck portion 410. The forward end 410f of the neck portion 410 is the forward end of the forwardmost bottom portion 310 among the plurality of bottom portions 310 of the neck portion 410. Notably, in the present embodiment, the forward end 410f of the neck portion 410 coincides with the forward end of the forwardmost bottom portion 310 connected to the forwardmost sloping surface 320. Also, even in the case where the crest portion 340 is formed on the forward direction D1 side of the forwardmost bottom portion 310, the forward end 410f of the neck portion 410 coincides with the forward end of the forwardmost bottom portion 310. Meanwhile, the rear end 410r of the neck portion 410 is the rear end of the rearmost bottom portion 310 among the plurality of bottom portions 310 of the neck portion 410. Notably, in the present embodiment, the rear end 410r of the neck portion 410 coincides with the rear end of the rearmost bottom portion 310 connected to the rearmost sloping surface 330. Also, even in the case where the crest portion 340 is formed on the rearward direction D1r side of the rearmost bottom portion 310, the rear end 410r of the neck portion 410 coincides with the rear end of the rearmost bottom portion 310.

[0050] A length Lf in FIG. 2(B) is the length of the neck portion 410 in the direction parallel to the axial line CL. This length Lf is the length between the forward end 410f and the rear end 410r of the neck portion 410 in the direction parallel to the axial line CL. An outer diameter Db in FIG. 2(B) is the smallest outer dimeter of the neck portion 410. In the present embodiment, the smallest outer dimeter Db is the outer dimeter of the neck portion 410 measured at each bottom portion 310 (hereinafter simply referred to as the "outer dimeter of the bottom portion 310"). In the present embodiment, the neck portion 410 is formed at a circular columnar portion of the center rod 30 whose outer diameter Dc is approximately constant. The smallest outer diameter Db of the neck portion 410 is smaller than the outer diameter Dc. A second distance Lb in FIG. 2(A) is the distance between the first position P1 and the forward end 410f of the neck portion 410 in the direction parallel to the axial line CL.

[0051] FIG. 2(C) is an enlarged view of a portion of the sectional view of FIG. 2(B), which portion includes the grooves 300. An angle Ang in FIG. 2(C) is the angle between the first sloping surface 320 and the second sloping surface 330. In the embodiment shown in FIG. 2(C), the angle Ang is the same among the plurality of grooves

300.

[0052] Various methods can be employed so as to form the plurality of bottom portions 310 and the plurality of crest portions 340 (accordingly, the neck portion 410 having the plurality of grooves 300) on the center rod 30. For example, so-called form rolling may be employed. Specifically, a roller having a portion whose shape is inverse to that of the neck portion 410 is pressed against the center rod 30. In this state, the roller and the center rod 30 are rotated, whereby the neck portion 410 is formed on the center rod 30. Such machining is also called knurling.

[0053] The neck portion 410 which has the grooves 300 each having the small outer diameter Db easily bends as compared with the remaining portion of the center rod 30. Accordingly, when a force is applied to the center rod 30, the neck portion 410 can prevent, by bending, the transmission of the force from the center rod 30 to other portions (for example, the heater element 40) of the glow plug 10. For example, when the glow plug 10 is manufactured (for example, when the packing 50 is fitted between the center rod 30 and the metallic shell 20), a force may be applied to the center rod 30. The force may be transmitted from the center rod 30 to the heater element 40. Also, when an internal combustion engine having the glow plug 10 vibrates, the center rod 30 may vibrate within the metallic shell 20. As a result, a force may be transmitted from the center rod 30 to the heater element 40. When the force transmitted to the heater element 40 is large, the heater element 40 may be broken. In the present embodiment, the neck portion 410 can prevent the transmission of force from the center rod 30 to the heater element 40 through deformation of the neck portion 410.

[0054] Also, as shown in FIG. 2(A), the rear end 410r of the neck portion 410 is located on the forward direction D1 side of the contact area Ac of the center rod 30 in contact with the packing 50. Namely, the neck portion 410 is not provided in the contact area Ac and is disposed on the forward direction D1 side of the contact area Ac. Accordingly, formation of a gap between the center rod 30 and the packing 50 can be prevented.

B. Evaluation test:

[0055] Next, an evaluation test will be described. FIG. 3 is a schematic sectional view of an assembly 200 used in the evaluation test. The assembly 200 includes the sleeve 70, the heater element 40 inserted into the sleeve 70, the connection member 90 fixed to the heater element 40, and the center rod 30 fixed to the connection member 90. The remaining elements (specifically, the metallic shell 20, the packing 50, the insulating member 60, and the terminal member 80) of the glow plug 10 (FIGS. 1(A) and 1(B)) are omitted from the assembly 200.

[0056] An outer diameter Da in FIG. 3 is the outer diameter of the heater element 40 at the second position P2. Afirst distance La is the distance between the first position P1 and the second position P2 in the direction parallel to the axial line CL. The second distance Lb, the length Lf of the neck portion 410, and the smallest outer diameter Db of the neck portion 410 have already been described with reference to FIGS. 2(A) and 2(B).

[0057] A method of carrying out the evaluation test is as follows. The sleeve 70 of the assembly 200 was fixed to the table of a tester (also called autograph). Subsequently, by using the tester, a load F1 in the direction toward the axial line CL was applied to the outer circumferential surface 30s of the center rod 30, at the first position P1, in the direction orthogonal to the axial line CL. As a result of application of the load F1, the center rod 30 bent in the direction of the load F1. In FIG. 3, a bent portion of the center rod 30x is shown by broken lines. Subsequently, the load F1 was increased until the distance df of movement of the first position P1 in the direction of the load F1 (i.e., the direction orthogonal to the axial line CL) due to the application of the load F1 reached a predetermined distance for reference. The load F1 at the time when the moving distance df reached the distance for reference was employed as a load for reference (in the following description, symbol "F" is used for the load for reference). From this load for reference F, the stress of the heater element 40 at the second position P2 was calculated. A portion (excluding the forward end portion 41) of the heater element 40 which extends from the second position P2 toward the forward direction D1 side is held by the sleeve 70. Accordingly, when the load F is applied to the center rod 30 as shown in FIG. 3, the stress acting on the portion of the heater element 40 corresponding to the second position P2 is large.

[0058] The stress of the heater element 40 at the second position P2 was calculated by a formula of "bending moment M/section modulus Z." The bending moment M is the bending moment at the second position P2 and calculated by a formula of "the load for difference F $\times$ the first distance La." The section modulus Z is the section modulus of the heater element 40 at the second position P2. The heater element 40 used in the present evaluation test has the shape of a circular column extending along the axial line CL. Therefore, the section modulus at the second position P2 is represented by "$(\pi \times Da^3)/32$." As a result, the stress Sa acting on the portion of the heater element 40 corresponding to the second position P2 is represented by $F \times La/((\pi \times Da^3)/32)$. Subsequently, the ratio of the calculated stress Sa to a reference stress Sz determined in advance was calculated as a stress ratio Ra (Ra = Sa/Sz). The reference stress Sz is a stress which can have an influence on cracking of the heater element 40. The larger the stress ratio Ra, the larger the stress acting on the heater element 40. From the viewpoint of prevention of breakage of the heater element 40, it is preferred that the stress ratio Ra be small, and it is particularly preferred that the stress ratio Ra be 1 or less (namely, the stress Sa be equal to or less than the reference stress Sz). In the evaluation test, the stress ratio Ra was obtained for each of samples of a plurality of assemblies 200 different from one another in the structure of the center rod 30. In all the samples, the neck portion 410 is formed to satisfy the relation of L1 = L2(FIG. 2(B)).

[0059] FIGS. 4(A) to 4(C) are graphs showing the results of the evaluation test. Black points in each graph represent the test results of the samples. First, the horizontal and vertical axes of these graphs will be described, and then the test results will be described.

[0060] In the graph of FIG. 4(A), the horizontal axis shows the distance ratio RLb, and the vertical axis shows the stress ratio Ra. The distance ratio RLb of the horizontal axis is the ratio of the second distance Lb to a reference distance Dz (RLb = Lb/Dz). The reference distance Dz is represented by $19.7\times La/(Da^3)$ (the details will be described later). The distance ratio RLb shows the position of the forward end 410f of the neck portion 410. The larger the distance ratio RLb, the greater the remoteness of the forward end 410f of the neck portion 410 from the first position P1; i.e., the greater the closeness of the forward end 410f to the heater element 40.

[0061] The reference distance Dz was determined as follows. As described above, the stress acting on the portion of the heater element 40 corresponding to the second position P2 is represented by $F\times La/((\pi\times Da^3)/32)$. Also, the stress acting on the forward end 410f of the neck portion 410 of the center rod 30 is represented by $F\times Lb/((\pi\times Db^3)/32)$. The forward end 410f of the neck portion 410 is a part of the neck portion 410 which is the most remote from the first position P1 and at which a large stress acts. In order to prevent the breakage of the heater element 40, it is preferred that the stress acting on the heater element 40 be equal to or less than that acting on the center rod 30. Namely, it is preferred that a relational expression of "$F\times Lb/((\pi\times Da^3)/32) < F\times Lb/((\pi\times Db^3)/32)$" be satisfied. When this relational expression is arranged for the smallest outer diameter Db of the neck portion 410, a relational expression of "Db < (the cubic root of (Lb/La))×Da" is derived. In order to prevent the breakage of the heater element 40, it is preferred that the smallest outer diameter Db of the neck portion 410 be small. For example, when the outer diameter Db is less than 2.7 mm, the breakage of the heater element 40 can be prevented. When Db = 2.7 mm, the above-mentioned relational expression becomes "$Lb > 19.7\times La/Da^3$." The right side of this relational expression; i.e., the smallest value of the second distance Lb represented by this relational expression, was employed as the reference distance Dz.

[0062] In the graph of FIG.4(B), the horizontal axis shows the length Lf of the neck portion 410, and the vertical axis shows the stress ratio Ra.

[0063] In the graph of FIG. 4(C), the horizontal axis shows outer diameter ratio RDb, and the vertical axis shows the stress ratio Ra. The outer diameter ratio RDb of the horizontal axis is the ratio of the smallest outer diameter Db of the neck portion 410 to a reference outer diameter Dy (RDb = Db/Dy). The reference outer diameter Dy is represented by (the cubic root of (Lb/La))×Da (the details will be described later). The smaller the outer diameter ratio RDb, the smaller the smallest outer diameter Db of the neck portion 410; i.e., the greater the easiness of bending of the center rod 30.

[0064] The reference outer diameter Dy was determined as follows. As described above, the stress acting on the portion of the heater element 40 corresponding to the second position P2 is represented by $F\times La/((\pi\times Da^3)/32)$. Also, the stress acting on the forward end 410f of the neck portion 410 of the center rod 30 is represented by $F\times Lb/((\pi\times Db^3)/32)$. It is preferred that the stress acting on the heater element 40 be less than the stress acting on the center rod 30. Namely, it is preferred that a relational expression of "$F\times La/((\pi\times Da^3)/32) < F\times Lb/((\pi\times Db^3)/32)$" be satisfied. When this relational expression is arranged for the smallest outer diameter Db, a relational expression of "Db < (the cubic root of (Lb/La))×Da" is derived. The right side of this relational expression; i.e., the upper limit of the smallest outer diameter Db represented by this relational expression is the reference outer diameter Dy.

[0065] Next, the test results will be described. The graph of FIG. 4(A) shows the results of the evaluation performed for four types of samples. These samples differed from one another in the distance ratio RLb (specifically, the second distance Lb, and therefore, the position of the neck portion 410), and were the same in the remaining configuration of the center rod 30. For example, the length Lf of the neck portion 410 was 20 mm, the outer diameter ratio RDb was 0.83, the angle Ang was 60 degrees, and the pitch Pt was 1.06 mm.

[0066] As shown in FIG. 4(A), the larger the distance ratio RLb (i.e., the larger the second distance Lb), the smaller the stress ratio Ra. The reason for this is presumably as follows. The larger the distance ratio RLb, the greater the remoteness of the neck portion 410 from the first position P1 at which the load F (FIG. 3) acts, and the larger the stress acting on the neck portion 410 of the center rod 30. Accordingly, the larger the distance ratio RLb, the greater the amount by which the neck portion 410 of the center rod 30 bends upon application of the same load. Specifically, as a result of bending at the plurality of bottom portions 310, the neck portion 410 of the center rod 30 bends greatly as a whole. As a result, the greater the distance ratio RLb, the smaller the stress acting on the heater element 40; i.e., the smaller the stress ratio Ra.

[0067] Also, as shown in FIG. 4(A), the stress ratio Ra of the sample whose distance ratio RLb was less than 1.0 was larger than 1.0. In contrast, the stress ratios Ra of the samples whose distance ratios RLb were larger than 1.0 were 1.0 or less. As described above, the stress acting on the heater element 40 was able to be decreased properly; i.e., the force transmitted from the center rod 30 to the heater element 40 was able to be mitigated properly, through employment of the distance ratios RLb larger than 1.0 (i.e., the second distances Lb larger than the reference distance Dz).

[0068] Notably, the distance ratios RLb which realized good stress ratios Ra of 1.0 or less were 1.10, 1.24, and 1.31. A preferred range of the distance ratio RLb (a range between the lower and upper limits of the distance ratio RLb) may be determined through use of the above-mentioned three values. Specifically, any one of the three values may be employed as the lower limit of the preferred range of the distance ratio RLb. For example, the distance ratio RLb may be equal to or greater than 1.10. Namely, the second distance Lb may be equal to or greater than 1.10 times of the reference distance Dz. Also, any one of the three values which is greater than the lower limit may be employed as the upper limit of the preferred range of the distance ratio RLb. For example, the distance ratio RLb may be equal to or less than 1.31. Namely, the second distance Lb may be equal to or less than 1.31 times of the reference distance Dz.

[0069] Notably, the larger the distance ratio RLb, the greater the remoteness of the neck portion 410 from the first position P1, and the larger the stress acting on the neck portion 410. In order to mitigate the force transmitted from the center rod 30 to the heater element 40 by bending of the neck portion 410 of the center rod 30, it is preferred that the distance ratio RLb (i.e., the second distance Lb) be large. For example, the distance ratio RLb may be larger than any of the distance ratios RLb of the samples shown in FIG. 4(A). Notably, the distance ratio RLb assumes the largest value when the position (in the direction parallel to the axial line CL) of the neck portion 410 in the center rod 30 is determined such that the forward end 410f of the neck portion 410 coincides with the forward end of the center rod 30. The distance ratio RLb may be any of various values equal to or smaller than such a largest value. Namely, the second distance Lb may be any of various values equal to or smaller than the distance between the first position P1 and the forward end of the center rod 30.

[0070] Notably, the distance ratio RLb may be outside the preferred range described above. For example, in the case where the length Lf is longer than 20 mm which is the length Lf of the samples, even when the distance ratio RLb is less than 1.0, it is expected that a good stress ratio Ra can be realized. Also, in the case where the outer diameter ratio RDb is smaller than 0.83 which is the outer diameter ratio RDb of the samples, even when the distance ratio RLb is less than 1.0, it is expected that a good stress ratio Ra can be realized.

[0071] The graph of FIG. 4(B) shows the results of the evaluation performed for six types of samples. These samples differed from one another in the length Lf of the neck portion 410 and were the same in the remaining configuration of the center rod 30. For example, the distance ratio RLb was 1.24, the outer diameter ratio RDb was 0.83, the angle Ang was 60 degrees, and the pitch Pt was 1.06 mm. The position of the forward end 410f of the neck portion 410 is the same among the six types of samples, and the position of the rear end 410r of the neck portion 410 differs among the six types of sample. In all the samples, the rear end 410r of the neck portion 410 is located on the forward direction D1 side of the contact area Ac between the center rod 30 (FIGS. 1(A) and 1(B)) and the packing 50 (i.e., located on the forward direction D1 side of the first position P1). Also, the total number of the grooves 300 changes in direct proportional to the length Lf.

[0072] As shown in FIG. 4(B), the greater the length Lf, the smaller the stress ratio Ra. The reason for this is presumably as follows. As having been described with reference to FIG. 2(B), the outer diameter Db of the portions of the center rod 30 which form the bottom portions 310 is smaller than the outer diameter of the remaining portion of the center rod 30. Accordingly, in the case where the load F is applied to the center rod 30 as shown in FIG. 3, the stress acting on the portions of the center rod 30 which form the bottom portions 310 becomes larger than the stress acting on the remaining portion of the center rod 30. Thus, the portions of the center rod 30 which form the bottom portions 310 bend. In the case where the length Lf is long, the total number of the grooves 300 of the neck portion 410 (namely, the total number of the bottom portions 310 having the smallest outer diameter Db) increases as compared with the case where the length Lf is short. Accordingly, the greater the length Lf of the neck portion 410, the greater the degree of bending of the neck portion 410 of the center rod 30 upon application of the same load to the center rod 30. As a result, the greater the length Lf of the neck portion 410, the smaller the stress acting on the heater element 40; i.e., the smaller the stress ratio Ra.

[0073] Also, as shown in FIG. 4(B), whereas the stress ratios Ra of the samples whose lengths Lf were less than 5 mm were larger than 1.0, the stress ratios Ra of the samples whose lengths Lf were 5 mm or greater were smaller than 1.0. As described above, through employment of lengths Lf equal to or greater than 5 mm, the stress acting on the heater element 40 was able to be decreased properly; namely, the force transmitted from the center rod 30 to the heater element 40 was able to be mitigated properly.

[0074] Notably, the lengths Lf which realized good stress ratios Ra of 1.0 or smaller were 5, 11, 50, and 80 (mm). A preferred range of the length Lf of the neck portion 410 (a range between the lower and upper limits of the length Lf) may be determined through use of the above-mentioned four values. Specifically, any one of the four values may be employed as the lower limit of the preferred range of the length Lf. For example, the length Lf may be equal to or greater than 5 mm. Also, any one of these values which is greater than the lower limit may be employed as the upper limit of the preferred range of the length Lf. For example, the length Lf may be equal to or less than 80 mm.

[0075] Notably, the greater the length Lf of the neck portion 410, the greater the total number of the bottom portions 310 at which the center rod 30 easily bends.

Accordingly, in order to mitigate the force transmitted from the center rod 30 to the heater element 40 by bending of the neck portion 410 of the center rod 30, it is preferred that the length Lf be long. For example, a length Lf which is greater than the lengths Lf of the samples shown in FIG. 4(B) may be employed. Notably, the possible maximum value of the length Lf is the same as the entire length of the center rod 30. The length Lf may have any value equal to or smaller than such a maximum value.

[0076] Notably, the length Lf may be outside the above-described preferred range. For example, in the case where the distance ratio RLb is larger than 1.24 which is the distance ratio RLb of the samples, it is expected that a good stress ratio Ra can be realized even when the length Lf is less than 5 mm. Also, in the case where the outer diameter ratio RDb is smaller than 0.83 which is the outer diameter ratio RDb of the samples, it is expected that a good stress ratio Ra can be realized even when the length Lf is less than 5 mm.

[0077] The graph of FIG. 4(C) shows the results of the evaluation performed for four types of samples. These samples differed from one another in the outer diameter ratio RDb (specifically, the smallest outer diameter Db) and were the same in the remaining configuration of the center rod 30. For example, the distance ratio RLb was 1.24, the length Lf of the neck portion 410 was 20 mm, the angle Ang was 60 degrees, and the pitch Pt was 1.06 mm.

[0078] As shown in FIG. 4(C), the smaller the outer diameter ratio RDb (namely, the smaller the smallest outer diameter Db), the smaller the stress ratio Ra. The reason for this is presumably as follows. The smaller the outer diameter ratio RDb, the smaller the smallest outer diameter Db of the bottom portions 310 of the neck portion 410, and the larger the stress acting on the portions of the center rod 30 corresponding to the bottom portions 310. Accordingly, the smaller the outer diameter ratio RDb, the greater the degree of bending of the portions of the center rod 30 corresponding to the bottom portions 310 upon application of the same load. As a result, the smaller the outer diameter ratio RDb, the smaller the stress acting on the heater element 40; i.e., the smaller the stress ratio Ra.

[0079] Also, as shown in FIG. 4(C), the outer diameter ratios RDb of the four types of evaluated samples were smaller than 1 (namely, their smallest outer diameters Db were smaller than the reference outer diameter Dy). The stress ratios Ra of all the samples were equal to or less than 1.0. As described above, through employment of outer diameter ratios RDb less than 1 (namely, smallest outer diameters Db less than the reference outer diameter Dy), the stress acting on the heater element 40 was able to be decreased properly; namely, the force transmitted from the center rod 30 to the heater element 40 was able to be mitigated properly.

[0080] Notably, the outer diameter ratios RDb which realized good stress ratios Ra of 1.0 or smaller were 0.83, 0.86, 0.90, and 0.93. A preferred range of the outer diameter ratio RDb may be determined through use of the above-mentioned four values. Specifically, any one of the four values may be employed as the upper limit of the preferred range of the outer diameter ratio RDb. For example, the outer diameter ratio RDb may be equal to or less than 0.93. Namely, the smallest outer diameter Db may be equal to or less than 0.93 times of the reference outer diameter Dy. Also, any of these values which is less than the upper limit may be employed as the lower limit of the outer diameter ratio RDb. For example, the outer diameter ratio RDb may be equal to or greater than 0.83. Namely, the smallest outer diameter Db may be equal to or greater than 0.83 times of the reference outer diameter Dy.

[0081] Notably, the smaller the smallest outer diameter Db, the larger the stress acting on the portions of the center rod 30 corresponding to the bottom portions 310. Accordingly, in order to mitigate the force transmitted from the center rod 30 to the heater element 40 by bending of the neck portion 410 of the center rod 30, it is preferred that the smallest outer diameter Db (thus, the outer diameter ratio RDb) be small. For example, an outer diameter ratio RDb which is smaller than the outer diameter ratios RDb of the samples shown in FIG. 4(C) may be employed. Notably, in the case where the smallest outer diameter Db is excessively small, a failure may occur (for example, the center rod 30 may be broken). Accordingly, the smallest outer diameter Db is preferably not excessively small and is preferably, for example, 2 mm or greater.

[0082] Notably, the outer diameter ratio RDb (thus, the smallest outer diameter Db) may be outside the above-described preferred range. For example, in the case where the distance ratio RLb is larger than 1.24 which is the distance ratio RLb of the samples, it is expected that a good stress ratio Ra can be realized even when the outer diameter ratio RDb is equal to or greater than 1. Also, in the case where the length Lf of the neck portion 410 is greater than 20 mm which is the length Lf of the samples, it is expected that a good stress ratio Ra can be realized even when the outer diameter ratio RDb is equal to or greater than 1.

C. Second embodiment:

[0083] FIGS. 5(A) and 5(B) are schematic views of a second embodiment of the center rod. FIG. 5(A) shows a schematic sectional view of an assembly 200b including a center rod 30b of the second embodiment as in the case of FIG. 3. FIG. 5(B) schematically shows the external appearance of the center rod 30b as in the case of FIG. 2(A). The center rod 30b of the second embodiment differs from the center rod 30 of the first embodiment shown in FIGS. 2(A), 2(B), 2(C), and 3 only in the point that a second neck portion 420 is provided. The configurations of other portions of the center rod 30b are identical with those of corresponding portions of the center rod 30 of the first embodiment (elements identical with the corresponding elements of the center rod 30 are denoted by the same reference numerals and their descriptions are omitted). This center rod 30b can be used in place of the center rod 30 shown in FIGS. 1(A) and 1(B).

[0084] Like the neck portion 410 shown in FIG. 2(B) (hereinafter also referred to as the "first neck portion 410"), the second neck portion 420 is a portion in which a plurality of grooves 300 are successively formed in the direction parallel to the axial line CL. When a load is applied to the center rod 30b, the second neck portion 420 can mitigate the force transmitted from the center rod 30b to the heater element 40 by bending, as in the case of the first neck portion 410. In particular, the center rod 30b of the second embodiment includes, as easily bending portions, the second neck portion 420 in addition to the first neck portion 410. Accordingly, the center rod 30b can further mitigate the force transmitted to the heater element 40.

[0085] A middle position Pc is shown in FIG. 5(A). The middle position Pc is a middle position between the first position P1 and the second position P2 in the direction parallel to the axial line CL. Namely, the distance between the middle position Pc and the first position P1 in the direction parallel to the axial line CL is equal to the distance between the middle position Pc and the second position P2 in the direction parallel to the axial line CL.

[0086] In the second embodiment, the entirety of the first neck portion 410 is disposed on the forward direction D1 side of the middle position Pc, and the entirety of the second neck portion 420 is disposed on the rearward direction D1 r side of the middle position Pc. As described above, neck portions are provided on both sides of the middle position Pc; i.e., on the forward direction D1 side and the rearward direction D1 r side. As a result, the center rod 30b can mitigate the force transmitted from the center rod 30b to the heater element 40 when the center rod 30b vibrates; for example, during operation of an internal combustion engine on which the glow plug is mounted.

[0087] Specifically, the center rod 30b mitigates the force transmitted to the heater element 40 as follows. When the assembly 200b is incorporated into the glow plug 10 (FIGS. 1(A) and 1(B)), a portion of the center rod 30b corresponding to the first position P1 is held by the packing 50, and a portion of the heater element 40 corresponding to the second position P2 is held by the sleeve 70. Accordingly, when the glow plug 10 vibrates, a portion of the center rod 30b in the vicinity of the middle position Pc between these positions P1 and P2 may vibrate with a large amplitude. In the present embodiment, when such a vibration occurs, the first neck portion 410 and the second neck portion 420 on the opposite sides of the middle position Pc can deform (for example, can bend). The deformation of these neck portions 410 and 420 prevents the transmission of vibration of a portion of the center rod 30b in the vicinity of the middle position Pc to other portions. In this manner, the force transmitted from the center rod 30b to the heater element 40 can be mitigated properly.

[0088] Notably, the entirety of the first neck portion 410 is disposed on the forward direction D1 side of the middle position Pc. However, the disposition of the first neck portion 410 is not limited thereto, and the first neck portion 410 may extend from the forward direction D1 side of the middle position Pc toward the rearward direction D1r side of the middle position Pc beyond the middle position Pc. In general, it is preferred that the forward end 410f of the first neck portion 410 be disposed on the forward direction D1 side of the middle position Pc between the first position P1 and the second position P2 in the direction parallel to the axial line CL, and the forward end 420f of the second neck portion 420 be disposed on the rearward direction D1r side of the middle position Pc. This configuration can prevent the transmission of vibration of a portion of the center rod 30b in the vicinity of the middle position Pc to other portions.

[0089] Notably, it is preferred that at least a portion of the preferred configurations of the neck portion 410 which have been described with reference to FIGS. 4(A) to 4(C) be applied to the first neck portion 410 of the center rod 30b of the second embodiment as well. As a result, like the center rod 30 of the first embodiment, the center rod 30b can properly mitigate the force transmitted from the center rod 30b to the heater element 40.

D. Third embodiment:

[0090] FIGS. 6(A), 6(B), and 6(C) are schematic views of another embodiment of the center rod. FIG. 6(A) schematically shows the external appearance of a center rod 30c as in the case of FIG. 2(A). The center rod 30c differs from the center rod 30 of the first embodiment shown in FIGS. 2(A), 2(B), and 2(C) only in the point that a first transition portion 500 is formed on the forward side of the neck portion 410 to be located adjacent thereto, and a second transition portion 700 is formed on the rear side of the neck portion 410 to be located adjacent thereto. The configurations of other portions of the center rod 30c are identical with those of corresponding portions of the center rod 30 of the first embodiment (elements identical with the corresponding elements of the center rod 30 are denoted by the same reference numerals and their descriptions are omitted). This center rod 30c can be used in place of the center rod 30 shown in FIGS. 1(A) and 1(B).

[0091] Each of the first transition portion 500 and the second transition portion 700 is a portion which has grooves formed on the outer circumferential surface 30s of the center rod 30c such that the grooves extend in the circumferential direction of the center rod 30c as in the case of the neck portion 410. However, the depth of the grooves differs from the depth of the grooves 300 of the neck portion 410 (the details will be described later).

[0092] The first transition portion 500 is connected to the end of the neck portion 410 on the forward direction D1 side, and is provided on the rearward direction D1r side of the forward end portion 31 of the center rod 30c.

No groove is formed on a portion 910 on the forward side of the first transition portion 500 (hereinafter referred to as the "first trunk portion 910"). The first trunk portion 910 is a circular columnar portion which is connected to the end of the first transition portion 500 on the forward direction D1 side and which has an approximately constant outer diameter Dc.

[0093] The second transition portion 700 is connected to the end of the neck portion 410 on the rearward direction D1 r side, and is provided on the forward direction D1 side of the rear end portion 39 of the center rod 30c. No groove is formed on a portion 920 on the rear side of the second transition portion 700 (hereinafter referred to as the "second trunk portion 920"). The second trunk portion 920 is a circular columnar portion which is connected to the end of the second transition portion 700 on the rearward direction D1r side and which has an approximately constant outer diameter Dc.

[0094] FIG. 6(B) shows a cross section (flat cross section containing the axial line CL) of the first transition portion 500 of the center rod 30c. In FIG. 6(B), hatching is omitted (similarly, hatching is omitted in FIG. 6(C), FIGS. 7(A) and 7(B), FIGS. 8(A) and 8(B), and FIGS. 9(A) and 9(B) which will be described later). As shown in FIG. 6(B), a plurality of grooves (i.e., radially inward recesses) 600 are formed on the outer circumferential surface of the first transition portion 500. Each groove 600 is a closed loop groove which extends, on the outer circumferential surface 30s of the center rod 30c, completely around the center rod 30c in the circumferential direction thereof. The plurality of grooves 600 are formed successively in the direction parallel to the axial line CL. In the present embodiment, the first transition portion 500 has three grooves 600.

[0095] On the cross section of FIG. 6(B), each groove 600 is defined by a bottom portion 610 and two sloping surfaces which are located on opposite sides of the bottom portion 610; i.e., a first sloping surface 620 on the forward direction D1 side and a second sloping surface 630 on the rearward direction D1r side. Like the first sloping surface 320 of each groove 300 of the neck portion 410, the first sloping surface 620 slants toward the forward direction D1 side, when the sloping surface is followed from the inner side toward the outer side in the radial direction. Like the second sloping surface 330 of each groove 300 of the neck portion 410, the second sloping surface 630 slants toward the rearward direction D1 r side, when the sloping surface is followed from the inner side toward the outer side in the radial direction. Although not illustrated, the angle formed between the first sloping surface 620 and the second sloping surface 630 is the same as the angle Ang formed between the first sloping surface 320 and the second sloping surface 330 described with reference to FIG. 2(C) (however, the angle formed between the sloping surfaces 620 and 630 may differ from the angle Ang formed between the sloping surfaces 320 and 330). The radially outer end of the first sloping surface 620 and the radially outer end of the adjacent second sloping surface 630 on the forward direction D1 side of the first sloping surface 620 are connected to a common crest portion 640. Each crest portion 640 has an outer circumferential surface approximately parallel to the axial line CL. The outer diameter of the crest portions 640 is the same as the outer diameter of the crest portions 340 of the neck portion 410 (however, the outer diameter of the crest portions 640 may differ from the outer diameter of the crest portions 340 of the neck portion 410).

[0096] Each bottom portion 610 has an outer circumferential surface approximately parallel to the axial line CL. The bottom portion 610 is a portion of the corresponding groove 600 which has the smallest outer diameter. Outer diameters D61 to D63 and radiuses R61 to R63 in FIG. 6(B) show the outer diameters and radiuses of the three bottom portions 610 successively arranged toward the forward direction D1 side. In the present embodiment, the three outer diameters D61 to D63 are the same. Also, the three outer diameters D61 to D63 are larger than the outer diameter Db of the bottom portions 310 of the neck portion 410 and smaller than the outer diameter Dc of the first trunk portion 910. Namely, the distances between the center axis of the center rod 30c (which is the same as the center axis CL in the present embodiment) and the outer circumferential surfaces of the bottom portions 610 of the grooves 600 of the first transition portion 500 (the radiuses R61 to R63 in the present embodiment) are larger than the distance (one half of Db) between the center axis CL and the outer circumferential surfaces of the bottom portions 310 of the grooves 300 of the neck portion 410, and smaller than the distance (one half of Dc) between the center axis CL and the outer circumferential surface of the first trunk portion 910.

[0097] As described above, between the neck portion 410 and the first trunk portion 910, there are formed the grooves 600 which are larger in outer diameter than the bottom portions 310 of the grooves 300 of the neck portion 410 and are smaller in outer diameter than the first trunk portion 910. Accordingly, when a force is applied to the center rod 30c, the bottom portions 610 of the grooves 600 bend, whereby the concentration of stress on the end of the neck portion 410 on the forward direction D1 side can be mitigated. As a result, excessive bending of the center rod 30c can be prevented.

[0098] Notably, the pitch Pt of the plurality of grooves 600 in the direction parallel to the axial line CL is the same as the pitch Pt of the plurality of grooves 300 of the neck portion 410. In FIG. 6(B), the pitch Pt is determined by using the center position of each of the bottom portions 610 and 310 in the direction parallel to the axial line CL as a reference. Also, as shown in FIG. 6(B), the pitch Pt1 (also referred to as the "first connection pitch Pt1") between the forwardmost groove 300 of the neck portion 410 and the rearmost groove 600 of the first transition portion 500 is also the same as the pitch Pt.

[0099] FIG. 6(C) shows a cross section (flat cross section containing the axial line CL) of the second transition portion 700 of the center rod 30c. In the present embodiment, the shape of the first transition portion 500 and the shape of the second transition portion 700 are plane symmetry with each other with respect to a symmetry plane Ps (FIG. 6(A)) orthogonal to the center axis CL of the center rod 30c (the symmetry plane Ps is located at the center of the neck portion 410). Specifically, a plurality of grooves (i.e., radially inward recesses) 800 are formed on the outer circumferential surface of the second transition portion 700. Each groove 800 is a closed loop groove which extends, on the outer circumferential surface 30s of the center rod 30c, completely around the center rod 30c in the circumferential direction thereof. The plurality of grooves 800 are formed successively in the direction parallel to the axial line CL. Notably, the shape of the first transition portion 500 may differ from the shape of the second transition portion 700.

[0100] Each groove 800 is defined by a bottom portion 810 and two sloping surfaces which are located on opposite sides of the bottom portion 810; i.e., a first sloping surface 820 on the forward direction D1 side and a second sloping surface 830 on the rearward direction D1r side. Like the first sloping surface 620 (FIG. 6(B)), the first sloping surface 820 slants toward the forward direction D1 side. Like the second sloping surface 630 (FIG. 6(B)), the second sloping surface 830 slants toward the rearward direction D1r side. Although not illustrated, the angle formed between the first sloping surface 820 and the second sloping surface 830 is the same as the angle Ang formed between the first sloping surface 320 and the second sloping surface 330 described with reference to FIG. 2(C) (however, the angle formed between the sloping surfaces 820 and 830 may differ from the angle Ang formed between the sloping surfaces 320 and 330). The radially outer end of the first sloping surface 820 and the radially outer end of the adjacent second sloping surface 830 on the forward direction D1 side of the first sloping surface 820 are connected to a common crest portion 840. Each crest portion 840 has an outer circumferential surface approximately parallel to the axial line CL. The outer diameter of the crest portions 840 is the same as the outer diameter of the crest portions 340 of the neck portion 410 (however, the outer diameter of the crest portions 840 may differ from the outer diameter of the crest portions 340 of the neck portion 410).

[0101] Each bottom portion 810 has an outer circumferential surface approximately parallel to the axial line CL. The bottom portion 810 is a portion of the corresponding groove 800 which has the smallest outer diameter. Outer diameters D81 to D83 and radiuses R81 to R83 in FIG. 6(C) show the outer diameters and radiuses of the three bottom portions 810 arranged toward the rearward direction D1r side. In the present embodiment, the three outer diameters D81 to D83 are the same. Also, the three outer diameters D81 to D83 are larger than the outer diameter Db of the bottom portions 310 of the neck portion 410 and smaller than the outer diameter Dc of the second trunk portion 920. Namely, the distances between the center axis CL of the center rod 30c and the outer circumferential surfaces of the bottom portions 810 of the grooves 800 of the second transition portion 700 (the radiuses R81 to R83 in the present embodiment) are larger than the distance (one half of Db) between the center axis CL and the outer circumferential surfaces of the bottom portions 310 of the grooves 300 of the neck portion 410, and smaller than the distance (one half of Dc) between the center axis CL and the outer circumferential surface of the second trunk portion 920.

[0102] As described above, between the neck portion 410 and the second trunk portion 920, there are formed the grooves 800 which are larger in outer diameter than the bottom portions 310 of the grooves 300 of the neck portion 410 and are smaller in outer diameter than the second trunk portion 920. Accordingly, when a force is applied to the center rod 30c, the bottom portions 810 of the grooves 800 bend, whereby the concentration of stress on the end of the neck portion 410 on the rearward direction D1r side can be mitigated. As a result, excessive bending of the center rod 30c can be prevented.

[0103] Notably, the pitch Pt of the plurality of grooves 800 in the direction parallel to the axial line CL is the same as the pitch Pt of the plurality of grooves 300 of the neck portion 410. In FIG. 6(C), the pitch Pt is determined by using the center position of each of the bottom portions 810 and 310 in the direction parallel to the axial line CL as a reference. Also, as shown in FIG. 6(C), the pitch Pt2 (also referred to as the "second connection pitch Pt2") between the rearmost groove 300 of the neck portion 410 and the forwardmost groove 800 of the second transition portion 700 is also the same as the pitch Pt.

[0104] Notably, the first transition portion 500 having the plurality of grooves 600 and the second transition portion 700 having the plurality of grooves 800 can be formed on the center rod 30c through use of any of various methods such as cutting and form rolling.

E. Fourth embodiment:

[0105] FIGS. 7(A) and 7(B) are schematic views of still another embodiment of the center rod. The center rod 30d of the present embodiment differs from the center rod 30c of the embodiment shown in FIGS. 6(A), 6(B), and 6(C) only in the point that the first transition portion 500 is replaced with a first transition portion 500d, and the second transition portion 700 is replaced with a second transition portion 700d. FIG. 7(A) shows a cross section of the first transition portion 500d and FIG. 7(B) shows a cross section of the second transition portion 700d (each of the cross sections is a flat cross section containing the axial line CL). The first transition portion 500d (FIG. 7(A)) differs from the first transition portion 500 (FIG. 6(B)) in terms of the total number of the grooves 600 and the outer diameters of the bottom portions 610. The second transition portion 700d (FIG. 7(B)) differs from the second transition portion 700 (FIG. 6(C)) in terms of the total number of the grooves 800 and the outer diameters of the bottom portions 810. The configurations of other portions of the center rod 30d of the present embodiment are identical with those of corresponding portions of the center rod 30c shown in FIGS. 6(A), 6(B), and 6(C) (elements identical with the corresponding elements of the center rod 30c are denoted by the same reference numerals and their descriptions are omitted).

[0106] As shown in FIG. 7(A), in the present embodiment, the first transition portion 500d has five grooves 600. Outer diameters D61 to D65 and radiuses R61 to R65 in FIG. 7(A) show the outer diameters and radiuses of the five bottom portions 610 arranged toward the forward direction D1 side. As in the case of the embodiment shown in FIG. 6(B), each of the outer diameters D61 to D65 is larger than the outer diameter Db of the bottom portions 310 of the neck portion 410 and smaller than the outer diameter Dc of the first trunk portion 910. Namely, each of the radiuses R61 to R65 is larger than one half of the outer diameter Db of the bottom portions 310 of the neck portion 410 and smaller than one half of the outer diameter Dc of the first trunk portion 910. Accordingly, as in the case of the embodiment shown in FIG. 6(B), when a force is applied to the center rod 30d, the bottom portions 610 of the grooves 600 bend, whereby the concentration of stress on the end of the neck portion 410 on the forward direction D1 side can be mitigated. As a result, excessive bending of the center rod 30d can be prevented.

[0107] In the present embodiment, unlike the embodiment shown in FIG. 6(B), the five bottom portions 610 have different outer diameters. Specifically, the outer diameters D61 to D65 of the five bottom portions 610 increase toward the forward direction D1 side (D65 > D64 > D63 > D62 > D61). Namely, as to the five grooves 600, the outer diameter of the bottom portion 610 of the groove 600 on the forward side is larger than the outer diameter of the bottom portion 610 of the groove 600 on the rear side. As described above, the plurality of grooves 600 of the first transition portion 500d are formed such that the groove outer diameter gradually changes between the neck portion 410 and the first trunk portion 910. Accordingly, it is possible to mitigate the concentration of stress on a portion of the first transition portion 500d (for example, an end portion on the forward direction D1 side or an end portion on the rearward direction D1r side). As a result, excessive bending of the center rod 30d can be prevented.

[0108] As shown in FIG. 7(B), in the present embodiment, the second transition portion 700d has five grooves 800. Outer diameters D81 to D85 and radiuses R81 to R85 in FIG. 7(B) show the outer diameters and radiuses of the five bottom portions 810 arranged toward the rearward direction D1r side. As in the case of the embodiment shown in FIG. 6(C), each of the outer diameters D81 to D85 is larger than the outer diameter Db of the bottom portions 310 of the neck portion 410 and smaller than the outer diameter Dc of the first trunk portion 910. Namely, each of the radiuses R81 to R85 is larger than one half of the outer diameter Db of the bottom portions 310 of the neck portion 410 and smaller than one half of the outer diameter Dc of the first trunk portion 910. Accordingly, as in the case of the embodiment shown in FIG. 6(C), when a force is applied to the center rod 30d, the bottom portions 810 of the grooves 800 bend, whereby the concentration of stress on the end of the neck portion 410 on the rearward direction D1r side can be mitigated. As a result, excessive bending of the center rod 30d can be prevented.

[0109] In the present embodiment, unlike the embodiment shown in FIG. 6(C), the five bottom portions 810 have different outer diameters. Specifically, the outer diameters D81 to D85 of the five bottom portions 810 increase toward the rearward direction D1r side (D81 < D82 < D83 < D84 < D85). Namely, as to the five grooves 800, the outer diameter of the bottom portion 810 of the groove 800 on the rear side is larger than the outer diameter of the bottom portion 810 of the groove 800 on the forward side. As described above, the plurality of grooves 800 of the second transition portion 700d are formed such that the groove outer diameter gradually changes between the neck portion 410 and the second trunk portion 920. Accordingly, it is possible to mitigate the concentration of stress on a portion of the second transition portion 700d (for example, an end portion on the forward direction D1 side or an end portion on the rearward direction D1r side). As a result, excessive bending of the center rod 30d can be prevented.

[0110] Notably, in the present embodiment as well, the pitch Pt of the plurality of grooves 600 of the first transition portion 500d is the same as the pitch Pt of the plurality of grooves 300 of the neck portion 410. The first connection pitch Pt1 between the neck portion 410 and the first transition portion 500d is the same as the pitch Pt. Similarly, the pitch Pt of the plurality of grooves 800 of the second transition portion 700d is the same as the pitch Pt of the plurality of grooves 300 of the neck portion 410. The second connection pitch Pt2 between the neck portion 410 and the second transition portion 700d is the same as the pitch Pt.

[0111] Notably, the first transition portion 500d having the plurality of grooves 600 and the second transition portion 700d having the plurality of grooves 800 can be formed on the center rod 30d through use of any of various methods such as cutting and form rolling.

F. Fifth embodiment:

[0112] FIGS. 8(A) and 8(B) are schematic views of yet another embodiment of the center rod. The center rod 30e of the present embodiment differs from the center rod 30d of the embodiment shown in FIGS. 7(A) and 7(B) only in the point that the first transition portion 500d is replaced with a first transition portion 500e, and the second transition portion 700d is replaced with a second transition portion 700e. FIG. 8(A) shows a cross section of the first transition portion 500e and FIG. 8(B) shows a cross section of the second transition portion 700e (each of the cross sections is a flat cross section containing the axial line CL). The present embodiment differs from the embodiment shown in shown in FIGS. 7(A) and 7(B) only in the point that in the present embodiment, the outer diameters of the crest portions 640 and 840 of the transition portions 500e and 700e differ from the outer diameter of the crest portions 340 of the neck portion 410. The configurations of other portions of the center rod 30e of the present embodiment are identical with those of corresponding portions of the center rod 30d shown in FIGS. 7(A) and 7(B) (elements identical with the corresponding elements of the center rod 30d are denoted by the same reference numerals and their descriptions are omitted).

[0113] An outer diameter D34 and a radius R34 in FIG. 8(A) show the outer diameter and radius of the crest portions 340 of the neck portion 410. Although not illustrated, the plurality of crest portions 340 of the neck portion 410 have the same outer diameter (namely, have the same radius).

[0114] The first transition portion 500e has five crest portions 640 each formed on the rearward direction D1r side of corresponding one of the five bottom portions 610. Outer diameters D641 to D645 and radiuses R641 to R645 show the outer diameters and radiuses of the five crest portions 640 arranged toward the forward direction D1 side. In the embodiment shown in FIG. 8(A), the outer diameters D641 to D645 are smaller than the outer diameter D34 of the crest portions 340 of the neck portion 410 and larger than the outer diameter Dc of the first trunk portion 910. Further, the outer diameters D641 to D645 of the five crest portions 640 decrease toward the forward direction D1 side (D645 < D644 < D643 < D642 < D641). As described above, the outer diameter of each crest portion 640 is determined such that the smaller the outer diameter of the bottom portion 610 adjacent to the crest portion 640, the larger the outer diameter of the crest portion 640.

[0115] The shape in which the smaller the outer diameter of the bottom portion 610 adjacent to the crest portion 640, the larger the outer diameter of the crest portion 640 can be easily formed in the case where form rolling is used, as well as in the case where cutting is used. In the case of form rolling, a roller having protrusions corresponding to the grooves 600 is pressed against the outer circumferential surface 30s having no groove. Portions of the outer circumferential surface 30s which are depressed radially inward as a result of pressing by the protrusions of the roller form the grooves 600 (thus, the bottom portions 610). As a result of portions of the outer circumferential surface 30s being depressed, other portions of the outer circumferential surface 30s (in particular, portions each located between a groove 600 and another groove 600 adjacent thereto) are bulged. The bulged portions form the crest portions 640. The degree of bulging of each crest portion 640 increases with the degree of depression of the adjacent bottom portion 610. Accordingly, the smaller the outer diameter of the adjacent bottom portion 610, the larger the outer diameter which the crest portion 640 tends to have.

[0116] The second transition portion 700e shown in FIG. 8(B) has the same configuration. The second transition portion 700e has five crest portions 840 each formed on the forward direction D1 side of corresponding one of the five bottom portions 810. Outer diameters D841 to D845 and radiuses R841 to R845 show the outer diameters and radiuses of the five crest portions 840 arranged toward the rearward direction D1 r side. In the embodiment shown in FIG. 8(B), the outer diameters D841 to D845 are smaller than the outer diameter D34 of the crest portions 340 of the neck portion 410 and larger than the outer diameter Dc of the second trunk portion 920. Further, the outer diameters D841 to D845 of the five crest portions 840 decrease toward the rearward direction D1 r side (D841 > D842 > D843 > D844 > D845). As described above, the outer diameter of each crest portion 840 is determined such that the smaller the outer diameter of the bottom portion 810 adjacent to the crest portion 840, the larger the outer diameter of the crest portion 840. Such a second transition portion 700e can be easily formed by cutting or form rolling as in the case of the first transition portion 500e shown in FIG. 8(A).

D. Modifications:

[0117]

(1) Instead of the above-described configuration, other various configurations can be employed as the configuration of the neck portion. For example, instead of a closed loop groove extending completely around the center rod in the circumferential direction, a spiral groove extending completely around the center rod in the circumferential direction may be formed as each of the plurality of grooves of the neck portion. Specifically, the groove may be a spiral groove which extends toward the forward direction D1 side on the outer circumferential surface of the center rod, while changing its position in the circumferential direction with respect to the axial line CL of the center rod which serves as a reference. A plurality of grooves may be formed such that they are successively arranged toward the forward direction D1 side, and are connected in series to form a single spiral groove. Both the closed loop groove and the spiral groove can be said to be provided on the outer circumferential surface of the center rod to extend in the circumferential direction of the center rod.

In any case, if a plurality of grooves are successively disposed along a line extending on the outer circumferential surface of the center rod in the direction parallel to the axial line CL such that the plurality of grooves intersect with the line, the plurality of grooves can be said to be successively disposed in the direction parallel to the axial line CL. Thus, the neck portion having the plurality of grooves can be said to extend in the direction parallel to the axial line CL. In the case where such a neck portion is provided on the center rod, the force transmitted from the center rod to the heater element can be mitigated through bending of the neck portion.

(2) The shape of the grooves 300 is not limited to the shape having been described with reference to FIG. 2(B), and the grooves 300 may have any of various other shapes. For example, the first length L1 of the bottom portions 310 may be longer than the second length L2 of the crest portions 340. Alternatively, the second length L2 of the crest portions 340 may be longer than the first length L1 of the bottom portions 310. The connection portions between the bottom portions 310 and the first sloping surfaces 320 may be rounded. Also, the connection portions between the bottom portions 310 and the second sloping surfaces 330 may be rounded. In any case, the pitch Pt is determined while the end (on the rearward direction D1r side) of a portion of each bottom portion 310 having the smallest outer diameter Db is used as a reference. The connection portions between the crest portions 340 and the first sloping surfaces 320 may be rounded. Also, the connection portions between the crest portions 340 and the second sloping surfaces 330 may be rounded. Also, the entire bottom portions 310 may be rounded. In this case, the pitch Pt is determined while the portion of each bottom portion 310 having the smallest outer diameter is used as a reference. Also, the entire crest portions 340 may be rounded. Alternatively, the each bottom portion may be a V-shaped portion formed by mutually connecting the two sloping surfaces on the opposite sides of the bottom portion. Also, each crest portion may be a V-shaped edge formed by mutually connecting the two sloping surfaces on the opposite sides of the crest portion. In any case, an angle formed between a straight portion of the first sloping surface 320 and a straight portion of the second sloping surface 330 on a cross section containing the axial line CL can be employed as the angle Ang. Also, the end (on the forward direction D1 side) of a smallest outer diameter portion of the forwardmost bottom portion among the plurality of bottom portions of the neck portion may be employed as the forward end of the neck portion. Similarly, the end (on the rearward direction D1r side) of a smallest outer diameter portion of the rearmost bottom portion among the plurality of bottom portions of the neck portion may be employed as the rear end of the neck portion. In the case where the smallest outer diameter portion of the forwardmost bottom portion does not extend along the axial line CL (for example, the case where the entire bottom portion is rounded, or the case where the bottom portion is a V-shaped portion), the smallest outer diameter portion of the bottom portion may be employed as the forward end of the neck portion. The same is true of the rear end of the neck portion.

(3) The total number of the neck portions provided on the center rod may be 3 or more. In general, the total number of the neck portions provided on the center rod may be an arbitrary number of 1 or greater. Notably, a wavy portion which is formed, as a result of disposition of a plurality of grooves, on a cross section of the center rod containing the axial line CL may be employed as one neck portion. In this case, two grooves in the wavy portion which are spaced from each other by a distance greater than the distance between two adjacent grooves (for example, the pitch) may be considered as grooves of neck portions different from each other. Also, the sizes of various portions of the neck portion of the center rod (for example, the angle Ang, the pitch Pt, etc.) are not limited to the sizes of the above-described samples, and may be various other sizes.

In any case, it is preferred that the distance (in the direction parallel to the axial line CL) between the first position P1 and the forward end of the forwardmost neck portion among one or more neck portions provided on the center rod (for example, the forward end 410f of the first neck portion 410 shown in FIG. 5(A)) fall within the preferred range of the second distance Lb having been described with reference to FIG. 4(A). Also, it is preferred that the length of the forwardmost neck portion (for example, the length Lf of the first neck portion 410 shown in FIG. 5(A)) fall within the preferred range of the length Lf having been described with reference to FIG. 4(B). Also, in the case where the forwardmost neck portion has closed loop grooves, it is preferred that the smallest outer diameter of the forwardmost neck portion (for example, the smallest outer diameter Db of the first neck portion 410 shown in FIG. 5(A)) fall within the preferred range of the smallest outer diameter Db having been described with reference to FIG. 4(C).

(4) Instead of form rolling, any of other methods may be employed so as to form the plurality of grooves of the neck portion on the center rod. For example, the plurality of grooves may be formed through cutting. In this case, the entire outer circumferential surface of the neck portion may be formed on the radially inner side of the outer circumferential surface of portions of the center rod where the neck portion is not formed (for example, the outer circumferential surfaces 30s of the portions of the center rod 30 shown in FIG. 2(B), the portions having the outer diameter Dc).

(5) The plurality of grooves formed on the center rod may include a plurality of grooves which differ from one another in terms of the distance between the bottom portion and the center axis of the center rod.

A portion in which one or more grooves which are the same in terms of the distance (for example, radius) between the bottom portion of the groove and the center axis of the center rod are successively formed in the direction parallel to the axial line CL may be employed as a neck portion. Notably, of the plurality of grooves formed on the center rod, one or more grooves may have rounded bottom portions. In this case, the smallest distance between the rounded bottom portion and the center axis may be employed as the distance between the rounded bottom portion and the center axis. Also, a portion where a plurality of grooves are successively arranged at the same pitch may be employed as a single neck portion.

(6) It is preferred that the first transition portion be connected to the forward end of the neck portion, and the first trunk portion where the outer diameter is approximately constant be connected to the forward end of the first transition portion. Instead of the configurations having been described with reference to FIGS. 6(B), 7(A), and 8(A), various other configurations may be employed as the configuration of the first transition portion. For example, the total number of grooves may be an arbitrary number of 1 or greater. Also, the first transition portion may be formed by a spiral groove as in the case of the above-described modifications of the neck portion. Also, the grooves of the first transition portion may have any of various shapes as in the case of the above-described embodiments and modifications of the grooves of the neck portion. In general, a portion having W grooves (W is an integer of 1 or greater) which satisfy the following condition may be employed as the first transition portion. The condition is such that the distance (for example, radius) between the bottom portion of each of the W grooves and the center axis of the center rod is larger than the distance between the bottom portions of the grooves of the neck portion and the center axis and is smaller than the distance between the outer circumferential surface of the first trunk portion and the center axis. Such a first transition portion can properly mitigate the concentration of stress on the end portion of the neck portion on the forward side.

The first transition portion may have a plurality of closed loop grooves each extending completely around the center rod in the circumferential direction. As in the case of the embodiments shown in FIGS. 7(A) and 8(A), as to the plurality of grooves of the first transition portion, the outer diameter of the bottom portion of the groove on the forward side may be larger than the outer diameter of the bottom portion of the groove on the rear side. According to this configuration, the plurality of grooves of the first transition portion gradually change the groove outer diameter between the neck portion and the first trunk portion. Therefore, it is possible to mitigate the concentration of stress on a portion of the first transition portion. As a result, excessive bending of the center rod can be prevented.

FIG. 9(A) shows a first transition portion 500f of a center rod 30f according to a modification. This modification differs from the embodiment shown in FIG. 7(A) only in the point that a plurality of grooves 600 whose bottom portions 610 have the same outer diameter are provided on the first transition portion 500f (specifically, Dc > D65 = D64 = D63 > D62 = D61 > Db). As described above, of the plurality of pairs each including two adjacent grooves of the first transition portion, one or more pairs may be configured such that the outer diameter of the bottom portion of the groove on the forward side is larger than the outer diameter of the bottom portion of the groove on the rear side, and one or more pairs different from the above-mentioned one or more pairs may be configured such that the outer diameter of the bottom portion of the groove on the forward side is the same as the outer diameter of the bottom portion of the groove on the rear side. In general, of N pairs (N is an integer of 2 or greater) which are formed by the plurality of grooves of the first transition portion and each of which includes two adjacent grooves, L pairs (L is an integer of 1 or greater but not greater than N-1) may be configured such that the outer diameter of the bottom portion of the groove on the forward side is larger than the outer diameter of the bottom portion of the groove on the rear side, and (N-L) pairs may be configured such that the outer diameter of the bottom portion of the groove on the forward side is the same as the outer diameter of the bottom portion of the groove on the rear side. According to this configuration, in at least one pair of the grooves of the first transition portion, the outer diameter of the bottom portion of the groove increases toward the forward direction D1 side. Therefore, the plurality of grooves of the first transition portion change the groove outer diameter in a plurality of steps between the neck portion and the first trunk portion. Accordingly, it is possible to mitigate the concentration of stress on a portion of the first transition portion. As a result, excessive bending of the center rod can be prevented.

Also, in the case where the first transition portion has W grooves, the first transition portion has W crest portions each formed on the rearward direction D1r side of the corresponding groove. In this case, as in the case of the embodiments shown in FIGS. 6(B) and 7(A), in each pair including two adjacent crest portions of the first transition portion, the crest portions may have the same outer diameter. Alternatively, as in the case of the embodiment shown in FIG. 8(A), in each pair including two adjacent crest portions of the first transition portion, the outer diameter of the crest portion on the forward side may be smaller than the outer diameter of the crest portion on the rear side. In general, of B (B = W-1) pairs which are formed by the W crest portions of the first transition portion and each of which includes two adjacent crest portions, C pairs (C is an integer of 1 or greater but not greater than B) may be configured such that the outer diameter of the crest portion on the forward side is smaller than the outer diameter of the crest portion on the rear side, and (B-C) pairs may be configured such that the outer diameter of the crest portion on the forward side is the same as the outer diameter of the crest portion on the rear side. In the case where each crest portion is rounded, the largest outer diameter of the rounded crest portion may be employed as the outer diameter of the rounded crest portion.

In the case where the first connection pitch between the rearmost groove of the first transition portion and the forwardmost groove of the neck portion is equal to or less than the three times of the pitch of the plurality of grooves of the neck portion (referred to as the "reference pitch"), the first transition portion can be said to be connected to the neck portion (in the embodiments shown in FIGS. 6(B), 7(A), 8(A), and 9(A), the pitch Pt1 corresponds to the first connection pitch). Notably, the pitch of the plurality of grooves of the first transition portion may differ from the reference pitch of the neck portion connected to the end of the first transition portion on the rearward direction D1r side. Also, the pitch may change among the plurality of grooves of the first transition portion.

(7) It is preferred that the second transition portion be connected to the rear end of the neck portion, and the second trunk portion where the outer diameter is approximately constant be connected to the rear end of the second transition portion. Instead of the configurations having been described with reference to FIGS. 6(C), 7(B), and 8(B), various other configurations may be employed as the configuration of the second transition portion. For example, the total number of grooves may be an arbitrary number of 1 or greater. Also, the second transition portion may be formed by a spiral groove as in the case of the above-described modifications of the neck portion. Also, the grooves of the second transition portion may have any of various shapes as in the case of the above-described embodiments and modifications of the grooves of the neck portion. In general, a portion having successively formed X grooves (X is an integer of 1 or greater) which satisfy the following condition may be employed as the second transition portion. The condition is such that the distance (for example, radius) between the bottom portion of each of the X grooves and the center axis of the center rod is larger than the distance between the bottom portions of the grooves of the neck portion and the center axis and is smaller than the distance between the outer circumferential surface of the second trunk portion and the center axis. Such a second transition portion can properly mitigate the concentration of stress on the end portion of the neck portion on the rear side.

The second transition portion may have a plurality of closed loop grooves each extending completely around the center rod in the circumferential direction. As in the case of the embodiments shown in FIGS. 7(B) and 8(B), as to the plurality of grooves of the second transition portion, the outer diameter of the bottom portion of the groove on the rear side may be larger than the outer diameter of the bottom portion of the groove on the forward side. According to this configuration, the plurality of grooves of the second transition portion gradually change the groove outer diameter between the neck portion and the second trunk portion. Therefore, it is possible to mitigate the concentration of stress on a portion of the second transition portion. As a result, excessive bending of the center rod can be prevented.

FIG. 9(B) shows a second transition portion 700f of the center rod 30f according to the modification. This modification differs from the embodiment shown in FIG. 7(B) only in the point that a plurality of grooves 800 whose bottom portions 810 have the same outer diameter are provided on the second transition portion 700f (specifically, Db < D81 = D82 < D83 = D84 = D85 < Dc). As described above, of the plurality of pairs each including two adjacent grooves of the second transition portion, one or more pairs may be configured such that the outer diameter of the bottom portion of the groove on the rear side is larger than the outer diameter of the bottom portion of the groove on the forward side, and one or more pairs different from the above-mentioned one or more pairs may be configured such that the outer diameter of the bottom portion of the groove on the rear side is the same as the outer diameter of the bottom portion of the groove on the forward side. In general, of P pairs (P is an integer of 2 or greater) which are formed by the plurality of grooves of the second transition portion and each of which includes two adjacent grooves, Q pairs (Q is an integer of 1 or greater but not greater than P-1) may be configured such that the outer diameter of the bottom portion of the groove on the rear side is larger than the outer diameter of the bottom portion of the groove on the forward side, and (P-Q) pairs may be configured such that the outer diameter of the bottom portion of the groove on the rear side is the same as the outer diameter of the bottom portion of the groove on the forward side. According to this configuration, in at least one pair of the grooves of the second transition portion, the outer diameter of the bottom portion of the groove increases toward the rearward direction D1 r side. Therefore, the plurality of grooves of the second transition portion change the groove outer diameter in a plurality of steps between the neck portion and the second trunk portion. Accordingly, it is possible to mitigate the concentration of stress on a portion of the second transition portion. As a result, excessive bending of the center rod can be prevented.

Also, in the case where the second transition portion has X grooves, the second transition portion has X crest portions each formed on the forward direction D1 side of the corresponding groove. In this case, as in the case of the embodiments shown in FIGS. 6(C) and 7(B), in each pair including two adjacent crest portions of the second transition portion, the crest portions may have the same outer diameter. Alternatively, as in the case of the embodiment shown in FIG. 8(B), in each pair including two adjacent crest portions of the second transition portion, the outer diameter of the crest portion on the rear side may be smaller than the outer diameter of the crest portion on the forward side. In general, of G (G = X-1) pairs which are formed by the X crest portions of the second transition portion and each of which includes two adjacent crest portions, H pairs (H is an integer of 1 or greater but not greater than G) may be configured such that the outer diameter of the crest portion on the rear side is smaller than the outer diameter of the crest portion on the forward side, and (G-H) pairs may be configured such that the outer diameter of the crest portion on the rear side is the same as the outer diameter of the crest portion on the forward side. In the case where each crest portion is rounded, the largest outer diameter of the rounded crest portion may be employed as the outer diameter of the rounded crest portion.

In the case where the second connection pitch between the forwardmost groove of the second transition portion and the rearmost groove of the neck portion is equal to or less than three times of the reference pitch of the neck portion, the second transition portion can be said to be connected to the neck portion (in the embodiments shown in FIGS. 6(C), 7(B), 8(B), and 9(B), the pitch Pt2 corresponds to the second connection pitch). Notably, the pitch of the plurality of grooves of the second transition portion may differ from the reference pitch of the neck portion connected to the end of the second transition portion on the forward direction D1 side. Also, the pitch may change among the plurality of grooves of the second transition portion.

(8) The first transition portion and the second transition portion may differ in configuration from each other. For example, a first transition portion arbitrarily selected from the first transition portions 500, 500d, and 500e shown in FIGS. 6(B), 7(A), and 8(A) and a second transition portion arbitrarily selected from the second transition portions 700, 700d, and 700e shown in FIGS. 6(C), 7(B), and 8(B) may be connected to a common neck portion. Also, the first transition portion may be connected to the neck portion, with the second transition portion omitted. Alternatively, the second transition portion may be connected to the neck portion, with the first transition portion omitted. Also, at least one of the first transition portion and the second transition portion may be applied to any neck portion of the center rod of any of the above-described embodiments. In general, in the case where T neck portions (T is an integer of 1 or greater) are provided on the center rod, the first transition portion may be connected to U neck portions (U is an integer of zero or greater but not greater than T), and the second transition portion may be connected to V neck portions (V is an integer of zero or greater but not greater than T). The value of V may be the same as or different from the value of U. Also, the configuration may differ among the U first transition portions, and the configuration may differ among the V second transition portions.

(9) The structure of the glow plug is not limited to the structure described with reference to FIGS. 1(A) and 1(B), and various structures may be employed. For example, there may be employed a structure in which a male screw is formed on the outer circumferential surface of the rear end portion 39 of the center rod 30, a female screw is formed on the terminal member 80, and the terminal member 80 is screwed onto the rear end portion 39 of the center rod 30, whereby the terminal member 80 is fixed to the center rod 30. In this case, instead of a cap-shaped member, a nut may be employed as the terminal member 80.

(10) The above-described glow plug is not limited to a glow plug used for assisting startup of an internal combustion engine, and can be applied to various glow plugs. For example, the above-described glow plug can be applied to various apparatuses such as an exhaust gas heater apparatus for heating exhaust gas, a burner system for reactivating a catalyst or a diesel particulate filter (DPF), and a water heater apparatus for heating cooling water.

Although the present invention has been described on the basis of the embodiments and modifications thereof, the above-mentioned mode of the invention is provided so as to facilitate the understanding of the invention and does not limit the present invention. The present invention may be modified or improved without departing from the spirit and scope of the claims, and encompasses equivalents thereof.

[Description of Symbols]

[0118] 10 ... ceramic glow plug (glow plug), 20 ... metallic shell, 20s ... inner circumferential surface, 20x ... through hole, 22 ... male screw portion, 28 ... tool engagement portion, 30, 30b, 30c, 30d, 30e, 30f... center rod, 30s ... outer circumferential surface, 31 ... forward end portion, 39 ... rear end portion, 40 ... ceramic heater element (heater element), 40s ... outer circumferential surface, 41 ... forward end portion, 49 ... rear end portion, 50 ... O-ring (packing), 60 ... insulating member, 62 ... tubular portion, 68 ... flange portion, 70 ... metal sleeve (sleeve), 70s ... inner circumferential surface, 70x ... through hole, 80 ... terminal member, 90 ... connection member, 200, 200b ... assembly, 210 ... base member, 220 ... heat generation resistor (resistor), 221 ... first lead portion, 222 ... second lead portion, 223 ... heat generation portion, 281 ... first electrode connection portion, 282 ... second electrode connection portion, 300, 600, 800 ... groove, 310, 610, 810 ... bottom portion, 320, 620, 820... first sloping surface, 330, 630, 830 ... second sloping surface, 340, 640, 840... crest portion, 410... neck portion, 410f... forward end, 410r... rear end, 420... neck portion, 420f... forward end, 490... heater module, 500, 500d, 500e, 500f... first transition portion, 700, 700d, 700e, 700f... second transition portion, 910 ... first trunk portion, 920 ... second trunk portion, OPa ... opening, OPb ... opening, D1 ... first direction (forward direction), D1r... rearward direction, D2 ... second direction, D3 ... third direction, P1 ... first position, P2 ... second position, Pc ... middle position, CL... center axis (axial line), Ac ... contact area, Ae ... contact area

Claims

1. A glow plug (10) comprising:

a metallic shell (20) having a through hole (20x) extending in the direction of an axial line (CL);
a sleeve (70) inserted into the through hole (20x) of the metallic shell (20) and fixed to the metallic shell (20);
a ceramic heater (40) inserted into the sleeve (70) and fixed to the sleeve (70);
a center rod (30, 30b, 30c, 30d, 30e, 30f) formed of a metal, inserted into the through hole (20x) of the metallic shell (20), and electrically connected to the ceramic heater (40); and
a packing (50) sandwiched between an inner circumferential surface (20s) of the metallic shell (20) and an outer circumferential surface (30s) of the center rod (30, 30b, 30c, 30d, 30e, 30f), wherein
the center rod (30, 30b, 30c, 30d, 30e, 30f) includes one or more neck portions (410, 420) which extend in the direction of the axial line (CL) and in which a plurality of grooves (300) each extending on the outer circumferential surface of the center rod (30, 30b, 30c, 30d, 30e, 30f) in the circumferential direction thereof are successively arranged in the direction of the axial line (CL); and
the following relational expression is satisfied:

$$Lb > \frac{19.7}{Da^3} \times La$$

where

La is a distance between a first position (P1) and a second position (P2) in the direction of the axial line (CL), the first position (P1) being a position of a center, in the direction of the axial line (CL), of a contact area (Ac) between the packing (50) and the outer circumferential surface (30s) of the center rod (30, 30b, 30c, 30d, 30e, 30f), the second position (P2) being a position of a rearmost end of a contact area (Ae) between the ceramic heater (40) and the sleeve (70),
Lb is a distance in the direction of the axial line (CL) between the first position (P1) and a forward end (410f) of a forwardmost neck portion (410) of the one or more neck portions (410, 420), and
Da is an outer diameter of the ceramic heater (40) at the second position (P2).

2. A glow plug (10) according to claim 1, wherein the one or more neck portions (410, 420) include a first neck portion (410) whose forward end (410f) is located forward of a middle position (Pc) between the first position (P1) and the second position (P2) in the direction of the axial line (CL), and a second neck portion (420) whose forward end (420f) is located rearward of the middle position (Pc).

3. A glow plug (10) according to claim 1 or 2, wherein a length (Lf) of the forwardmost neck portion (410) in the direction of the axial line (CL) is 5 mm or more.

4. A glow plug (10) according to any one of claims 1 to 3, wherein the forwardmost neck portion (410) is formed by closed loop grooves (300) each extending, on the outer circumferential surface (30s) of the center rod (30, 30b, 30c, 30d, 30e, 30f), completely around the center rod (30, 30b, 30c, 30d, 30e, 30f) in the circumferential direction thereof; and
the following relational expression is satisfied:

$$Db < \sqrt[3]{\frac{Lb}{La}} \times Da$$

where Db is a smallest outer diameter of a portion of the center rod (30, 30b) where the forwardmost neck portion (410) is formed.

5. A glow plug (10) according to any one of claims 1 to 4, wherein the center rod (30c, 30d, 30e, 30f) includes
a first transition portion (500, 500d, 500e, 500f) which is connected to a forward end of at least one neck portion (410) of the one or more neck portions and

which includes a groove (600) extending on the outer circumferential surface (30s) of the center rod (30c, 30d, 30e, 30f) in the circumferential direction thereof, and

a first trunk portion (910) which is connected to a forward end of the first transition portion (500, 500d, 500e, 500f) and which has an approximately constant outer diameter,

wherein a distance (R61 - R65) between a bottom portion (610) of the groove (600) of the first transition portion (500, 500d, 500e, 500f) and the center axis (CL) of the center rod (30c, 30d, 30e, 30f) is larger than a distance (Db/2) between a bottom portion (310) of each of the grooves (300) of the neck portion (410) and the center axis (CL), and is smaller than a distance (Dc/2) between an outer circumferential surface of the first trunk portion (910) and the center axis (CL).

6. Aglow plug (10) according to claim 5, wherein the first transition portion (500d, 500e) has a plurality of closed loop grooves (600) each extending, on the outer circumferential surface (30s) of the center rod (30d, 30e), completely around the center rod (30d, 30e) in the circumferential direction thereof; and the plurality of grooves (600) of the first transition portion (500d, 500e) are formed such that the bottom portion (610) of a groove (600) on a forward side has an outer diameter larger than that of the bottom portion (610) of a groove (600) on a rear side.

7. A glow plug (10) according to claim 5, wherein the first transition portion (500f) has a plurality of closed loop grooves (600) each extending, on the outer circumferential surface (30s) of the center rod (30f), completely around the center rod (30f) in the circumferential direction thereof; and of N pairs (N is an integer of 2 or greater) which are formed by the plurality of grooves (600) of the first transition portion (500f) and each of which includes two adjacent grooves (600), L pairs (L is an integer of 1 or greater but not greater than N-1) are configured such that the outer diameter of the bottom portion (610) of the groove (600) on the forward side is larger than that of the bottom portion (610) of the groove (600) on the rear side, and (N-L) pairs are configured such that the outer diameter of the bottom portion (610) of the groove (600) on the forward side is the same as that of the bottom portion (610) of the groove (600) on the rear side.

8. A glow plug (10) according to any one of claims 1 to 7, wherein the center rod (30c, 30d, 30e, 30f) includes

a second transition portion (700, 700d, 700e, 700f) which is connected to a rear end of at least one neck portion (410) of the one or more neck portions and which includes a groove (800) extending on the outer circumferential surface (30s) of the center rod (30c, 30d, 30e, 30f) in the circumferential direction thereof, and

a second trunk portion (920) which is connected to a rear end of the second transition portion (700, 700d, 700e, 700f) and which has an approximately constant outer diameter,

wherein a distance (R81 - R85) between a bottom portion (810) of the groove (800) of the second transition portion (700, 700d, 700e, 700f) and the center axis (CL) of the center rod (30c, 30d, 30e, 30f) is larger than a distance (Db/2) between a bottom portion (310) of each of the grooves (300) of the neck portion (410) and the center axis (CL), and is smaller than a distance (Dc/2) between an outer circumferential surface of the second trunk portion (920) and the center axis (CL).

9. A glow plug (10) according to claim 8, wherein the second transition portion (700d, 700e) has a plurality of closed loop grooves (800) each extending, on the outer circumferential surface (30s) of the center rod (30d, 30e), completely around the center rod (30d, 30e) in the circumferential direction thereof; and the plurality of grooves (800) of the second transition portion (700d, 700e) are formed such that the bottom portion (810) of a groove (800) on a rear side has an outer diameter larger than that of the bottom portion (810) of a groove (800) on a forward side.

10. A glow plug (10) according to claim 8, wherein the second transition portion (700f) has a plurality of closed loop grooves (800) each extending, on the outer circumferential surface (30s) of the center rod (30f), completely around the center rod (30f) in the circumferential direction thereof; and of P pairs (P is an integer of 2 or greater) which are formed by the plurality of grooves (800) of the second transition portion (700f) and each of which includes two adjacent grooves (800), Q pairs (Q is an integer of 1 or greater but not greater than P-1) are configured such that the outer diameter of the bottom portion (810) of the groove (800) on the rear side is larger than that of the bottom portion (810) of the groove (800) on the forward side, and (P-Q) pairs are configured such that the outer diameter of the bottom portion (810) of the groove (800) on the rear side is the same as that of the bottom portion (810) of the groove (800) on the forward side.

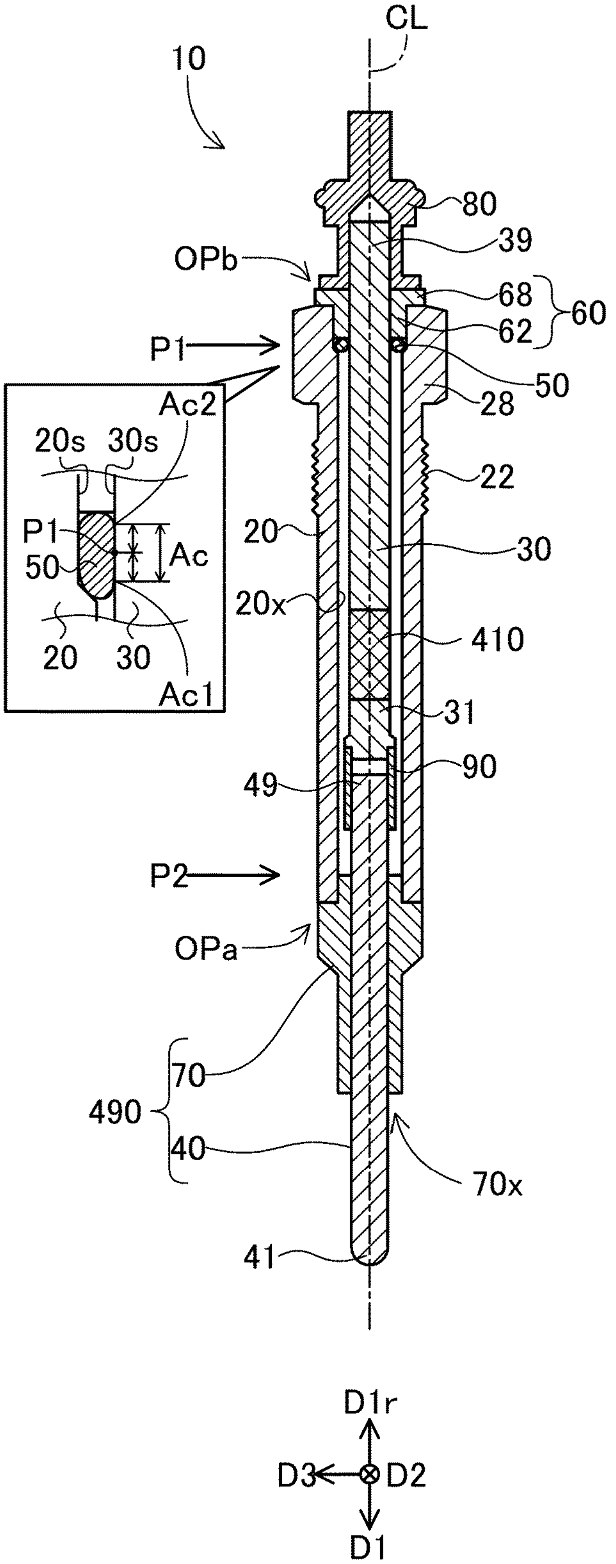

CL
10
80
39
OPb
68
62
60
P1
50
28
Ac2
20s
30s
P1
50
Ac
20
30
Ac1
22
20
30
20x
410
31
90
49
P2
OPa
70
490
40
70x
41
D1r
D3
D2
D1

FIG. 1(A)

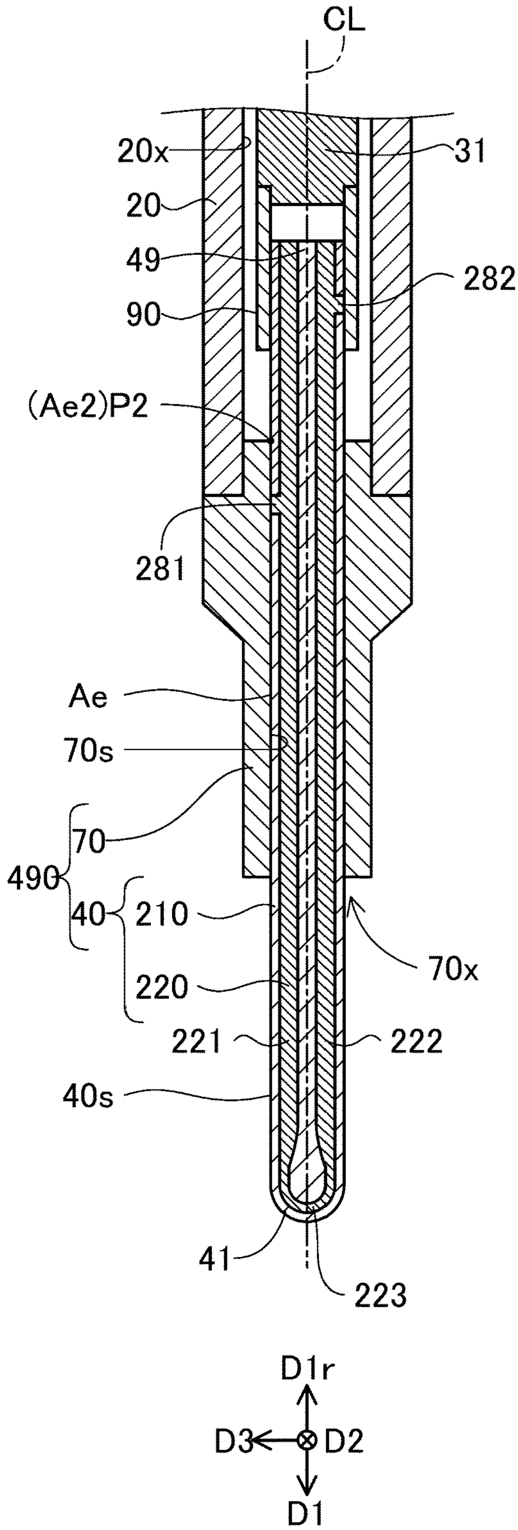

CL
20x
31
20
49
282
90
(Ae2)P2
281
Ae
70s
70
490
40
210
70x
220
221
222
40s
41
223
D1r
D3
D2
D1

FIG. 1(B)

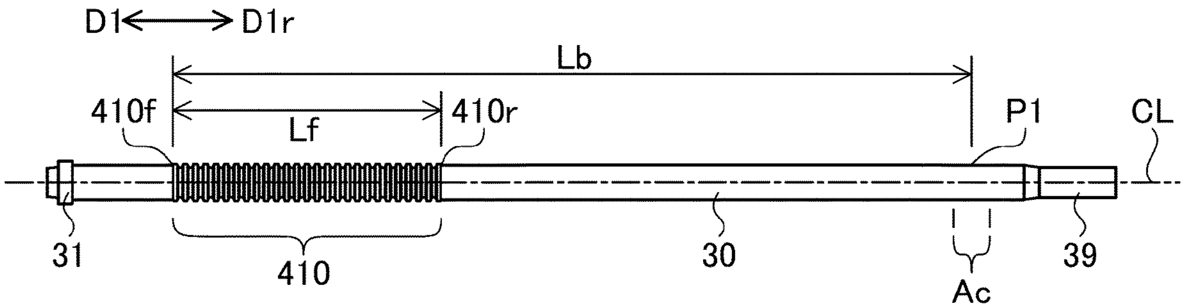

D1
D1r
Lb
Lf
410f
410r
P1
CL
31
410
30
Ac
39

FIG. 2(A)

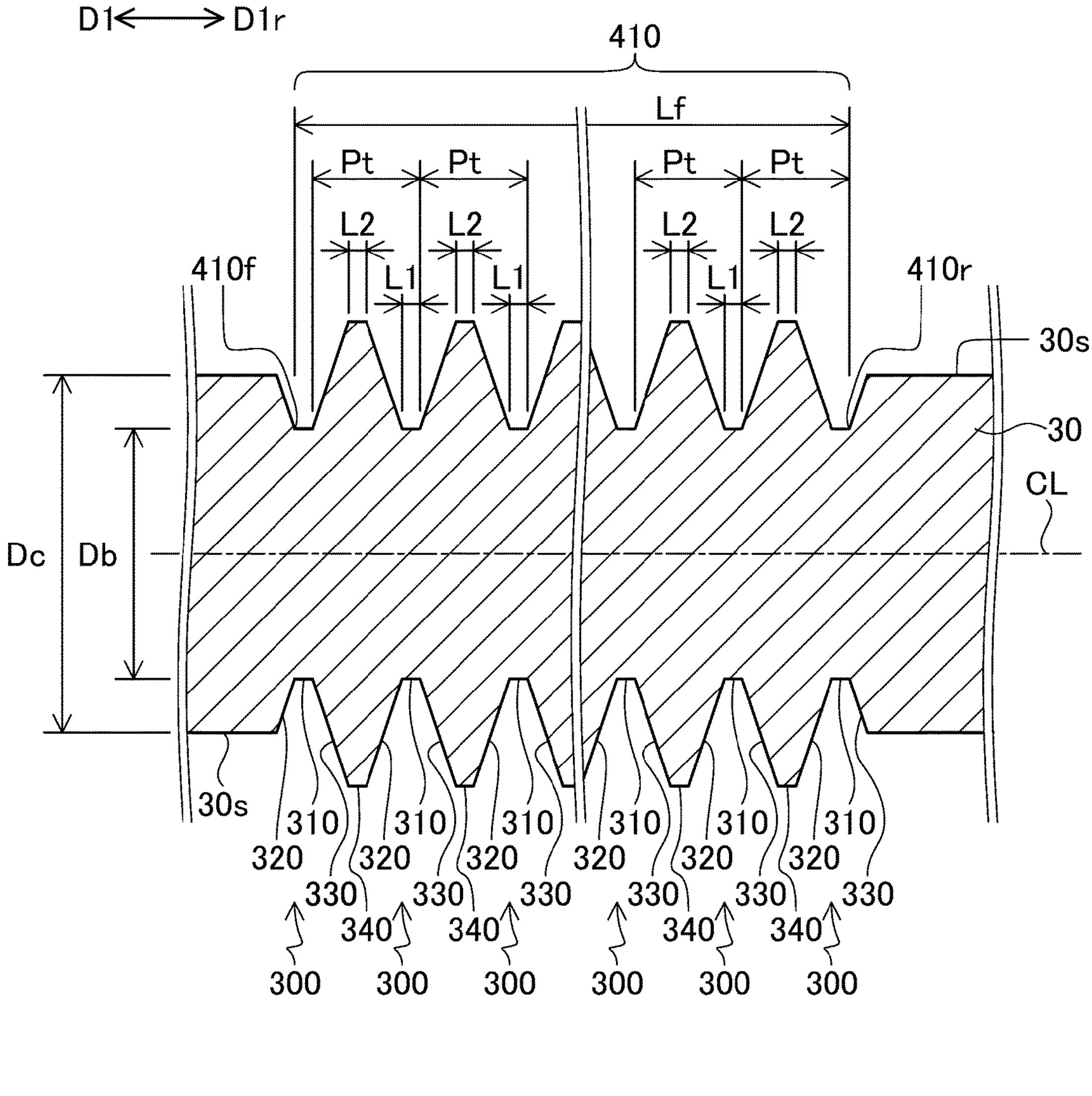
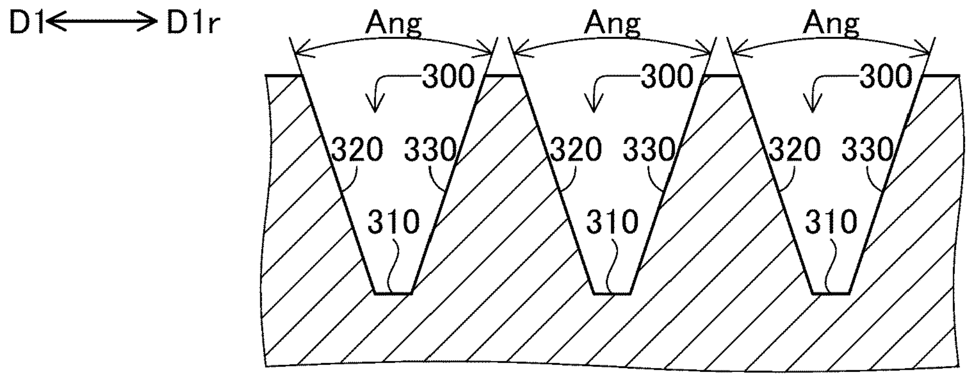
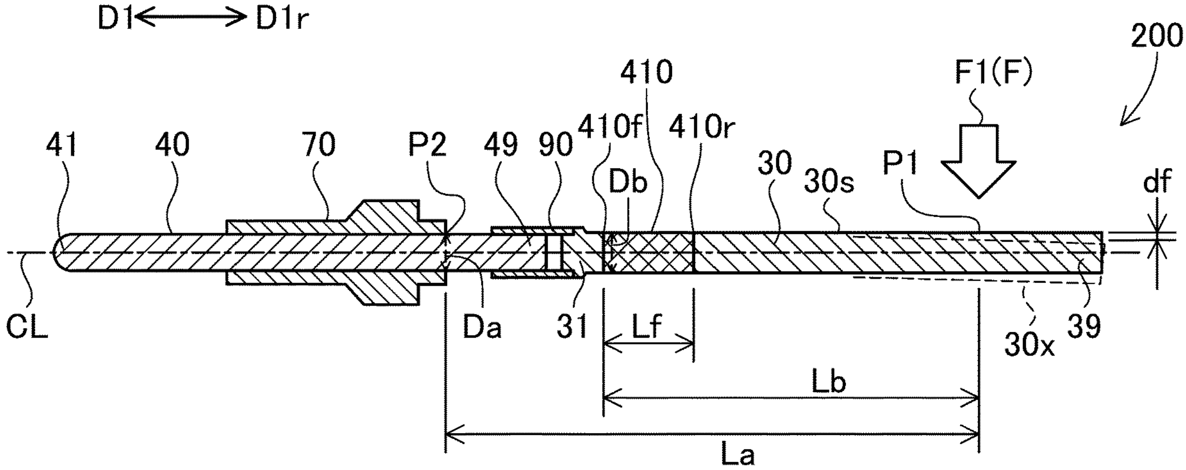

D1
D1r
410
Lf
Pt
L2
L1
410f
410r
30s
30
CL
Dc
Db
310
320
330
340
300

FIG. 2(B)



D1
D1r
Ang
Ang
Ang
300
300
300
320
330
320
330
320
330
310
310
310

FIG. 2(C)



D1
D1r
200
410
F1(F)
41
40
70
P2
49
90
410f
410r
Db
30
30s
P1
df
CL
Da
31
Lf
30x
39
Lb
La

FIG. 3

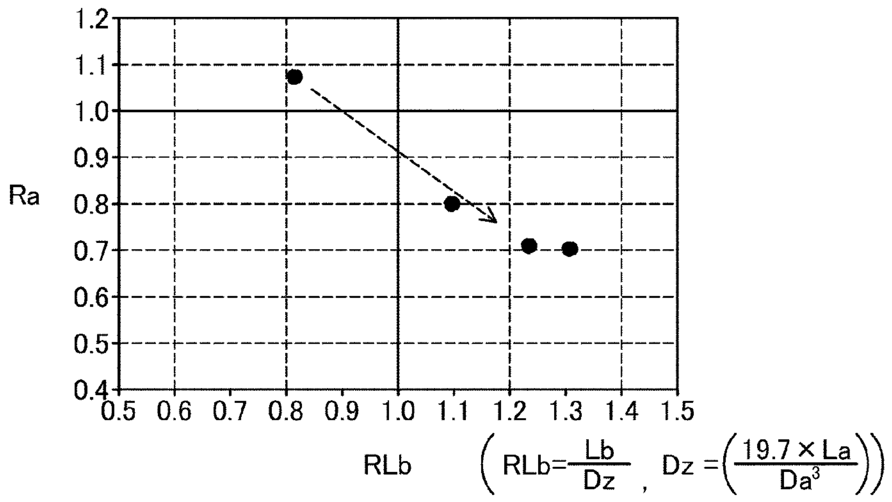


FIG. 4(A)

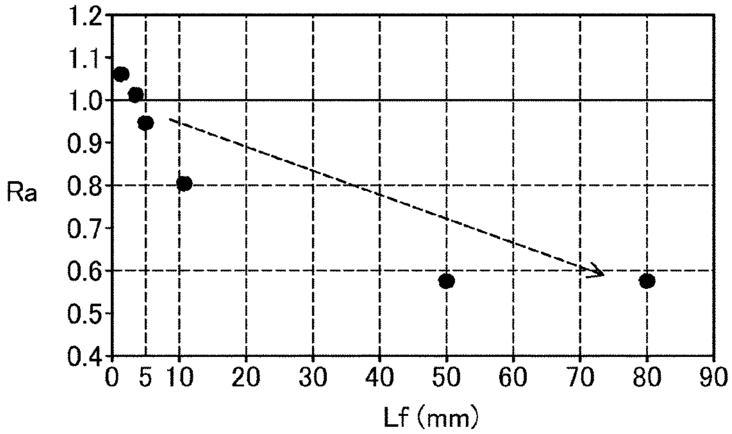


FIG. 4(B)

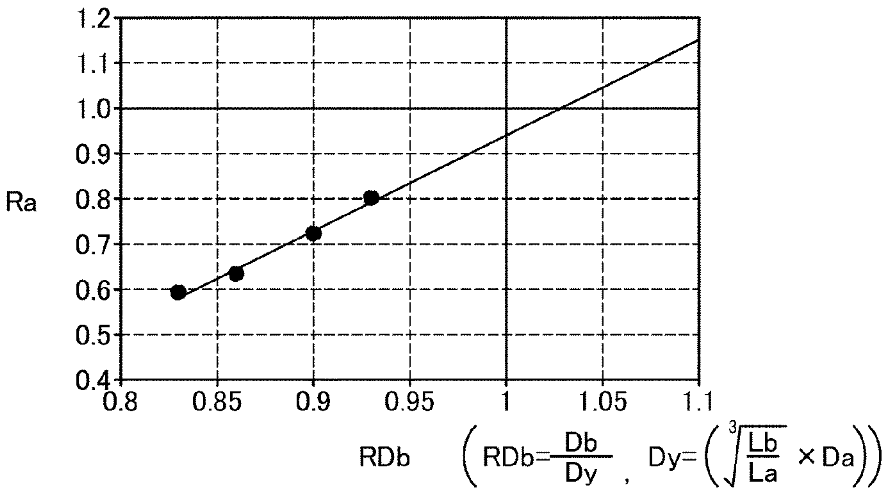


FIG. 4(C)

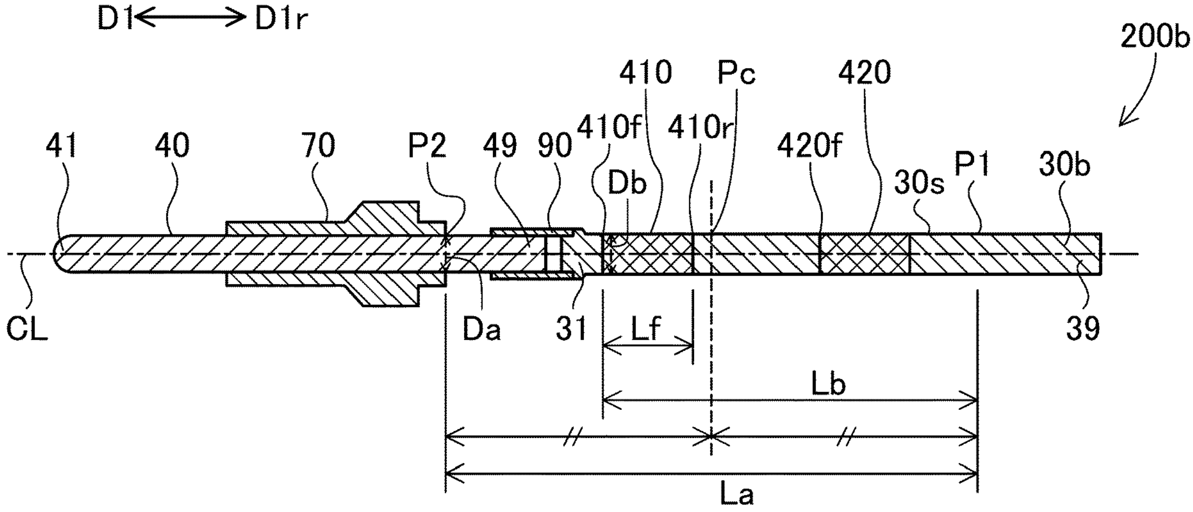


FIG. 5(A)

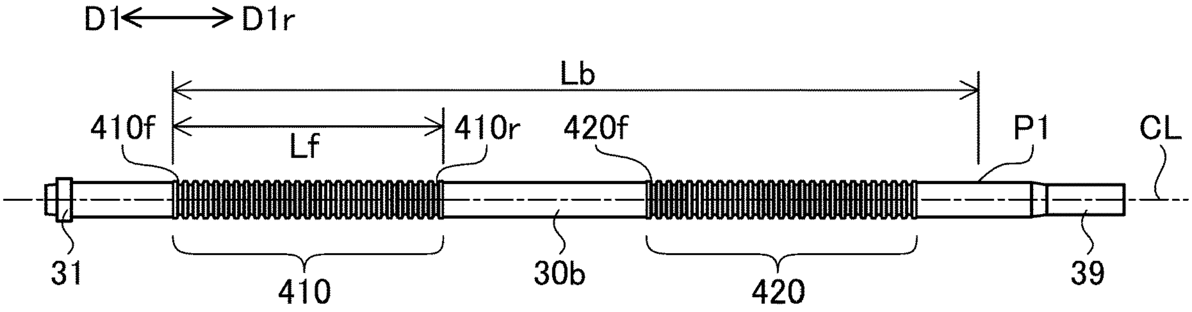


FIG. 5(B)

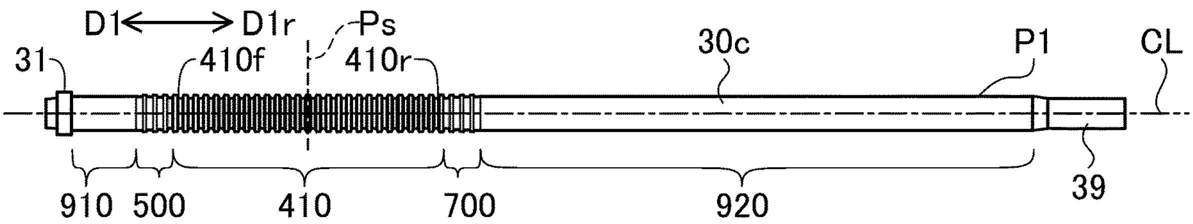


FIG. 6(A)

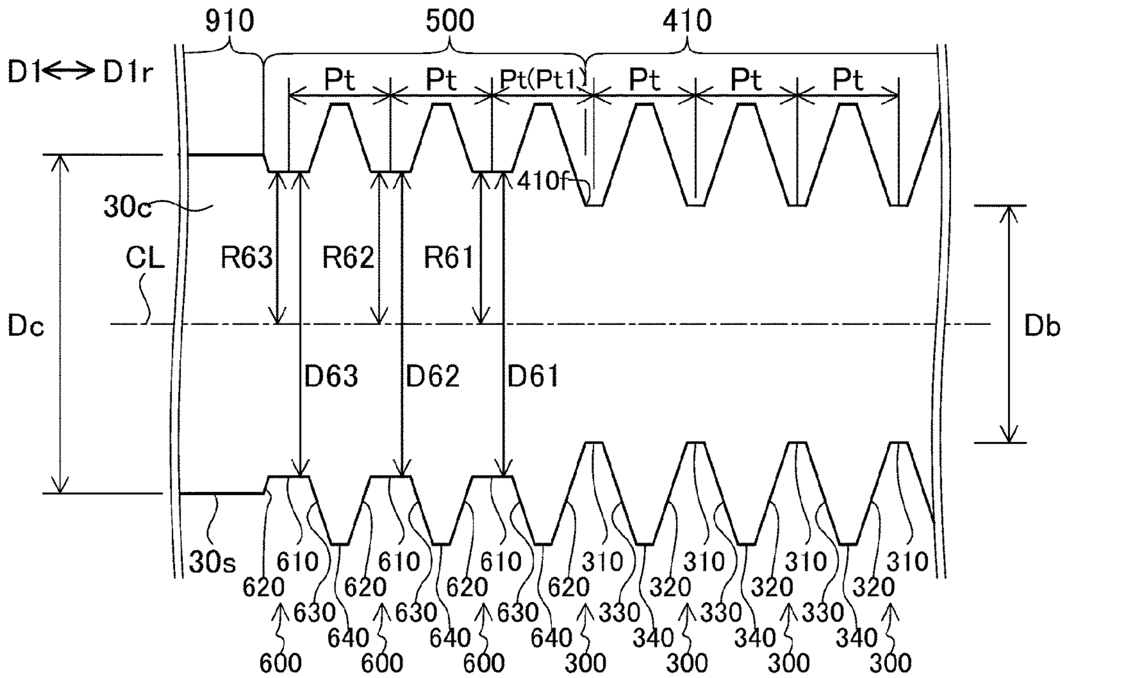

910
500
410
D1 D1r
Pt
Pt(Pt1)
410f
30c
CL
R63
R62
R61
Dc
Db
D63
D62
D61
30s
610
620
630
640
600
310
320
330
340
300

FIG. 6(B)

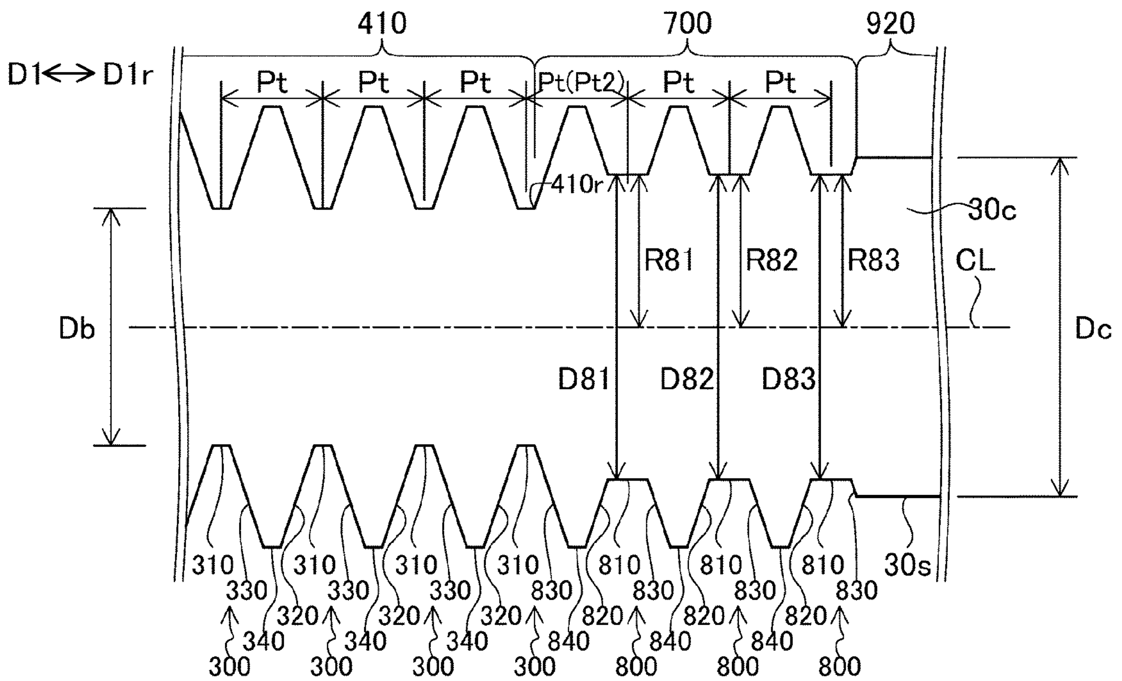

410
700
920
D1 D1r
Pt
Pt(Pt2)
410r
30c
R81
R82
R83
CL
Db
Dc
D81
D82
D83
310
330
320
340
300
810
830
820
840
800
30s

FIG. 6(C)

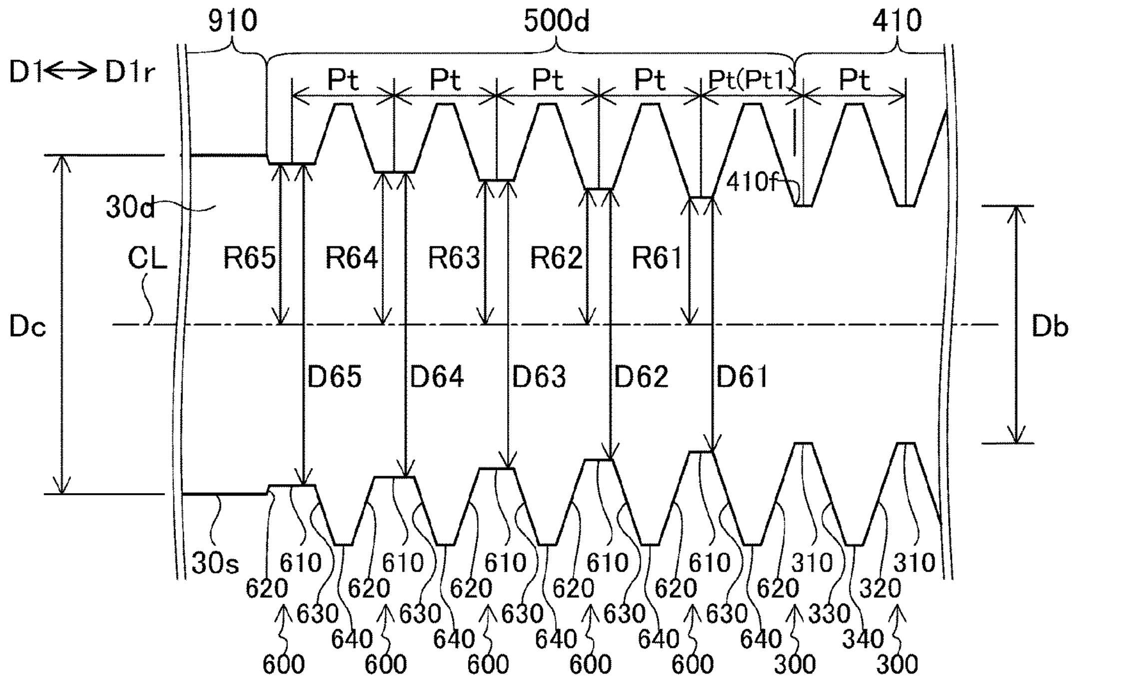

910
500d
410
D1 ↔ D1r
Pt
Pt
Pt
Pt
Pt(Pt1)
Pt
410f
30d
CL
R65
R64
R63
R62
R61
Dc
Db
D65
D64
D63
D62
D61
30s
610
620
630
640
600
310
320
330
340
300

FIG. 7(A)

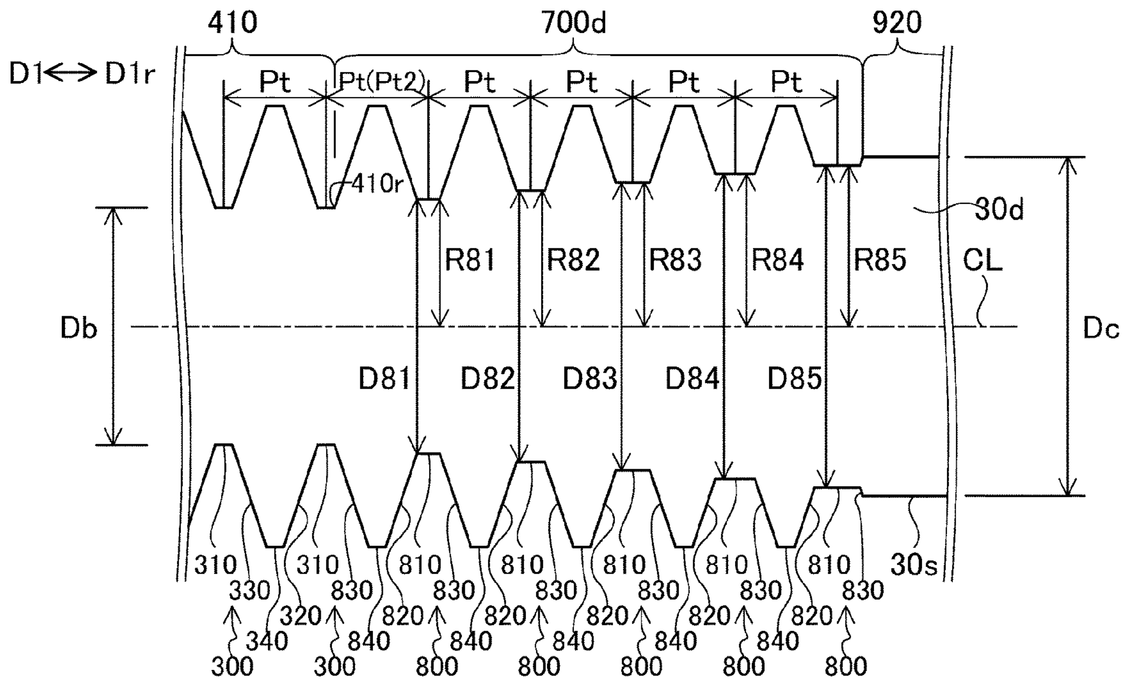

410
700d
920
D1 ↔ D1r
Pt
Pt(Pt2)
Pt
Pt
Pt
Pt
410r
30d
CL
R81
R82
R83
R84
R85
Db
Dc
D81
D82
D83
D84
D85
310
330
320
340
300
810
820
830
840
800
30s

FIG. 7(B)

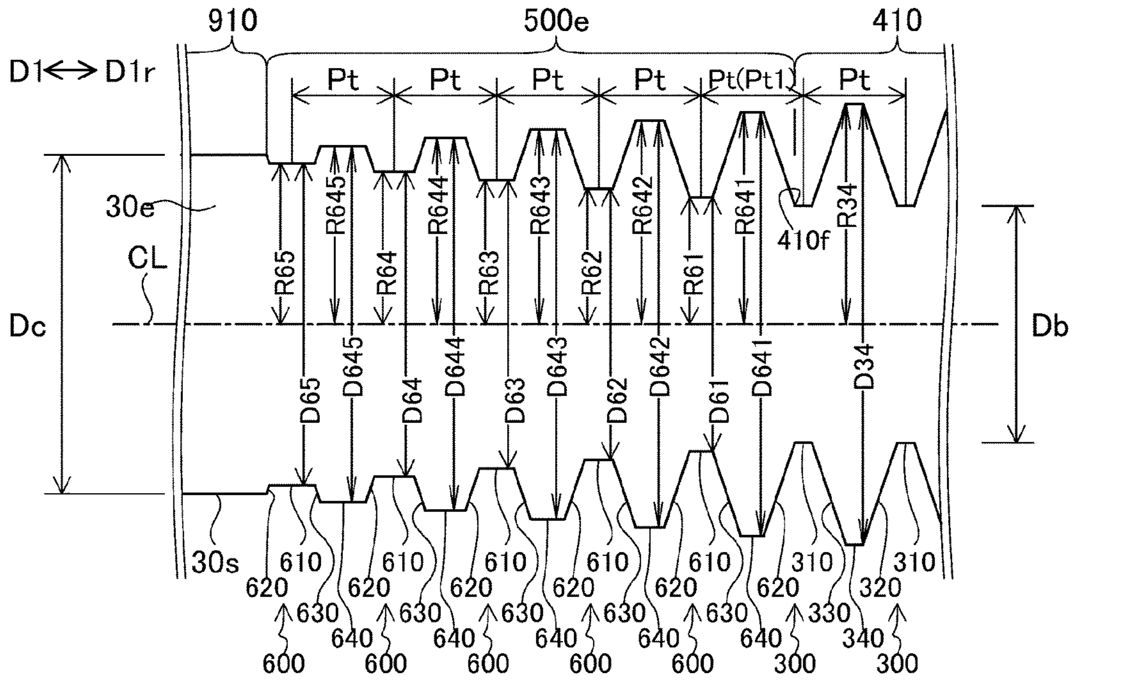

910
500e
410
D1 D1r
Pt
Pt(Pt1)
30e
CL
Dc
Db
410f
R65
R645
R64
R644
R63
R643
R62
R642
R61
R641
R34
D65
D645
D64
D644
D63
D643
D62
D642
D61
D641
D34
30s
610
620
630
640
600
310
320
330
340
300

FIG. 8(A)

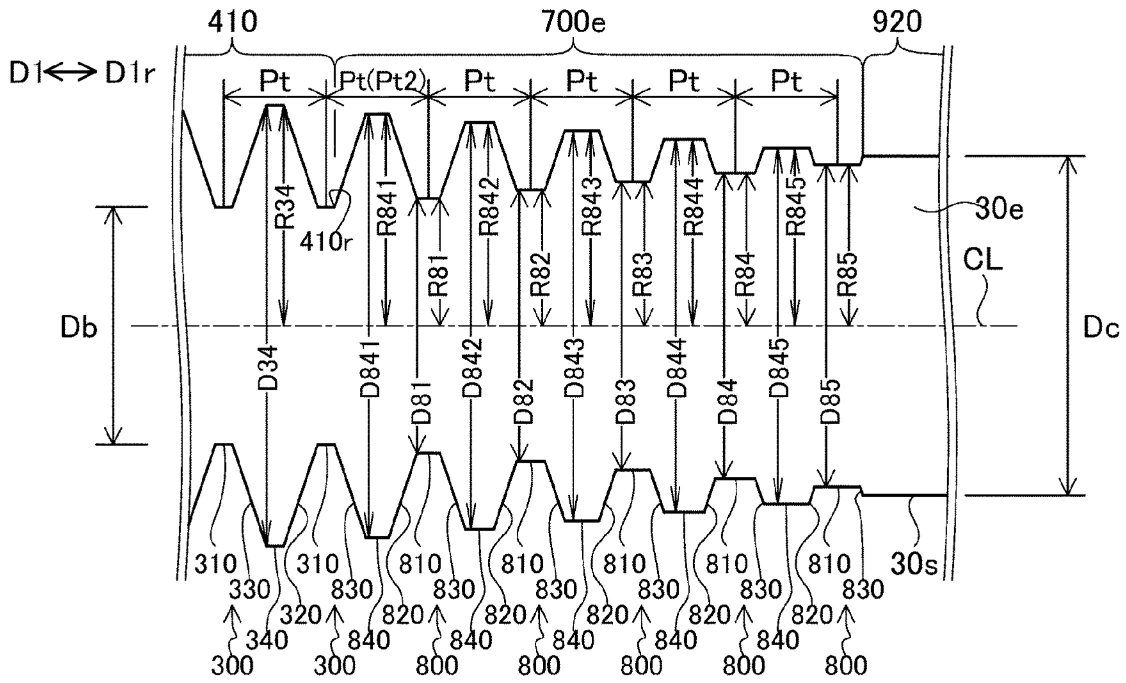

410
700e
920
D1 D1r
Pt
Pt(Pt2)
30e
CL
Db
Dc
410r
R34
R841
R81
R842
R82
R843
R83
R844
R84
R845
R85
D34
D841
D81
D842
D82
D843
D83
D844
D84
D845
D85
310
330
320
340
300
810
820
830
840
800
30s

FIG. 8(B)

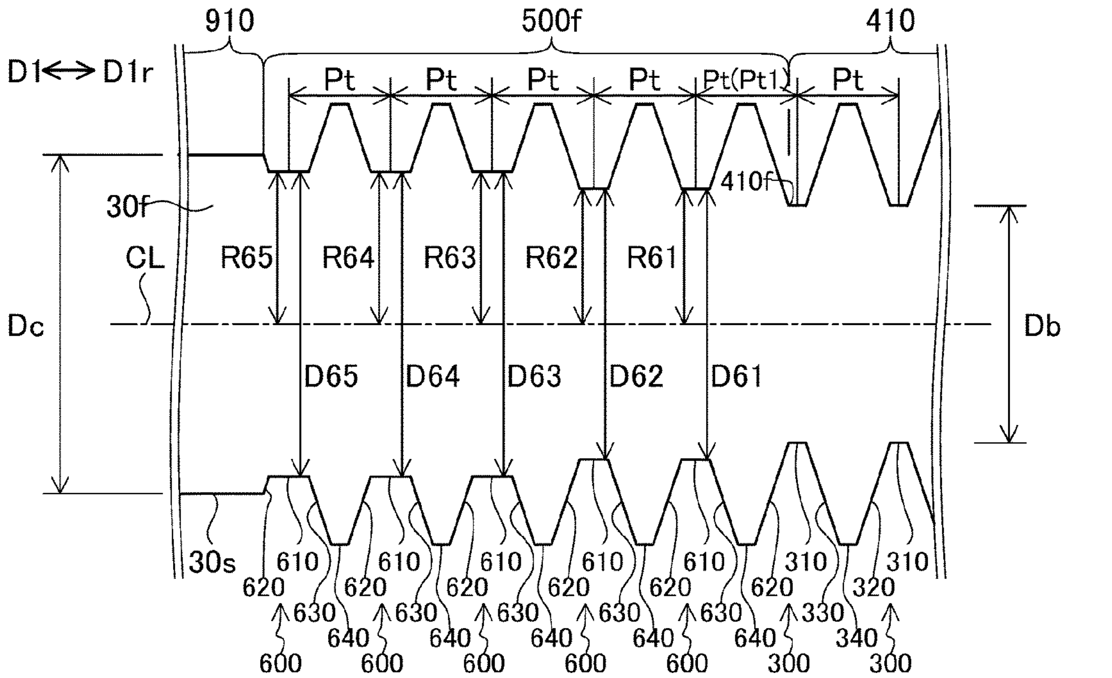

910
500f
410
D1
D1r
Pt
Pt(Pt1)
30f
410f
CL
R65
R64
R63
R62
R61
Dc
Db
D65
D64
D63
D62
D61
30s
610
620
630
640
600
310
320
330
340
300

FIG. 9(A)

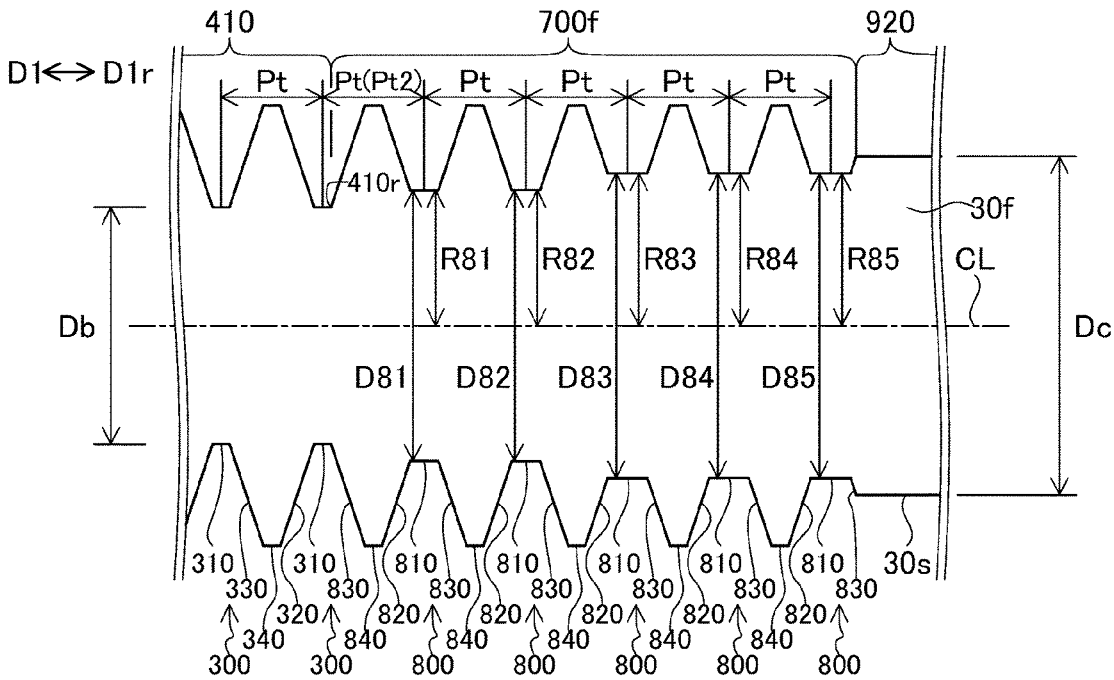

410
700f
920
D1
D1r
Pt
Pt(Pt2)
410r
30f
R81
R82
R83
R84
R85
CL
Db
Dc
D81
D82
D83
D84
D85
310
330
320
340
300
810
830
820
840
800
30s

FIG. 9(B)

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EUROPEAN SEARCH REPORT

Application Number
EP 17 17 5520

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F23Q

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	27 November 2017	Vogl, Paul

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