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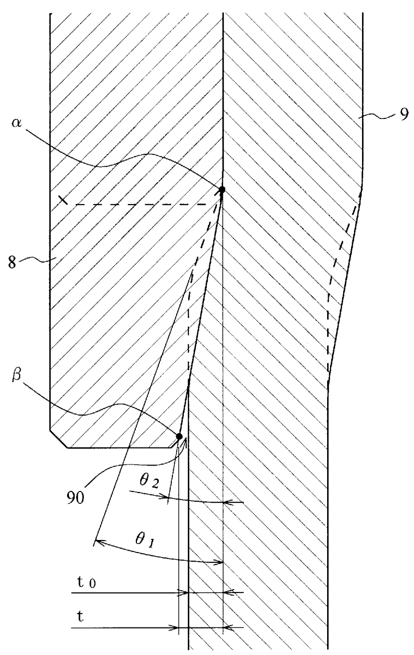
(54) **ROTOR AND VACUUM PUMP**

(57) Provided are a rotor having a load variation relaxation structure that relaxes load variations in the boundary portion of a cylindrical body and a cylindrical rotating portion, and a vacuum pump in which rotation performance (that is, discharge performance), reliability, and durability are improved over those in the related art by incorporating the cylindrical body. In the vacuum pump, a rotating portion made from a metal (aluminum alloy or the like) is provided with the load variation relaxation structure, which relaxes load variations caused by thermal stresses, in a joined section where the cylindrical rotating portion formed from a different material (FRP or the like) is joined. More specifically, any one from among a gentle taper, a curved section and a taper section, and a corner R is provided in the boundary portion of the rotating portion and the cylindrical rotating portion.

Fig.2



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Description

[0001] The present invention relates to a rotor and a vacuum pump, and more particularly to a rotor having a load variation relaxation structure that relaxes load variations in a joined section and to a vacuum pump including such a rotor.

[0002] Among a variety of vacuum pumps, turbomolecular pumps and spiral-groove pumps are widely used for creating high-vacuum environment.

[0003] In such vacuum pumps, structural components that demonstrate a discharge function in the vacuum pumps are accommodated inside a casing provided with an inlet port and an outlet port. Those structural components demonstrating a discharge function can be generally constituted by a rotating portion (rotor portion) that is disposed rotationally and a stator portion fixed to the casing.

[0004] In a turbomolecular pump, the rotating portion is constituted by a rotating shaft and a rotating body fixed to the rotating shaft, and rotating blades (dynamic blades) disposed radially are provided in multiple stages at the rotating body. Stator blades (stationary blades) are provided alternately with the rotating blades in multiple stages at the stator portion. The turbomolecular pump is also provided with a motor for rotating the rotating shaft at a high speed, and where the rotating shaft is rotated at a high speed by the motor, a gas is sucked in from the inlet port and discharged from the outlet port by the interaction of the rotating blades and the stator blades.

[0005] In a vacuum pump of such a configuration, such as a turbomolecular pump and a spiral-groove pump, the rotating portion is usually manufactured from a metal such as aluminum or an aluminum alloy.

[0006] However, a cylindrical rotating portion that rotates at a high speed is sometimes manufactured from lightweight and strong fiber-reinforced composite materials (fibers reinforced plastics; referred to as FRP hereinbelow) with the object of improving performance (in particular, to enable rotation at a higher speed). In this case, the fibers used for the FRP can be aramid fibers (AFRP), boron fibers (BFRP), glass fibers (GFRP), carbon fibers (CFRP), and polyethylene fibers (DFRP).

[0007] Where a cylindrical rotating portion provided below the rotating portion of the vacuum pump is formed from a lightweight and strong FRP, the cylindrical portion can be reduced in weight and increased in size. Therefore, the discharge performance of the vacuum pump equipped with such cylindrical rotating portion can be increased.

[0008] The rotating portion (rotating blade) made from a metal such as an aluminum alloy and a cylindrical rotating portion formed from a FRP are typically joined, as shown in FIGS. 9A and 9B, by installing a guide below the rotating portion, such that a rotor (rotating portion) 80 (800) is provided on the inner side and a cylindrical rotating portion 9 is provided on the outer side, and press fitting or bonding, or press fitting and bonding.

[0009] Under certain operation conditions, the temperature of the rotor of the vacuum pump can rise from normal temperature to about 150°C. Because of such a wide temperature range, large thermal stresses are generated by the difference in thermal expansion between the two materials at a high temperature.

[0010] Since the thermal expansion coefficient of aluminum alloys is several times that of FRP, where the temperature rises with the operation time, the rotating portion made from a metal and located on the inner side rapidly expands. Meanwhile, the cylindrical rotating portion formed from the FRP and joined at the outer side does not expand that much. Therefore, extremely large stresses are generated at the contact surface of the joined section during the operation.

[0011] Japanese Patent No. 3098139 describes a composite molecular pump constituted by a turbomolecular pump portion and a spiral-groove pump portion, in which a rotor of the turbomolecular pump portion is made from a metal, whereas a cylindrical rotor of the spiral-groove pump portion and a support plate (5) joining the rotor of the turbomolecular pump portion and the cylindrical rotor of the spiral-groove pump portion is made from a fiber-reinforced plastic (FRP).

[0012] Thus, in the invention described in Japanese Patent Publication No. 3098139, a member (support plate) having a thermal expansion coefficient between those of the metal and FRP is inserted between the metallic rotor of the turbomolecular pump portion and the cylindrical rotor made from the FRP, and thermal stresses caused by the aforementioned difference in thermal expansions are relaxed.

[0013] Japanese Patent Application Publication No. 2004-278512 describes a filament winding method by which a fiber bundle is wound and fixed with a resin and a sheet winding method by which a sheet obtained by embedding (immersing) fibers in a resin in advance is wound as a method for manufacturing the above-described cylindrical rotating portion from a FRP. This document describes a Holweck type skirt downstream rotor segment (5c) fabricated from a composite material of an organic base material based on a resin loaded with reinforcing fibers (FRP) such as glass fibers and carbon fibers and produced by continuously winding on a core by the filament winding method.

[0014] In the invention disclosed in Japanese Patent Application Publication No. 2004-278512, a load in the vicinity of a joined section is relaxed by optimizing FRP winding conditions, for example, by winding the fibers obliquely, or by setting a larger content ratio for the resin than for the fibers and reducing intentionally the Young's modulus of the material so as to decrease the load generated when the material expands from the inner side due to thermal expansion.

[0015] However, the objective of the aforementioned Japanese Patent Publication No. 3098139 and Japanese Patent Application Publication No. 2004-278512 is to relax a load applied to the entire joined section of the metallic rotating portion and the cylindrical rotating portion made from the FRP in the vacuum pump.

[0016] Therefore, in the aforementioned Japanese Patent Publication No. 3098139 and Japanese Patent Application Publication No. 2004-278512 no attention is paid to rapid load variations occurring in the cylindrical body (cylindrical rotating portion) formed from the FRP in a boundary section of a portion which is actually in contact with the metallic rotor provided on the inner side of the cylindrical body and to which a load is applied and a portion which is not in contact with the metallic rotor and to which, therefore, no load is applied.

[0017] Further, where a FRP is used for the cylindrical body portion of rotating blades of a vacuum pump, when the FRP is designed, fibers strengthening a material are wound in the circumferential direction to ensure resistance to a load created by a centrifugal force applied in the circumferential direction. In the direction in which the fibers are inserted (that is, the circumferential direction) in the cylindrical body using the FRP formed in such a manner, the fibers bear the load applied to the cylindrical body and, therefore, the strength of the cylindrical body is increased.

[0018] However, in the direction in which the fibers are not inserted (that is, an axial direction or a radial direction), the resin joining the fibers bears the load applied to the cylindrical body. For this reason, the strength in the direction in which the fibers are not inserted is practically the same as that before the fibers have been inserted, or the strength can even decrease as a result of stress concentration.

[0019] Further, because of the above-described anisotropy, the cylindrical body formed from the FRP can be deformed even by a slight load in the axial direction or radial direction in which the fibers are not inserted.

[0020] A vacuum pump including such a cylindrical rotating portion manufactured from a FRP is sometimes provided in an environment in which a corrosive gas (for example, a halogen gas) is discharged. In such a case, the surface of the portions (parts) where such gas flows is subjected to anticorrosive surface treatment such as electroless nickel plating. Other examples of anticorrosive surface treatment include vapor deposition processes such as physical vapor deposition (PVD), chemical vapor deposition (CVD), sputtering, and ion plating, and electrodeposition coating.

[0021] When the cylindrical rotating portion is thus subjected to the anticorrosive surface treatment (anticorrosive coating on the surface), where large load variations occur in the axial direction in a boundary portion of a joined section where the metallic rotating portion and the cylindrical rotating portion formed from a FRP are joined and a non-joined section where the two are not joined in a vacuum pump and the boundary portion of the joined section and non-joined section is partially significantly deformed, the anticorrosive surface coating in this portion (joined portion) can be damaged due to cracking of a plated layer on a boundary surface.

[0022] Accordingly, it is an object of the present invention to provide a rotor having a relaxation structure for load variations in a joined section with a rotating body

[0023] (rotor) in a vacuum pump, and a vacuum pump that includes such a rotor and has improved gas discharge performance.

[0024] The invention as in claim 1 provides a rotor provided in a vacuum pump and joined to a cylindrical body formed from a different material, wherein a load variation relaxation structure is provided at a surface that is in contact with the cylindrical body.

[0025] The invention as in claim 2 provides the rotor according to claim 1, wherein the load variation relaxation structure is a gradual taper structure formed at an outer diametrical surface of the rotor such that an outer diameter of the rotor decreases gradually from an end surface side where the cylindrical body is joined to the rotor toward a center of the cylindrical body.

[0026] The invention as in claim 3 provides the rotor according to claim 1 or 2, wherein the load variation relaxation structure is a gradual taper structure formed at an outer diametrical surface of the rotor such that an outer diameter of the rotor decreases gradually from a center of the cylindrical body toward an end surface side where the cylindrical body is joined to the rotor.

[0027] The invention as in claim 4 provides the rotor according to claim 2, wherein a taper angle of the taper structure is less than an angle at which the cylindrical body gradually reduces in diameter from the end surface side that is joined to the rotor toward the center of the cylindrical body.

[0028] The invention as in claim 5 provides the rotor according to claim 3, wherein a taper angle of the taper structure is less than an angle at which the cylindrical body gradually reduces in diameter from the center of the cylindrical body toward the end surface side that is joined to the rotor.

[0029] The invention as in claim 6 provides the rotor according to any one of claims 2 to 5, wherein the load variation relaxation structure is configured such that an end point of the taper structure on the end surface side where the cylindrical body is joined to the rotor is formed in a curved shape.

[0030] The invention as in claim 7 provides the rotor according to any one of claims 2 to 6, wherein the load variation relaxation structure is configured such that the taper structure is extended to a position where the rotor and the cylindrical body do not have a contact surface in common.

[0031] The invention as in claim 8 provides the rotor according to claim 1, wherein the load variation relaxation structure is a gradual curved structure formed at an outer diametrical surface of the rotor such that an outer diameter of the rotor decreases gradually from an end surface side where the cylindrical body is joined to the rotor toward a center of the cylindrical body.

[0032] The invention as in claim 9 provides the rotor according to claim 1 or 8, wherein the load variation relaxation structure is a gradual curved structure formed at an outer diametrical surface of the rotor such that an outer diameter of the rotor decreases gradually from a center of the cylindrical body toward an end surface side where the cylindrical body is joined to the rotor.

[0033] The invention as in claim 10 provides the rotor according to claim 8 or 9, wherein the load variation relaxation structure is configured such that the curved structure is extended to a position where the rotor and the cylindrical body do not have a contact surface in common.

[0034] The invention as in claim 11 provides a vacuum pump including a spiral-groove pump portion and a rotor joined to a cylindrical body formed from a different material, wherein the rotor is the rotor of any one of claims 1 to 10.

[0035] In accordance with the present invention, it is possible to provide a rotor having a relaxation structure for load variations in a joined section with a rotating body of a vacuum pump, and also a vacuum pump that includes the rotor and has improved discharge performance.

FIG. 1 illustrates a schematic configuration example of a turbomolecular pump provided with a load variation relaxation structure according to the first embodiment of the present invention;
FIG. 2 is a schematic drawing of the load variation relaxation structure according to the first embodiment of the present invention;
FIG. 3 illustrates the load variation relaxation structure according to variation example 1 of the first embodiment of the present invention;
FIG. 4 illustrates the load variation relaxation structure according to variation example 2 of the first embodiment of the present invention;
FIG. 5 illustrates the load variation relaxation structure according to variation example 3 of the first embodiment of the present invention;
FIG. 6 illustrates the load variation relaxation structure according to variation example 4 of the first embodiment of the present invention;
FIG. 7 is a schematic drawing of the load variation relaxation structure according to the second embodiment of the present invention;
FIG. 8 illustrates a schematic configuration example of a spiral-groove pump provided with the load variation relaxation structure according to the third embodiment of the present invention; and
FIG. 9 illustrates a schematic configuration example of the joined section of a rotating portion and a cylindrical rotating portion according to the related art.

(i) Summary of Embodiments

[0036] In the embodiments of the present invention, the vacuum pump has a load variation relaxation structure that relaxes load variations caused by thermal stresses or the like in a joined section in which the cylindrical rotating portion formed from a FRP or the like is joined to a metallic rotating portion made from an aluminum alloy or the like.

[0037] More specifically, a gentle taper is provided in a boundary portion of the rotating portion and the cylindrical rotating portion.

(ii) Detailed Description of Embodiments

[0038] The preferred embodiments of the present invention will be described below in greater detail with reference to FIGS. 1 to 8.

[0039] A first embodiment is explained using the so-called composite turbomolecular pump equipped with a turbomolecular pump portion and a spiral-groove pump portion as an example of a vacuum pump.

[0040] In the present embodiment, a turbomolecular pump 1 explained by way of example has provided therein a rotor 8 manufactured from an aluminum alloy and a cylindrical rotor portion 9 manufactured from a FRP.

[0041] FIG. 1 shows a schematic configuration example of the turbomolecular pump 1 provided with a load variation relaxation structure according to the first embodiment of the present invention. FIG. 1 shows a cross section in the axial line direction of the turbomolecular pump 1.

[0042] A casing 2 forming a casing of the turbomolecular pump 1 has a substantially cylindrical shape and constitutes, together with a base 3 provided below (outlet port 6 side) the casing 2, a housing of the turbomolecular pump 1. A gas transfer mechanism, which is a structural component demonstrating a discharge function in the turbomolecular pump 1, is accommodated inside the housing.

[0043] The gas transfer mechanism is mainly constituted by a rotationally disposed rotor portion and a stator portion fixed to the housing.

[0044] An inlet port 4 for introducing a gas into the turbomolecular pump 1 is formed in an end section of the casing 2. A flange portion 5 projecting to the outer peripheral side is formed in an end surface of the casing 2 on the inlet port 4 side.

[0045] An outlet port 6 for discharging the gas from the turbomolecular pump 1 is formed in the base 3.

[0046] The rotating portion is constituted by a shaft 7, which is a rotating shaft, a rotor 8 provided on the shaft 7, a plurality of rotating blades 8a provided at the rotor 8, and a cylindrical rotating portion 9 provided at the outlet port 6 side (spiral-groove pump portion). A rotor portion is constituted by the shaft 7 and the rotor 8.

[0047] Each rotating blade 8a is constituted by a blade that extends radially from the shaft 7 and is inclined at a predetermined angle to a plane perpendicular to an axial line of the shaft 7.

[0048] The cylindrical rotating portion 9 is constituted by a cylindrical member having a cylindrical shape coaxial with the rotation axial line of the rotor 8.

[0049] A motor portion 20 for rotating the shaft 7 at a high speed is provided at the intermediate location in the axial line direction of the shaft 7 and included in a stator column 10.

[0050] Further, radial magnetic bearing devices 30, 31 for rotationally supporting the shaft 7 in a radial direction in a contactless manner are provided at the inlet port 4 side and outlet port 6 side of the shaft 7 with respect to the motor portion 20, and an axial magnetic bearing device 40 for rotationally supporting the shaft 7 in the axial direction in a contactless manner is provided at a lower end of the shaft 7.

[0051] The stator portion is formed at an inner circumferential side of the housing. The stator portion is constituted by a plurality of fixed blades 50 provided at the inlet port 4 side (turbomolecular pump portion) and a groove spacer 60 provided on an inner circumferential surface of the casing 2.

[0052] Each fixed blade 50 is constituted by a blade that extends from the inner circumferential surface of the housing toward the shaft 7 and is inclined at a predetermined angle to a plane perpendicular to the axial line of the shaft 7.

[0053] The fixed blades 50 of different stages are separated from each other by the spacer 70 having a cylindrical shape.

[0054] In the turbomolecular pump portion, the fixed blades 50 and rotating blades 8a are disposed alternately in a plurality of stages in the axial direction.

[0055] In the spiral groove spacer 60, a spiral groove is formed at a surface facing the cylindrical rotating portion 9.

[0056] The spiral groove spacer 60 faces an outer circumferential surface of the cylindrical rotating portion 9, with a predetermined clearance being left therebetween. Where the cylindrical rotating portion 9 rotates at a high speed, the gas compressed in the turbomolecular pump 1 is fed, while being guided by the groove (spiral groove), to the outlet port 6 side following the rotation of the cylindrical rotating portion 9. Thus, the spiral groove serves as a flow channel for transferring the gas. The spiral groove spacer 60 and the cylindrical rotating portion 9 face each other, with a predetermined clearance being left therebetween, thereby constituting a gas transfer mechanism transferring the gas in the spiral groove.

[0057] It is preferred that the clearance should be as small as possible to reduce a force causing the gas to flow back to the inlet port 4 side.

[0058] A direction of the spiral groove formed in the spiral groove spacer 60 is such that where the gas is transferred in a rotation direction of the rotor 8 inside the spiral groove, this direction is toward the outlet port 6.

[0059] A depth of the spiral groove decreases as the outlet port 6 is approached, and the gas transferred in the spiral groove is compressed as the outlet port 6 is approached. Thus, after the gas sucked in from the inlet port 4 has been compressed in the turbomolecular pump portion, the gas is further compressed in the spiral-groove pump portion and discharged from the outlet port 6.

[0060] When the turbomolecular pump 1 that is configured in the above-described manner and has provided therein the cylindrical rotating portion 9 manufactured using FRP is used in the semiconductor fabrication process including a large number of steps in which a semiconductor substrate is treated with a variety of process gases such as a halogen gas, a fluorine gas, a chlorine gas, or a bromine gas, the locations that come into contact with the gas (constituent parts) are subjected to anticorrosive surface treatment such as electroless nickel plating to prevent corrosion induced by the gases.

[0061] The turbomolecular pump 1 of the first embodiment of the present invention that has the above-described configuration has a load variation relaxation structure at a boundary portion (joined section) of the rotor 8 and the cylindrical rotating portion 9.

[0062] FIG. 2 is an enlarged view of portion A (joined section) in FIG. 1 which is a schematic view of the load variation relaxation structure according to the first embodiment of the present invention.

[0063] As shown by a segment $\alpha\beta$ in FIG. 2, the turbomolecular pump 1 of the first embodiment of the present invention has a gradual taper (segment $\alpha\beta$) as the load variation relaxation structure in a boundary portion where the rotor 8 and the cylindrical portion 9 are joined together. This taper can be formed by forming an outer diameter of the rotor 8 such that degreases gradually from an end surface side of the cylindrical rotating portion 9 toward a center thereof.

[0064] An angle represented by $\theta 1$ in FIG. 2 indicates a deformation angle (diameter reduction angle) of the cylindrical rotating portion 9 deformed by thermal expansion of the rotor 8 when the taper serving as the load variation relaxation structure is not provided (FIG. 9).

[0065] An angle represented by $\theta 2$ in FIG. 2 indicates a taper angle of the taper provided as the load variation relaxation structure.

[0066] A width represented by t in FIG. 2 indicates a taper length of the taper as the load variation relaxation structure according to the first embodiment of the present invention, that is, a projection length of the segment $\alpha\beta$.

[0067] A width represented by t0 in FIG. 2 indicates an interference width of the cylindrical rotation portion 9 and the rotor 8. In other words, this width is a difference between the outer diameter of the rotor 8, which is a part provided on the inner side, and an inner diameter of the cylindrical rotating portion 9, which is a part provided on the outer side.

[0068] Typically, when a part is to be inserted, a taper having a taper angle of about 15 degrees to 30 degrees is provided at a portion to be inserted in order to facilitate the insertion.

[0069] However, since the deformation angle $\theta 1$ of the cylindrical rotating portion 9 observed when the rotor 8 rotates at a high speed and undergoes thermal deformation is an angle (generally, several degrees) much smaller than the taper angle (15 degrees to 30 degrees), the usually provided taper angle, such as described hereinabove, fails to check load variations caused by thermal expansion.

[0070] Accordingly, the taper angle θ2 relating to the load variation relaxation structure of the first embodiment, is set to be much smaller than the deformation angle of a material, that is, the FRP forming the cylindrical rotating portion 9.

[0071] In other words, as shown in FIG. 2, in the first embodiment, a configuration is used in which the rotor 8 is provided with a taper having the taper angle θ2 which is smaller than the deformation angle θ1 of the cylindrical rotating portion 9. With such a configuration, the taper functions as a relaxation structure that relaxes the load, so that the shape of the cylindrical rotating portion 9 deformed smoothly.

[0072] Further, in the first embodiment, the taper angle θ2 is set, for example, to a value equal to or less than 5 degrees. However, taking into account that the angle θ1 varies depending on the thickness of the cylindrical rotating portion 9, material constituting the cylindrical rotating portion 9, content of fibers in the material, and winding angle of the fibers contained in the material, it is desirable that the taper angle θ2 be changed as appropriate.

[0073] With the above-described configuration, in the turbomolecular pump 1 having the load variation relaxation structure according to the first embodiment of the present invention, the deformation of the cylindrical rotating portion 9 is made smooth by the taper serving as the load variation relaxation structure. Therefore, rapid load variations caused by thermal stresses at the boundary of the rotor 8 and the cylindrical rotating portion 9 can be relaxed. As a result, damage such as cracking of the anticorrosive coating which is caused by failure to relax the rapid load variations can be prevented.

[0074] Further, the load variation relaxation structure according to the first embodiment of the present invention is configured such that the taper length t (projection length of the segment αβ) of the taper provided at the rotor 8 is sufficiently large. More specifically, the taper (segment αβ) is extended to a position where the rotor 8 and the cylindrical rotating portion 9 do not have a contact surface in common and a gap 90 is formed between the rotor 8 and the cylindrical rotating portion 9 by an outer surface of the rotor 8 and an inner surface of the cylindrical rotating portion 9.

[0075] The length (taper length t : segment αβ) necessary for the taper becomes larger when the rotor 8 provided in the inner side undergoes thermal expansion at a high temperature and a force causing outward expansion increases. Accordingly, when the aforementioned taper length t is determined, it is desirable that the taper length t be determined under the condition of increasing interference width t0, that is, a portion where the rotor 8 and the cylindrical rotating portion 9 have a contact surface in common, in other words, under the condition of the temperature rising to a maximum.

[0076] With the above-described configuration, in the turbomolecular pump 1 having the load variation relaxation structure according to the first embodiment of the present invention, the deformation of the cylindrical rotating portion 9 is made smooth by the taper serving as the load variation relaxation structure. Therefore, rapid load variations caused by thermal stresses at the boundary of the rotor 8 and the cylindrical rotating portion 9 can be relaxed. As a result, damage such as cracking of the anticorrosive coating which is caused by failure to relax the rapid load variations can be prevented.

[0077] The turbomolecular pump 1 having the load variation relaxation structure according to the first embodiment of the present invention can be also used as a means for preventing the deformation when intensive deformations are also caused by a centrifugal force in addition to thermal expansion.

[0078] The boundary portion (contact portion) of the rotor 8 and the cylindrical rotating portion 9 should not necessarily be in a taper (linear) form. In other words, since it is desirable that a portion (portion where straight lines intersect) where the taper starts in the rotor 8 be rounded rather than angular, the boundary portion for buffering the load may be provided with a smooth curve.

[0079] Accordingly, the following variation examples can be considered for the load variation relaxation structure according to the first embodiment of the present invention.

(iii) variation example 1

[0080] FIG. 3 illustrates a load variation relaxation structure according to variation example 1 of the first embodiment of the present invention.

[0081] In FIG. 3, the rotor 81 according to variation example 1 of the first embodiment of the present invention is arranged side by side with a rotor 80 of a conventional shape selected for comparison with the rotor 81. A two-dot-dash line on the rotor 81 indicates the end position of the conventional rotor 80.

[0082] As shown in FIG. 3, the rotor 81 relating to the load variation relaxation structure of variation example 1 has a curved section (curve αγ) and a taper section (segment γβ) in a contact portion with the cylindrical rotating portion 9.

[0083] Where the boundary portion of the rotor 81 and the cylindrical rotating portion 9 is thus constituted by a gentle curved section and taper section, rapid load variations caused by thermal stresses on the boundary of the rotor 81 and the cylindrical rotating portion 9 can be relaxed more effectively. As a result, the damage such as cracking of the anticorrosive coating that results from the failure to check such rapid load variations can be prevented.

[0084] In variation example 1, a configuration is used in which the joined section of the rotor 80 of the conventional shape is extended to provide the load variation relaxation structure, but the load variation relaxation structure may be also provided without extending the joined section.

(iv) variation example 2

[0085] FIG. 4 illustrates a load variation relaxation structure according to variation example 2 of the first embodiment of the present invention.

[0086] FIG. 4 shows a rotor 82 according to variation example 2 of the first embodiment of the present invention. A two-dot-dash line on the rotor 82 indicates the end position of the conventional rotor 80.

[0087] As shown in FIG. 4, the rotor 82 relating to the load variation relaxation structure of variation example 2 has a corner R (curve $\alpha\beta$) in a contact portion with the cylindrical rotating portion 9.

[0088] Where the boundary portion of the rotor 82 and the cylindrical rotating portion 9 is thus constituted by a gentle curved section, rapid load variations caused by thermal stresses on the boundary of the rotor 82 and the cylindrical rotating portion 9 can be relaxed more effectively. As a result, the damage such as cracking of the anticorrosive coating that results from the failure to check such rapid load variations can be prevented.

[0089] Further, in variation example 2, a configuration is used in which the joined section of the rotor 80 of the conventional shape is extended to provide the load variation relaxation structure, but the load variation relaxation structure may be also provided without extending the joined section.

(v) variation example 3

[0090] FIG. 5 illustrates a load variation relaxation structure according to variation example 3 of the first embodiment of the present invention.

[0091] FIG. 5 shows a rotor 83 according to variation example 3 of the first embodiment of the present invention. A two-dot-dash line on the rotor 83 indicates the end position of the conventional rotor 80.

[0092] As shown in FIG. 5, in the rotor 83 relating to the load variation relaxation structure of variation example 3, the lower section (outlet port 6 side) to which the cylindrical rotating portion 9 is to be joined and which is in contact with the cylindrical rotating portion 9 has a thin-sheet portion 84 that is formed thinner than the rotor on the inlet port 4 side.

[0093] Further, in the rotor 83 according to variation example 3 of the first embodiment of the present invention, a corner R (curve $\alpha\beta$) is provided in the contact portion with the cylindrical rotating portion 9 by bending the aforementioned thin-sheet portion 84 radially inward to obtain a bent thin-sheet portion 85.

[0094] Where the boundary portion of the rotor 83 (bent thin-sheet portion 85) and the cylindrical rotating portion 9 is thus constituted by a gentle curved section, rapid load variations caused by thermal stresses on the boundary of the rotor 83 (bent thin-sheet portion 85) and the cylindrical rotating portion 9 can be relaxed more effectively. As a result, the damage such as cracking of the anticorrosive coating that results from the failure to check such rapid load variations can be prevented.

[0095] Further, in variation example 3, a configuration is used in which the joined section of the rotor 80 of the conventional shape is extended to provide the load variation relaxation structure, but the load variation relaxation structure may be also provided without extending the joined section.

[0096] The above-described variation examples 1 to 3 can be also applied, as shown in the below-described FIGS. 6A to 6C, even in the case in which a rotor 800 and the cylindrical rotating portion 9 are joined in the conventional manner as shown in FIG. 9B.

(vi) variation example 4

[0097] FIG. 6 illustrates a load variation relaxation structure according to variation example 4 of the first embodiment of the present invention.

[0098] FIG. 6A shows a rotor 801 according to variation example 4 of the first embodiment of the present invention. In this rotor, a taper (segment $\alpha\beta$) is present in a contact portion with the cylindrical rotating portion 9.

[0099] FIG. 6B shows a rotor 802 according to variation example 4 of the first embodiment of the present invention. In this rotor, a curved section (curve $\alpha\gamma$) and a taper section (segment $\gamma\beta$) are present in a contact portion with the cylindrical rotating portion 9.

[0100] FIG. 6C shows a rotor 803 according to variation example 4 of the first embodiment of the present invention. In this rotor, a corner R (curve $\alpha\beta$) is present in a contact portion with the cylindrical rotating portion 9.

[0101] With the configurations shown in FIGS. 6A to 6C, rapid load variations caused by thermal stresses on the boundaries of the rotors 801, 802, and 803 relating to the load variation relaxation structures of variation example 4 and the cylindrical rotating portion 9 can be relaxed more effectively. As a result, the damage such as cracking of the anticorrosive coating that results from the failure to check such rapid load variations can be prevented.

(vii) Second Embodiment

[0102] FIG. 7 illustrates a load variation relaxation structure according to the second embodiment of the present invention.

[0103] FIG. 7A shows a rotor 8001 according to the second embodiment of the present invention. This rotor has a taper also on the upper section of the contact portion with the cylindrical rotating portion 9.

[0104] For reference, a conventional rotor 8000 is shown in FIG. 7B.

[0105] As shown in FIG. 7A, in the second embodiment, the load variation relaxation structure is also provided on the upper section of the contact portion. The taper angle thereof is much less than the deformation angle of the material, that is, the FRP constituting the cylindrical rotating portion 9. In the second embodiment, the rotor 8001 is provided with the taper having an angle less than the deformation angle of the cylindrical rotating portion 9. With such a configuration, the taper functions as a relaxation structure relaxing a load, so that the cylindrical rotating portion 9 is gently deformed.

[0106] In the second embodiment, this taper angle is, for example, equal to or less than 5 degrees. However, it is desirable that the taper angle be changed, as appropriate, according to the thickness of the cylindrical rotating portion 9, material constituting the cylindrical rotating portion 9, content of fibers in the material, and winding angle of the fibers contained in the material.

[0107] With the above-described configuration, in the turbomolecular pump 1 having the load variation relaxation structure according to the second embodiment of the present invention, the deformation of the cylindrical rotating portion 9 is made smooth by the taper on the upper side in the contact direction, which serves as the load variation relaxation structure. Therefore, rapid load variations caused by thermal stresses at the boundary of the rotor 8001 and the cylindrical rotating portion 9 can be relaxed. As a result, damage such as cracking of the anticorrosive coating which is caused by failure to relax the rapid load variations can be prevented.

[0108] Further, the turbomolecular pump 1 having the load variation relaxation structure according to the second embodiment of the present invention can be also used as a means for preventing the deformation when intensive deformations are also caused by a centrifugal force in addition to thermal expansion.

[0109] The boundary portion (contact portion) of the rotor 8001 and the cylindrical rotating portion 9 should not necessarily be in a taper (linear) form. In other words, since it is desirable that a portion (portion where straight lines intersect) where the taper starts in the rotor 8001 be rounded rather than angular, the boundary portion for buffering the load may be provided with a smooth curve. A configuration may be used in which the taper or rounded smooth curve is provided only on the upper side.

[0110] The load variation relaxation structure according to the second embodiment of the present invention may be combined with the embodiments and variation examples of the load variation relaxation structure on the lower side that is described in the first embodiment.

(viii) Third Embodiment

[0111] The above-described first embodiment and variation examples 1 to 4 thereof and the second embodiment are explained with reference to the so-called composite turbomolecular pump 1, which includes a turbomolecular pump portion and a spiral-groove pump portion, as an example of a vacuum pump, but such a configuration is not limiting, and the present invention can be also applied to a spiral-groove pump which does not have a turbomolecular pump portion.

[0112] FIG. 8 is a schematic configuration diagram of a spiral-groove pump 100 according to the third embodiment of the present invention. The explanation of features same as those in the above-described first embodiment and second embodiment of the present invention is omitted.

[0113] In the spiral-groove pump 100 according to the third embodiment of the present invention that is shown in FIG. 8, the load variation relaxation structure explained in the first embodiment and second embodiment is also formed in the boundary portion (portion A) of the rotor 8 and the cylindrical rotating portion 9. Furthermore, the above-described variation examples can be also used.

[0114] In the embodiments and variation examples of the present invention, the rotor 8 is made from an aluminum alloy, and the cylindrical rotating portion 9 is a cylindrical body formed from a FRP, but such selection of materials is not limiting, and any two materials for which large thermal stresses are generated by the difference in thermal expansion at a high temperature can be used. For example, the above-described embodiments and variation examples are also applicable to a configuration in which the rotor 8 is made from an aluminum alloy, and the cylindrical rotating portion 9 is a cylindrical body formed from a titanium alloy or a precipitation-hardened stainless steel.

[0115] The vacuum pumps according to the above-described embodiments and variation examples of the present invention are explained under an assumption that the inner diameter of the cylindrical body prior to joining is substantially constant, but when the inner diameter of the cylindrical body changes in the axial direction, for example, when the inner diameter decreases gradually toward the end surface side that is joined to the rotor, the taper angle may be determined according thereto.

[0116] Thus, in the vacuum pumps according to the embodiments and variation examples of the present invention, the deformation of the cylindrical rotating portion 9 is made gentle by the taper serving as the load variation relaxation structure, and rapid load variations at the boundary of the rotor 8 and the cylindrical rotating portion 9 can be relaxed.

[0117] In other words, with the above-described configurations of the embodiments and variation examples of the present invention, a rotating body can be configured by providing the cylindrical rotating portion 9 of a lighter, different material (FRP or the like) at the rotor 8 from an aluminum alloy. Therefore, it is possible to provide a vacuum pump with rotation performance and discharge performance improved over those in the related art.

[0118] Further, with the above-described configurations of the embodiments and variation examples of the present invention, the function of relaxing load variations in the boundary portion of the rotor 8 and the cylindrical rotating portion 9 is improved, thereby making it possible to provide the rotor 8 in which the anticorrosive coating can be prevented from damage caused by rapid variations in the load. As a result, by providing the rotor 8, it is possible to provide a vacuum pump in which corrosion resistance is improved and, therefore, reliability and durability are improved over those in the conventional vacuum pump.

[0119]

1	turbomolecular pump
2	casing
3	base
4	inlet port
5	flange portion
6	outlet port
7	shaft
8	rotor
8a	rotating blade
9	cylindrical rotating portion
10	stator column
20	motor portion
30, 31	radial magnetic bearing devices
40	axial magnetic bearing device
50	fixed blade
60	spiral groove spacer
70	spacer
80	rotor (conventional)
81	rotor
82	rotor
83	rotor
84	thin-sheet portion
85	bent thin-sheet portion
90	gap
100	spiral-groove pump
800	rotor (conventional)
801	rotor
802	rotor
803	rotor
8000	rotor (conventional)
8001	rotor

Claims

1. A rotor provided in a vacuum pump and joined to a cylindrical body formed from a different material, wherein
a load variation relaxation structure is provided at a surface that is in contact with the cylindrical body.

2. The rotor according to claim 1, wherein the load variation relaxation structure is a gradual taper structure formed at an outer diametrical surface of the rotor such that an outer diameter of the rotor decreases gradually from an end surface side where the cylindrical body is joined to the rotor toward a center of the cylindrical body.

3. The rotor according to claim 1 or 2, wherein the load variation relaxation structure is a gradual taper structure formed at an outer diametrical surface of the rotor such that an outer diameter of the rotor decreases gradually from a center of the cylindrical body toward an end surface side where the cylindrical body is joined to the rotor.

4. The rotor according to claim 2, wherein a taper angle of the taper structure is less than an angle at which the cylindrical body gradually reduces in diameter from the end surface side that is joined to the rotor toward the center of the cylindrical body.

5. The rotor according to claim 3, wherein a taper angle of the taper structure is less than an angle at which the cylindrical body gradually reduces in diameter from the center of the cylindrical body toward the end surface side that is joined to the rotor.

6. The rotor according to any one of claims 2 to 5, wherein the load variation relaxation structure is configured such that an end point of the taper structure on the end surface side where the cylindrical body is joined to the rotor is formed in a curved shape.

7. The rotor according to any one of claims 2 to 6, wherein the load variation relaxation structure is configured such that the taper structure is extended to

a position where the rotor and the cylindrical body do not have a contact surface in common.

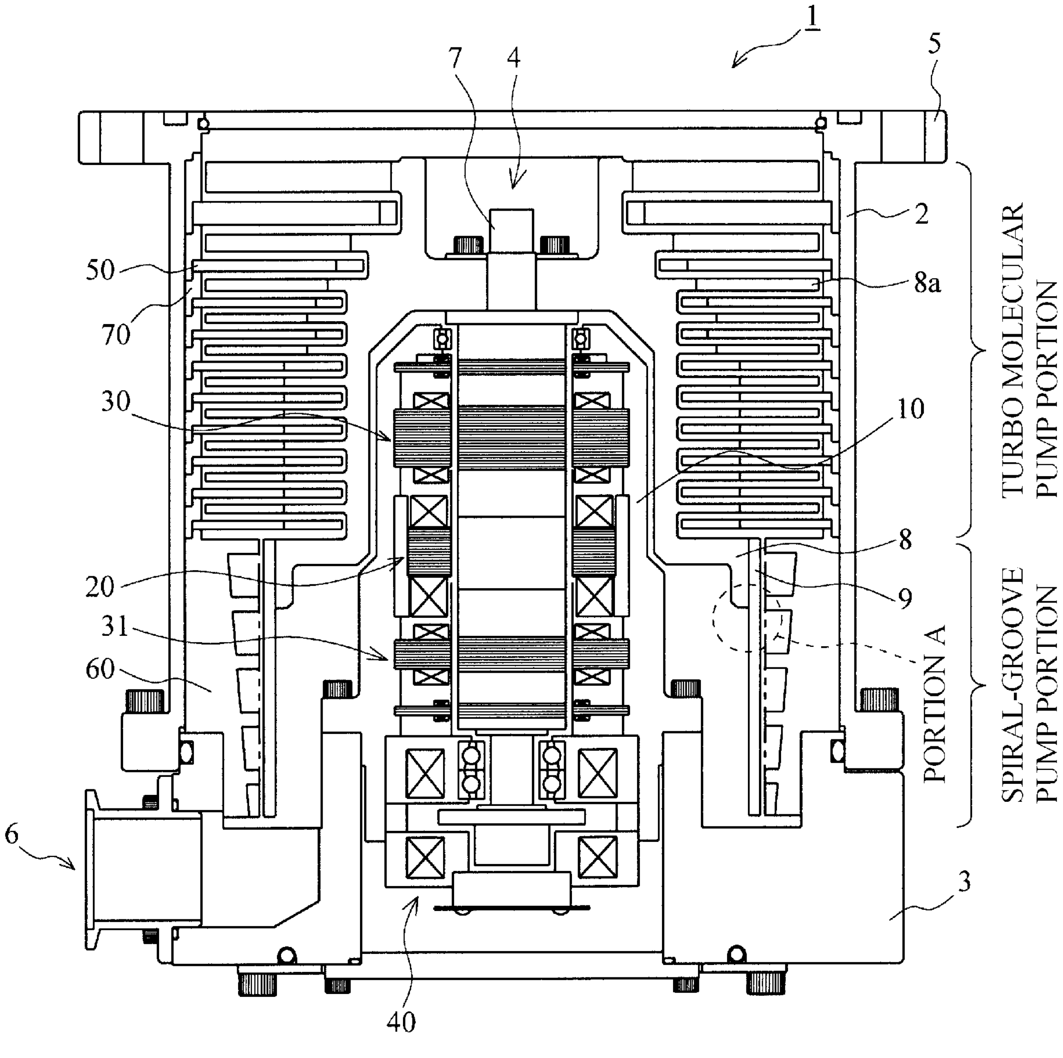
8. The rotor according to claim 1, wherein the load variation relaxation structure is a gradual curved structure formed at an outer diametrical surface of the rotor such that an outer diameter of the rotor decreases gradually from an end surface side where the cylindrical body is joined to the rotor toward a center of the cylindrical body.

9. The rotor according to claim 1 or 8, wherein the load variation relaxation structure is a gradual curved structure formed at an outer diametrical surface of the rotor such that an outer diameter of the rotor decreases gradually from a center of the cylindrical body toward an end surface side where the cylindrical body is joined to the rotor.

10. The rotor according to claim 8 or 9, wherein the load variation relaxation structure is configured such that the curved structure is extended to a position where the rotor and the cylindrical body do not have a contact surface in common.

11. A vacuum pump comprising a spiral-groove pump portion and
a rotor joined to a cylindrical body formed from a different material, wherein
the rotor is the rotor of any one of claims 1 to 10.

Fig.1


1
7
4
5
2
50
8a
70
30
10
8
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9
31
60
6
3
40
TURBO MOLECULAR PUMP PORTION
SPIRAL-GROOVE PUMP PORTION
PORTION A

Fig.2

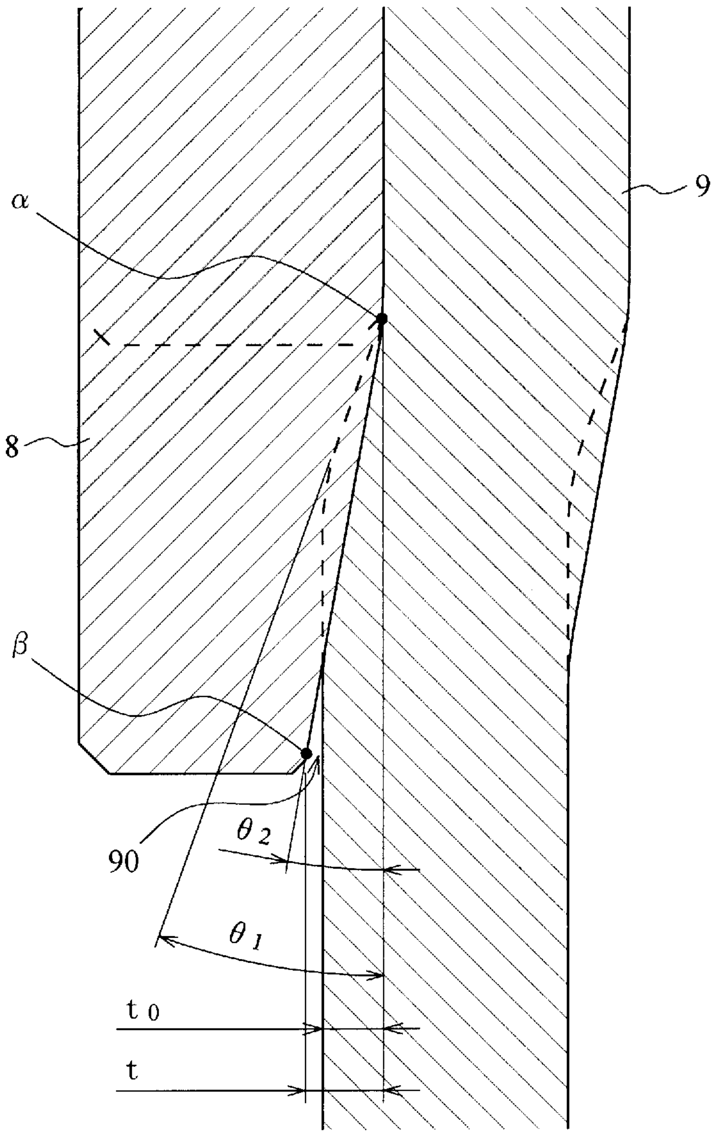


Fig.3

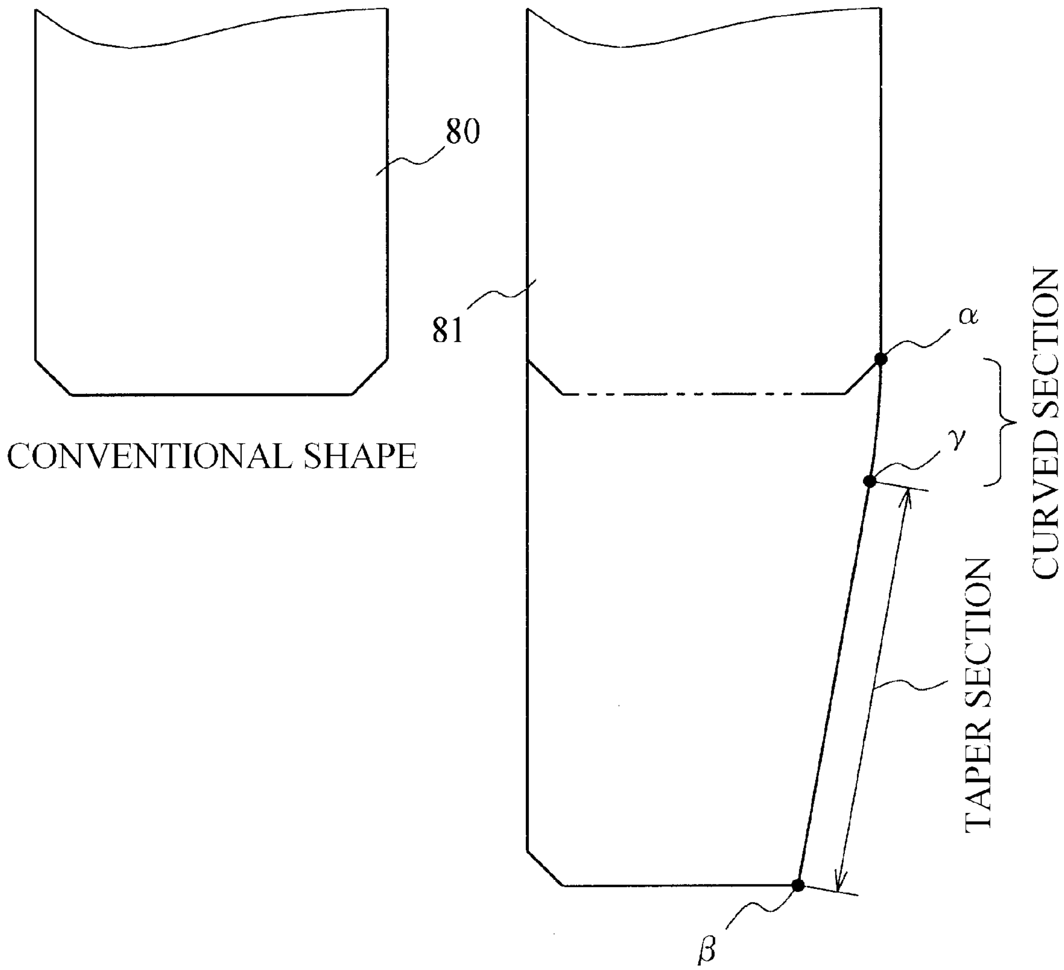


Fig.4

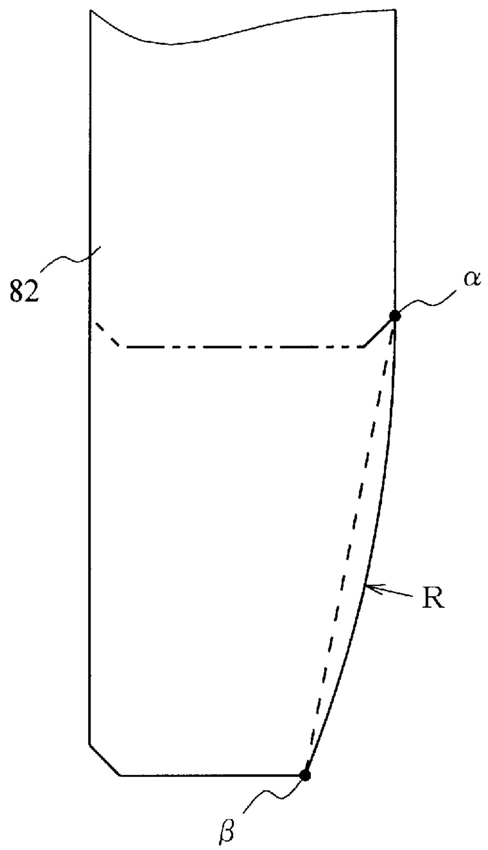


Fig.5

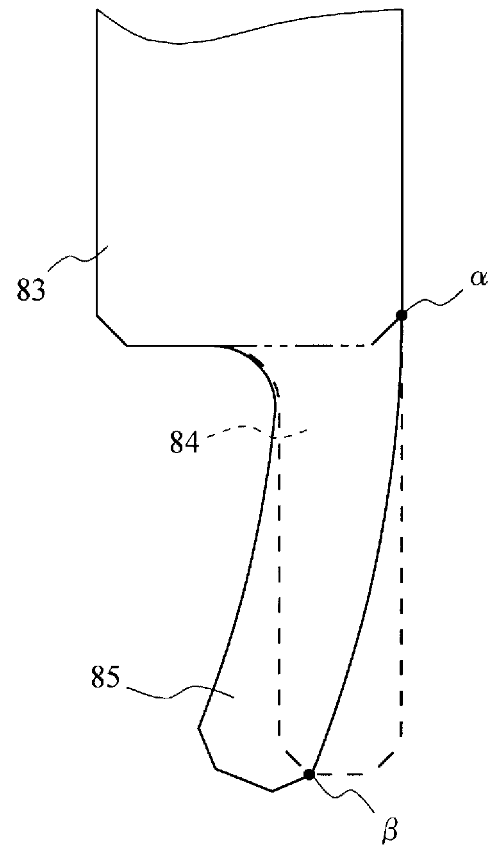


Fig.6

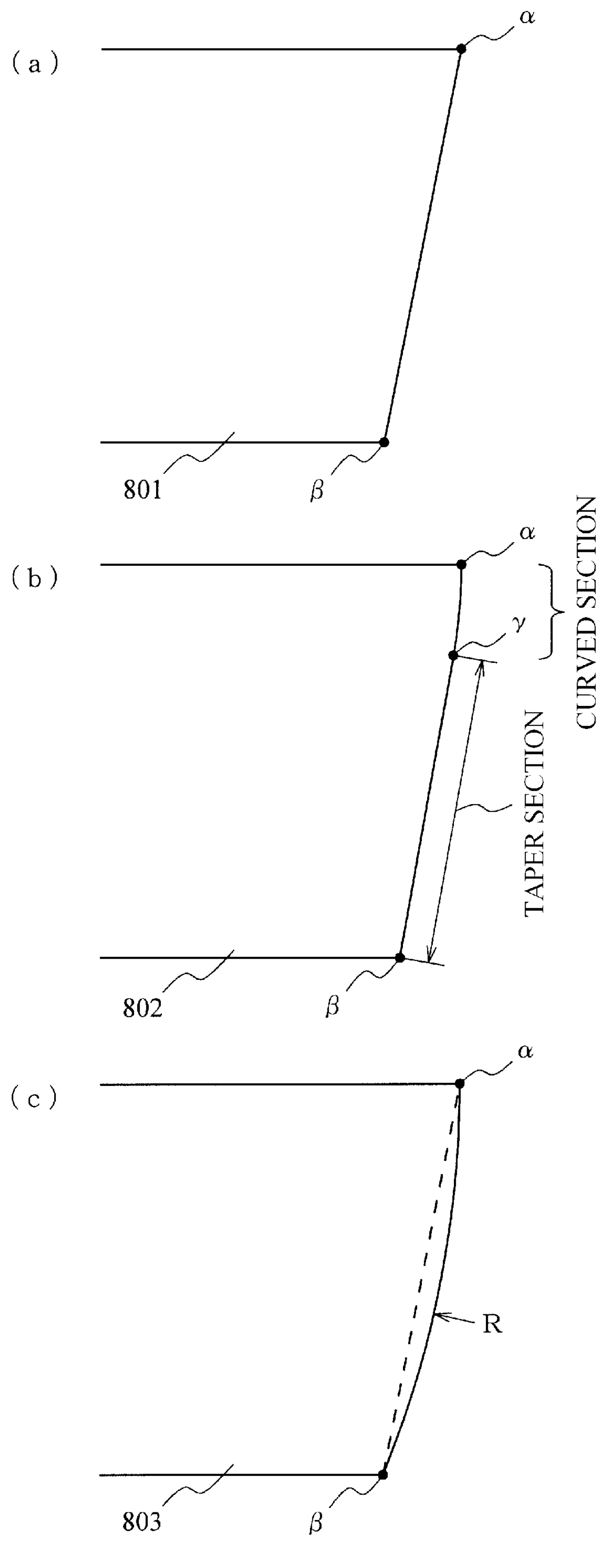


Fig.7

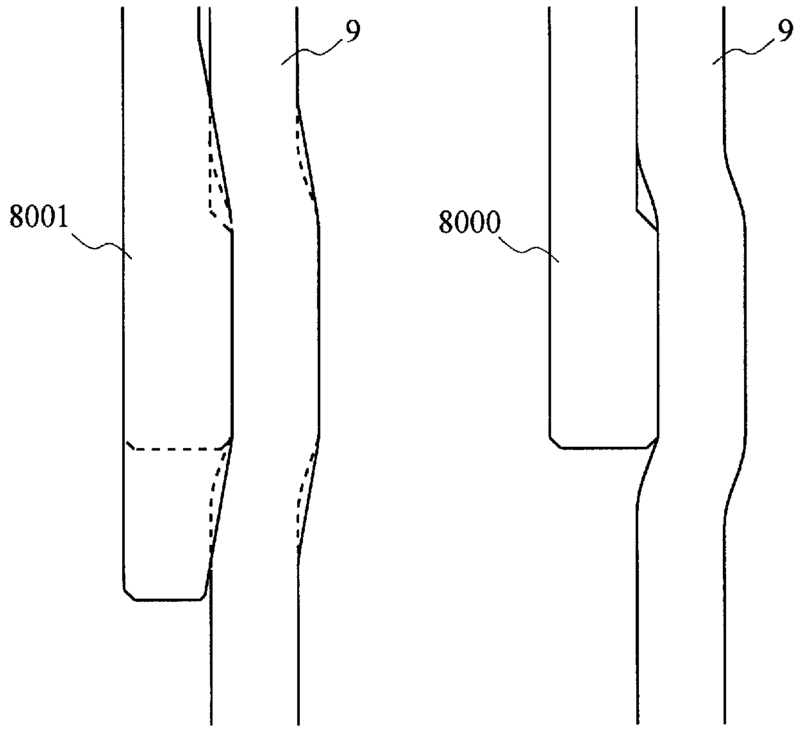


Fig.8

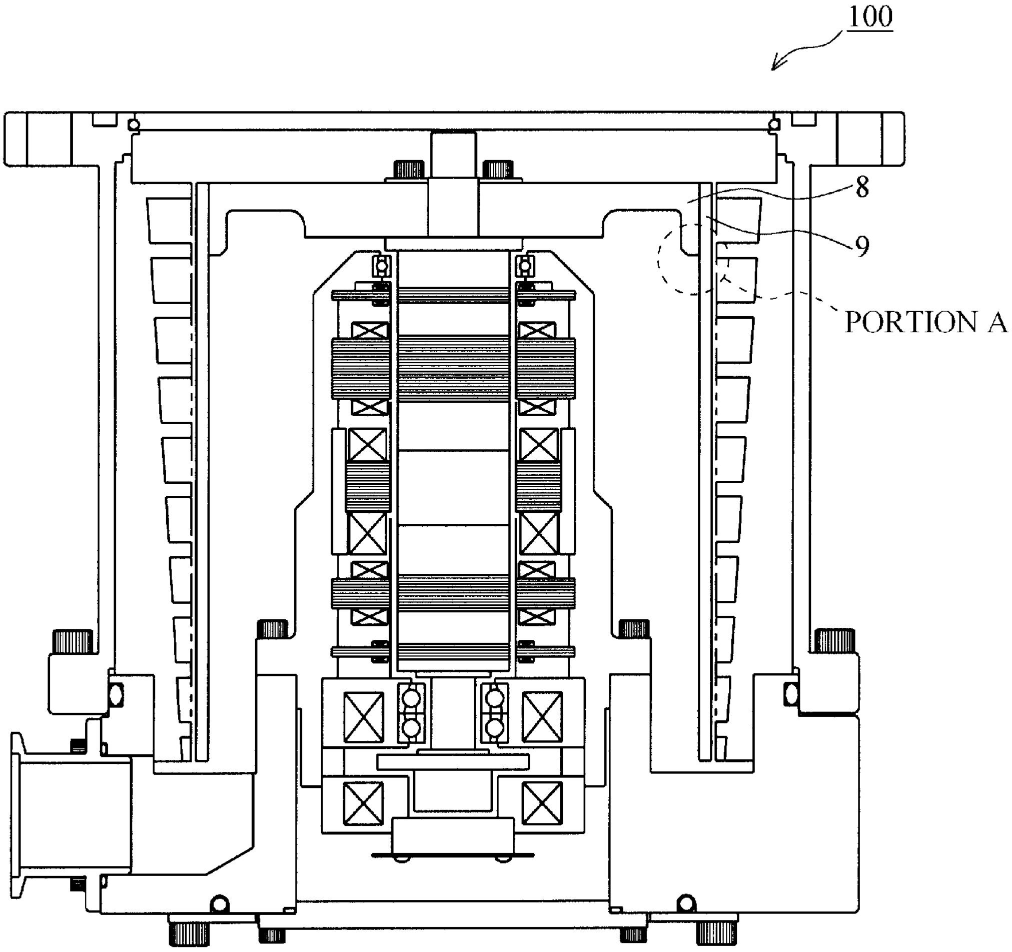
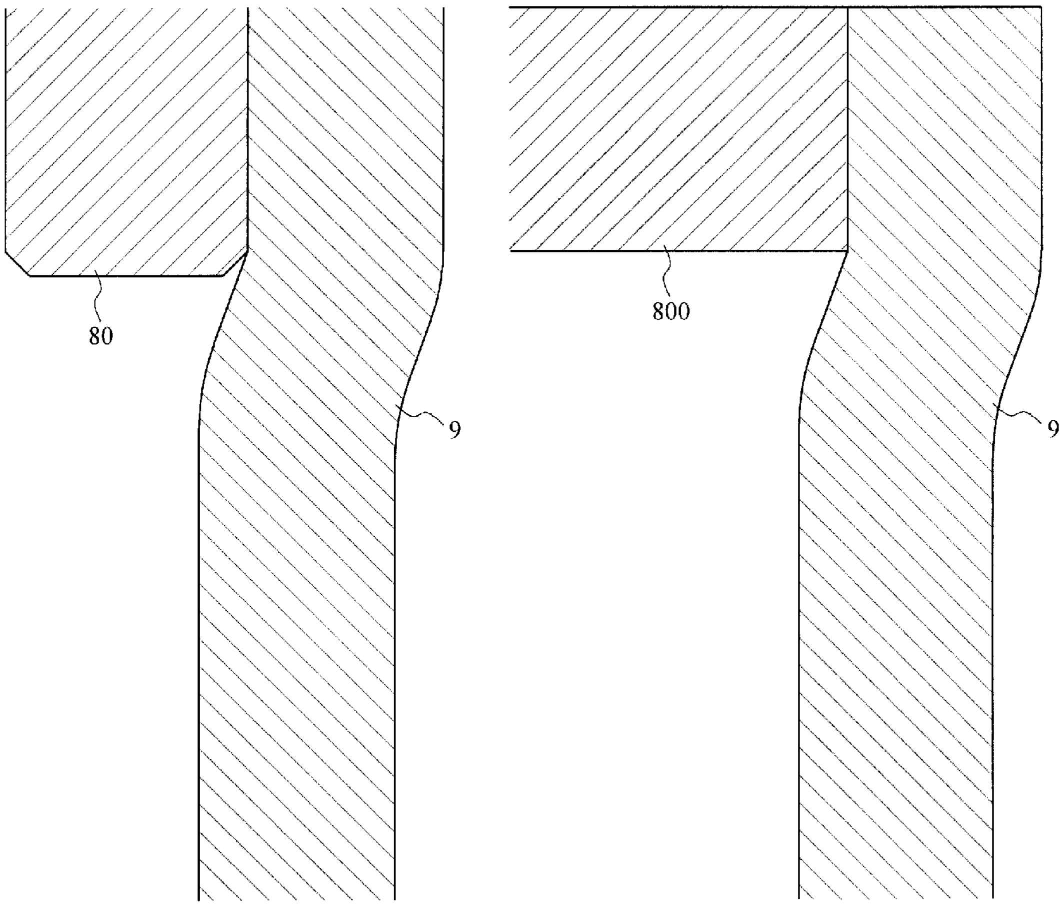


Fig.9

(a)

(b)



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/064125

A. CLASSIFICATION OF SUBJECT MATTER
F04D19/04(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04D19/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2012
Kokai Jitsuyo Shinan Koho	1971-2012	Toroku Jitsuyo Shinan Koho	1994-2012

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 116413/1989(Laid-open No. 056896/1991) (Ebara Corp.), 31 May 1991 (31.05.1991), page 5, line 8 to page 6, line 16; fig. 1 to 3 (Family: none)	1-11

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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Date of the actual completion of the international search 10 August, 2012 (10.08.12)	Date of mailing of the international search report 21 August, 2012 (21.08.12)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2012/064125

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 157851/1986(Laid-open No. 175317/1988) (Mitsubishi Heavy Industries, Ltd.), 14 November 1988 (14.11.1988), page 3, lines 6 to 13; page 6, line 16 to page 7, line 7; fig. 1, 4 (Family: none)	1-11
A	JP 3098139 B2 (Osaka Vacuum Ltd.), 16 October 2000 (16.10.2000), paragraphs [0012] to [0020]; fig. 1 (Family: none)	1-11
A	JP 2007-071139 A (Osaka Vacuum Ltd.), 22 March 2007 (22.03.2007), paragraphs [0013] to [0015]; fig. 1 (Family: none)	1-11

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 3098139 B **[0011] [0012] [0015] [0016]**
- JP 2004278512 A **[0013] [0014] [0015] [0016]**