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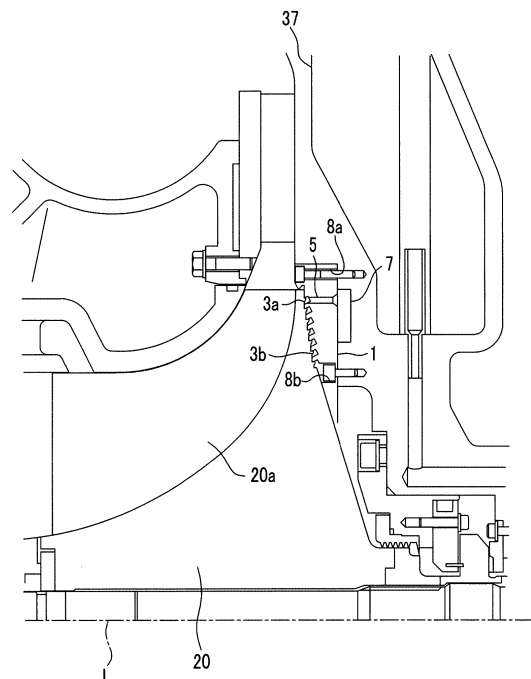
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(54) **CENTRIFUGAL COMPRESSOR, SUPERCHARGER WITH SAME, AND METHOD FOR OPERATING CENTRIFUGAL COMPRESSOR**

(57) This centrifugal compressor is provided with an impeller (20) which rotates about an axis (L) and a labyrinth seal section (1) which seals between a wall section located on the rear surface side of the impeller (20) and the rear surface of the impeller (20). The labyrinth seal (1) has labyrinth grooves which are circumferential grooves centered on the axis (L). A cooling hole through which a cooling medium flows is connected to at least one of the labyrinth grooves.

FIG. 4



Description

Technical Field

[0001] The present invention relates to a centrifugal compressor, a supercharger including the centrifugal compressor, and a method of operating a centrifugal compressor, and more particularly, to the cooling of a centrifugal compressor.

Background Art

[0002] In a centrifugal compressor in the related art, the temperature of air at an outlet of an impeller rises according to a pressure ratio of the centrifugal compressor. For example, even though the centrifugal compressor takes in normal-temperature air, the temperature of air at the outlet of the impeller reaches 200°C or more when a pressure ratio is about 4.5. When this high-temperature air passes through a labyrinth seal sealing between the outlet of the impeller and a space that is formed on the back portion of the impeller, the temperature of the air further rises due to frictional heat that is generated by the rotation of fins of the impeller relative to the labyrinth seal and the back surface of the impeller is heated by the heat. Generally, an aluminum alloy is used as the material of the impeller in a single-stage centrifugal compressor taking in the air. However, since the strength of the aluminum alloy is rapidly reduced as the temperature of an aluminum alloy rises to 250°C or more from 220°C, it is difficult to make a design or an operation that requires a high pressure ratio.

[0003] Further, PTL 1 discloses a technique in which air passages are formed in an intermediate portion of a labyrinth seal and which prevents the temperature rise of an impeller by the supply of cooling air.

[0004] Furthermore, PTL 2 discloses a technique that allows a cooling medium to flow in from the outer peripheral side of an impeller.

Citation List

Patent Literature

[0005]

[PTL 1] Japanese Patent No. 2934530

[PTL 2] Japanese Patent No. 4503726

Summary of Invention

Technical Problem

[0006] However, since the outer peripheral side of the impeller where the temperature of the impeller is highest is still spaced apart from the air passages of the intermediate portion to which the cooling air is supplied even in the technique disclosed in PTL 1, an effect for cooling

the outer peripheral side of the impeller is low. Moreover, the air passages, which are separate from the labyrinth grooves, are provided in the intermediate portion of the labyrinth seal, and the width of air passage is increased so that the flow of air is uniform in the circumferential direction. Accordingly, since the wide air passages are present, the number of labyrinth grooves is reduced. For this reason, the deterioration of sealing performance is caused.

[0007] Meanwhile, since a cooling medium is not directly guided to the outer peripheral side of the impeller where the temperature of the impeller is highest in the technique disclosed in PTL 2, a cooling effect is low.

[0008] The invention has been made in consideration of the above-mentioned circumstances, and an object of the invention is to provide a centrifugal compressor that can lower metal temperature by cooling an impeller while ensuring the sealing performance of a labyrinth seal, a supercharger including the centrifugal compressor, and a method of operating a centrifugal compressor.

Solution to Problem

[0009] In order to solve the above-mentioned problems, a centrifugal compressor of the invention, a supercharger including the centrifugal compressor, and a method of operating a centrifugal compressor employ the following means.

[0010] That is, a centrifugal compressor according to a first aspect of the invention includes an impeller that is rotated about an axis, and a labyrinth seal that seals between a wall section positioned on a back side of the impeller and a back surface of the impeller. The labyrinth seal includes labyrinth grooves that are formed of a plurality of circumferential grooves having a center on the axis, and a cooling hole, which allows a cooling medium to flow, is connected to at least one of the plurality of labyrinth grooves.

[0011] According to the first aspect of the invention, the cooling hole for supplying the cooling medium to the impeller is connected to the labyrinth grooves that are formed of the circumferential grooves. Since the labyrinth grooves are utilized as a space for supplying a cooling medium as described above, it is possible to cool the impeller without reducing the number of the labyrinth grooves. Accordingly, the cooling of the impeller and sealing performance, which is obtained from the labyrinth seal, are compatible with each other.

[0012] Further, since the cooling hole is provided in the labyrinth groove and a cooling medium is supplied to the impeller through the cooling hole, the metal temperature of the impeller can be lowered. Accordingly, it is possible to avoid the reduction of the strength of the material of the impeller that is caused by the rise of the temperature of the impeller.

[0013] Furthermore, in a centrifugal compressor according to the second aspect of the invention, an annular space in which the cooling medium flows is provided on

a back side of the labyrinth seal and a plurality of the cooling holes are formed so as to connect the annular space to the labyrinth grooves while being spaced apart from each other.

[0014] According to the second aspect of the invention, since the annular space in which the cooling medium flows is provided, the cooling medium can become uniform in the circumferential direction.

[0015] Further, since the annular space, which makes the cooling medium uniform in the circumferential direction, is disposed on the back surface of the labyrinth seal and the cooling hole is provided so as to connect the annular space to the labyrinth grooves, the air passages, which cannot be used as the labyrinth grooves, do not need to be formed unlike in PTL 1 and the labyrinth grooves can be directly used for cooling. Accordingly, since the number of the labyrinth grooves does not need to be reduced, the sealing performance of the labyrinth seal can be ensured.

[0016] Furthermore, since the plurality of cooling holes are formed so as to be spaced apart from each other, it is possible to effectively cool the impeller at each point in the circumferential direction.

[0017] Moreover, in a centrifugal compressor according to a third aspect of the invention, the cooling hole is connected to the labyrinth groove, which is positioned on an outermost peripheral portion, among the plurality of labyrinth grooves having a center on the axis.

[0018] According to the third aspect of the invention, since the cooling hole is connected to the labyrinth groove positioned on the outermost peripheral portion, it is possible to directly send a cooling medium to a portion where metal temperature is highest.

[0019] Further, a method of operating a centrifugal compressor according to a fourth aspect of the invention includes a step of rotating an impeller about an axis by a rotation of an exhaust turbine, and a step of allowing a cooling medium to flow in at least one of labyrinth grooves formed of a plurality of circumferential grooves that are provided on a labyrinth seal positioned on a back side of the impeller and have a center on the axis.

[0020] According to the fourth aspect of the invention, since the cooling medium is made to flow to at least one of the plurality of labyrinth grooves of the labyrinth seal, it is possible to operate the centrifugal compressor at a metal temperature, which is lowered through the cooling of an impeller, while ensuring the sealing performance of the labyrinth seal. Accordingly, it is possible to lengthen the life of the impeller.

[0021] Furthermore, in a method of operating a centrifugal compressor according to a fifth aspect of the invention, the step of allowing the cooling medium to flow supplies the cooling medium to the labyrinth groove, which is positioned on an outermost peripheral portion, among the plurality of labyrinth grooves.

[0022] According to the fifth aspect of the invention, since the cooling hole is connected to the labyrinth groove that is positioned on the outermost peripheral portion, it

is possible to directly send the cooling medium to a portion where metal temperature is highest.

[0023] Moreover, a supercharger according to a sixth aspect of the invention includes any one of the centrifugal compressors and an exhaust turbine that drives the centrifugal compressor.

[0024] According to the sixth aspect of the invention, since the supercharger includes any one of the centrifugal compressors, it is possible to obtain a supercharger that can lower metal temperature by cooling the impeller while ensuring the sealing performance of the labyrinth seal.

Advantageous Effects of Invention

[0025] According to the invention, since a cooling hole, which allows a cooling medium to flow, is connected to at least one of a plurality of labyrinth grooves of a labyrinth seal, it is possible to lower metal temperature by cooling an impeller while ensuring the sealing performance of the labyrinth seal. Accordingly, it is possible to lengthen the life of the impeller.

Brief Description of Drawings

[0026]

Fig. 1 is a longitudinal cross-sectional view of an exhaust turbine supercharger including a labyrinth seal according to an embodiment of the invention.

Fig. 2 shows the labyrinth seal of Fig. 1 in which Fig. 2(a) is a longitudinal cross-sectional view of the labyrinth seal and Fig. 2(b) is a plan view of the labyrinth seal.

Fig. 3 is a side cross-sectional view showing a state in which a cooling hole is connected to a labyrinth groove of the labyrinth seal shown in Fig. 2 positioned on the radially outermost side having a center on an axis.

Fig. 4 is a longitudinal cross-sectional view of main parts around the labyrinth seal shown in Fig. 1.

Fig. 5 is a graph showing a relationship between a cooling air-insertion position and the metal temperature of an impeller while a horizontal axis represents the cooling air-insertion position and a vertical axis represents the impeller metal temperature.

Description of Embodiments

[0027] An embodiment of the invention will be described below with reference to the drawings.

[0028] One embodiment of the invention will be described below with reference to Figs. 1 to 5.

[0029] Fig. 1 is a longitudinal cross-sectional view of an exhaust turbine supercharger (supercharger) 10 according to this embodiment. A gas inlet casing 11, a gas outlet casing 12, a bearing stand 13, and a compressor-side air guide casing 14 are integrally fastened with bolts

(not shown), so that the exhaust turbine supercharger 10 is formed. A rotor shaft 15 is rotatably supported in the bearing stand 13 by a thrust bearing 16 and radial bearings 17 and 18, a turbine (exhaust turbine) 19 forming a turbine unit is fixed to one end portion of the rotor shaft 15, and an impeller 20 forming a compressor unit is fixed to the other end portion thereof.

[0030] The turbine 19 includes a plurality of blades 19a that are provided at an outer peripheral portion thereof. The blades 19a are disposed between an exhaust gas introduction passage 22 that is provided in the gas inlet casing 11 and an exhaust gas discharge passage 23 that is provided in the gas outlet casing 12.

[0031] Meanwhile, the impeller 20 is disposed in the rear of an intake air introduction passage 24 that is provided in the air guide casing 14. The intake air introduction passage 24 is connected to a scroll casing 25 through the impeller 20, and the scroll casing 25 is connected to a combustion chamber of an engine through an intake air introduction passage (not shown).

[0032] Meanwhile, reference numeral 26 denotes a filter that is provided at the front stage of the intake air introduction passage 24 into which air is taken and rectifies intake air by allowing the intake air to pass there-through.

[0033] Further, a lubricating oil supply passage 27 is formed in the bearing stand 13, and a base end portion of the lubricating oil supply passage 27 is connected to an oil pump (not shown) for the engine. Meanwhile, the other end portion of the lubricating oil supply passage 27 is branched into branch passages 28, 29, and 30 that are connected to the thrust bearing 16 and the radial bearings 17 and 18, respectively.

[0034] Furthermore, a labyrinth seal 1, which seals between a wall section positioned on the back side of the impeller 20 and the back surface of the impeller 20, is provided at an end portion of the bearing stand 13 close to the impeller 20. The labyrinth seal 1 prevents the leakage of compressed air by sliding on the impeller 20.

[0035] When the exhaust turbine supercharger 10 having the above-mentioned structure is operated, for example, exhaust gas from a marine diesel engine passes through the exhaust gas introduction passage 22 and the turbine 19 is rotationally driven by an axial exhaust gas flow that has been expanded by a turbine nozzle under static pressure. Further, the exhaust gas having driven the turbine 19 is discharged to the outside through the exhaust gas discharge passage 23.

[0036] The rotation of the turbine 19 rotates the impeller 20 through a turbine rotor shaft 15, and air taken through the intake air introduction passage 24 is pressurized by the impeller 20 and is supplied to the marine diesel engine through a diffuser 33 and an outlet scroll 35.

[0037] Next, the structure of the labyrinth seal 1 will be described in detail.

[0038] As shown in Fig. 2, the labyrinth seal 1 is formed in the shape of a ring that has the axis L as a central axis. For example, SS400 steel is suitably used for the labyrinth seal 1.

rinth seal 1.

[0039] Bolts are inserted into a plurality of outer peripheral bolt holes 8a and a plurality of inner peripheral bolt holes 8b substantially parallel to the axis L, so that the labyrinth seal 1 is fixed to a casing body 37 (see Fig. 1) (Meanwhile, Fig. 4 shows a state in which the labyrinth seal 1 is fixed by bolts). The outer peripheral bolt holes 8a and the inner peripheral bolt holes 8b are provided at substantially regular intervals over the entire circumference of the labyrinth seal 1.

[0040] As enlarged in Fig. 3, a plurality of labyrinth grooves 3 are formed on one end face of the labyrinth seal 1, that is, an end face facing the impeller 20. The labyrinth grooves 3 are a plurality of circumferential grooves that have a center on the axis L. Here, the dimensions (depths and widths) of the respective labyrinth grooves 3 are set to be substantially the same.

[0041] As shown in Fig. 4, an annular space 7 in which a cooling medium flows is formed on the back surface (the right side in Fig. 4) of the labyrinth seal 1. A cooling medium supplied from a main engine is taken into the annular space 7 from the bearing stand 13 that is provided on the side portion of the supercharger. The annular space 7 is formed in an annular shape having the axis L as a central axis, and is formed so as to be opened toward the back surface of the labyrinth seal 1. Here, the longitudinal cross-section of the annular space 7 has a substantially rectangular shape in Fig. 4. In addition, the longitudinal dimension of the annular space 7, that is, the length of the annular space in a direction (a vertical direction in Fig. 4) orthogonal to the axis L, is about a length that covers the plurality of (four in the embodiment shown in Fig. 4) labyrinth grooves 3. Meanwhile, the longitudinal dimension of the annular space 7 is appropriately set according to the amount of air to be required.

[0042] The labyrinth seal 1 is provided with cooling holes 5 formed from an end face (a right end face in Fig. 4) of the labyrinth seal opposite to an end face (hereinafter, referred to as "a front surface".) thereof, on which the labyrinth grooves 3 are formed, toward the front surface. The cooling holes 5 extend substantially parallel to the axis L, and connect the outermost peripheral groove 3a to the annular space 7 facing the back surface. Here, the diameter of the cooling hole 5 is smaller than the diameter of the outermost peripheral groove 3a. Meanwhile, since taper machining, which allows the diameter of the cooling hole to increase toward the annular space 7, is performed on the back side of the cooling hole 5 as shown in Fig. 3, the cooling hole 5 is formed in a shape that allows the flow of air flowing from the annular space 7 to be smooth.

[0043] As shown in Fig. 2(b), the cooling holes 5 are formed at substantially regular intervals, for example, at twenty-four positions over the entire circumference of the labyrinth seal 1.

[0044] Fig. 5 is a graph showing a relationship between a cooling air-insertion position and the metal temperature of an impeller while a horizontal axis represents the cool-

ing air-insertion position and a vertical axis represents the metal temperature of the impeller (relative comparison). As shown in Fig. 5, metal temperature at the outermost peripheral portion of the impeller is highest, and metal temperature at an intermediate position (between the outermost peripheral portion and the innermost peripheral portion of the impeller 20) is higher than metal temperature near the center (a portion of the impeller 20 near the rotor shaft 15).

[0045] Further, the insertion of cooling air into a first stage (the cooling holes 5 connecting the outermost peripheral groove 3a to the annular space 7) has the greatest cooling effect, and the cooling effect of the insertion of cooling air into a second stage (the cooling holes 5 positioned on the first inner peripheral side of the outermost peripheral groove 3a from the axis L) is greater than the cooling effect of the insertion of cooling air into a third stage (the cooling holes 5 positioned on the second inner peripheral side of the outermost peripheral groove 3a from the axis L).

[0046] Furthermore, it is found that a cooling effect obtained when cooling air is inserted into the cooling hole 5 of the first stage is significantly greater than a cooling effect obtained when cooling air is inserted into the cooling holes 5 of the second and third stages. The reason for this is that, when cooling air is inserted from the second and third stages, the temperature of air taken into the back surface of the impeller from the outer peripheral portion of the impeller becomes high due to friction and the amount of heat is increased in comparison with a case in which cooling air is inserted from the first stage.

[0047] According to this embodiment, the following effects are obtained from the above-mentioned structure.

[0048] Since the annular space 7 in which a cooling medium flows is formed on the back surface of the labyrinth seal 1 and the cooling holes 5 are formed so as to connect the annular space 7 to the outermost peripheral groove 3a, sealing air flows in the annular space 7 in the circumferential direction and becomes uniform. Then, it is possible to supply cooling air to the outermost peripheral groove 3a from the twenty-four cooling holes 5 of the labyrinth seal 1. Accordingly, it is not necessary to reduce the number of the labyrinth grooves 3, and it is possible to lower the metal temperature of the impeller 20, which has risen up to about 230°C, by about 7°C in comparison with a case in which cooling is not performed while ensuring the sealing performance of the labyrinth seal 1.

[0049] Meanwhile, in the description of the above-mentioned embodiment, the cooling holes 5 have been connected to the outermost peripheral groove 3a of the plurality of labyrinth grooves 3. However, the invention is not limited thereto, and for example, the cooling holes 5 may be connected to the labyrinth groove 3 positioned on the inner peripheral side next to the outermost peripheral groove 3a. Further, the number of holes of the labyrinth seal 1 has been 24 in the description of each of the above-mentioned embodiments. However, the inven-

tion is not limited thereto, and the number of holes of the labyrinth seal 1 may be determined in consideration of a cooling effect. For example, the number of holes of the labyrinth seal 1 may be an even number, such as 12 or 36, or an odd number, such as 21.

[0050] Furthermore, SS400 has been described as the material of the labyrinth seal 1 in the description of each of the above-mentioned embodiments. However, the invention is not limited thereto, and the material of the labyrinth seal 1 may be, for example, steel, such as SS490 or SS540.

[0051] Moreover, the cooling holes 5 have been provided substantially parallel to the axis L in the description. However, the invention is not limited thereto, and the cooling holes 5 only have to connect the labyrinth grooves 3 to the annular space 7. For example, the cooling holes 5 may be inclined to the axis L.

[0052] Further, air has been used as the cooling medium in each of the above-mentioned embodiments. However, the invention is not limited thereto, and for example, steam may be used as the cooling medium.

Reference Signs List

[0053]

1:	labyrinth seal
3:	labyrinth groove
3a:	outermost peripheral groove (a labyrinth groove positioned on the radially outermost side having a center on an axis)
5:	cooling hole
7:	annular space
8a:	outer peripheral bolt hole
8b:	inner peripheral bolt hole
10:	exhaust turbine supercharger
11:	gas inlet casing
12:	gas outlet casing
13:	bearing stand
14:	compressor-side air guide casing
15:	rotor shaft
16:	thrust bearing
17, 18:	radial bearing
19:	turbine
19a:	blade
20:	impeller
22:	exhaust gas introduction passage
23:	exhaust gas discharge passage
24:	intake air introduction passage
25:	scroll casing
26:	filter
27:	lubricating oil supply passage
28, 29, 30:	branch passage
31:	compressor housing
33:	diffuser
35:	outlet scroll
37:	casing body
L:	axis

Claims

1. A centrifugal compressor comprising:
 - an impeller that is rotated about an axis; and
 - a labyrinth seal that seals between a wall section positioned on a back side of the impeller and a back surface of the impeller, wherein the labyrinth seal includes labyrinth grooves that are formed of a plurality of circumferential grooves having a center on the axis, and
 - a cooling hole, which allows a cooling medium to flow, is connected to at least one of the plurality of labyrinth grooves.
2. The centrifugal compressor according to claim 1, wherein an annular space in which the cooling medium flows is provided on a back side of the labyrinth seal, and a plurality of the cooling holes are formed so as to connect the annular space to the labyrinth grooves while being spaced apart from each other.
3. The centrifugal compressor according to claim 1 or 2, wherein the cooling hole is connected to the labyrinth groove, which is positioned on an outermost peripheral portion, among the plurality of labyrinth grooves having a center on the axis.
4. A supercharger comprising:
 - the centrifugal compressor according to any one of claims 1 to 3; and
 - an exhaust turbine that drives the centrifugal compressor.
5. A method of operating a centrifugal compressor, the method comprising:
 - a step of rotating an impeller about an axis by a rotation of an exhaust turbine; and
 - a step of allowing a cooling medium to flow in at least one of labyrinth grooves formed of a plurality of circumferential grooves that are provided on a labyrinth seal positioned on a back side of the impeller and have a center on the axis.
6. The method of operating a centrifugal compressor according to claim 5, wherein the step of allowing the cooling medium to flow supplies the cooling medium to the labyrinth groove, which is positioned on an outermost peripheral portion, among the plurality of labyrinth grooves.

Amended claims under Art. 19.1 PCT

1. (Amended)
A centrifugal compressor comprising:
 - an impeller that is rotated about an axis; and
 - a labyrinth seal that is provided between a wall section positioned on a back side of the impeller and a back surface of the impeller and seals air taken into the back surface of the impeller from an outer peripheral portion of the impeller, wherein the labyrinth seal includes labyrinth grooves that are formed of a plurality of circumferential grooves having a center on the axis, and
 - a cooling hole, which allows a cooling medium to flow, is connected to the labyrinth groove that is positioned on an outermost peripheral portion among the plurality of labyrinth grooves.
2. The centrifugal compressor according to claim 1, wherein an annular space in which the cooling medium flows is provided on a back side of the labyrinth seal, and a plurality of the cooling holes are formed so as to connect the annular space to the labyrinth grooves while being spaced apart from each other.
3. Deleted)
4. (Amended)
A supercharger comprising:
 - the centrifugal compressor according to claim 1 or 2; and
 - an exhaust turbine that drives the centrifugal compressor.
5. (Amended)
A method of operating a centrifugal compressor, the method comprising:
 - a step of rotating an impeller about an axis by a rotation of an exhaust turbine; and
 - a step of allowing a cooling medium to flow in a labyrinth groove, which is positioned on an outermost peripheral portion, among labyrinth grooves formed of a plurality of circumferential grooves that are provided on a labyrinth seal positioned on a back side of the impeller and sealing air taken into the back surface of the impeller from an outer peripheral portion of the impeller and have a center on the axis.
6. (Amended)
The method of operating a centrifugal compressor according to claim 5, wherein the step of allowing the cooling medium to

flow supplies the cooling medium to the labyrinth groove, which is positioned on an outermost peripheral portion, among the plurality of labyrinth grooves.

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FIG. 1

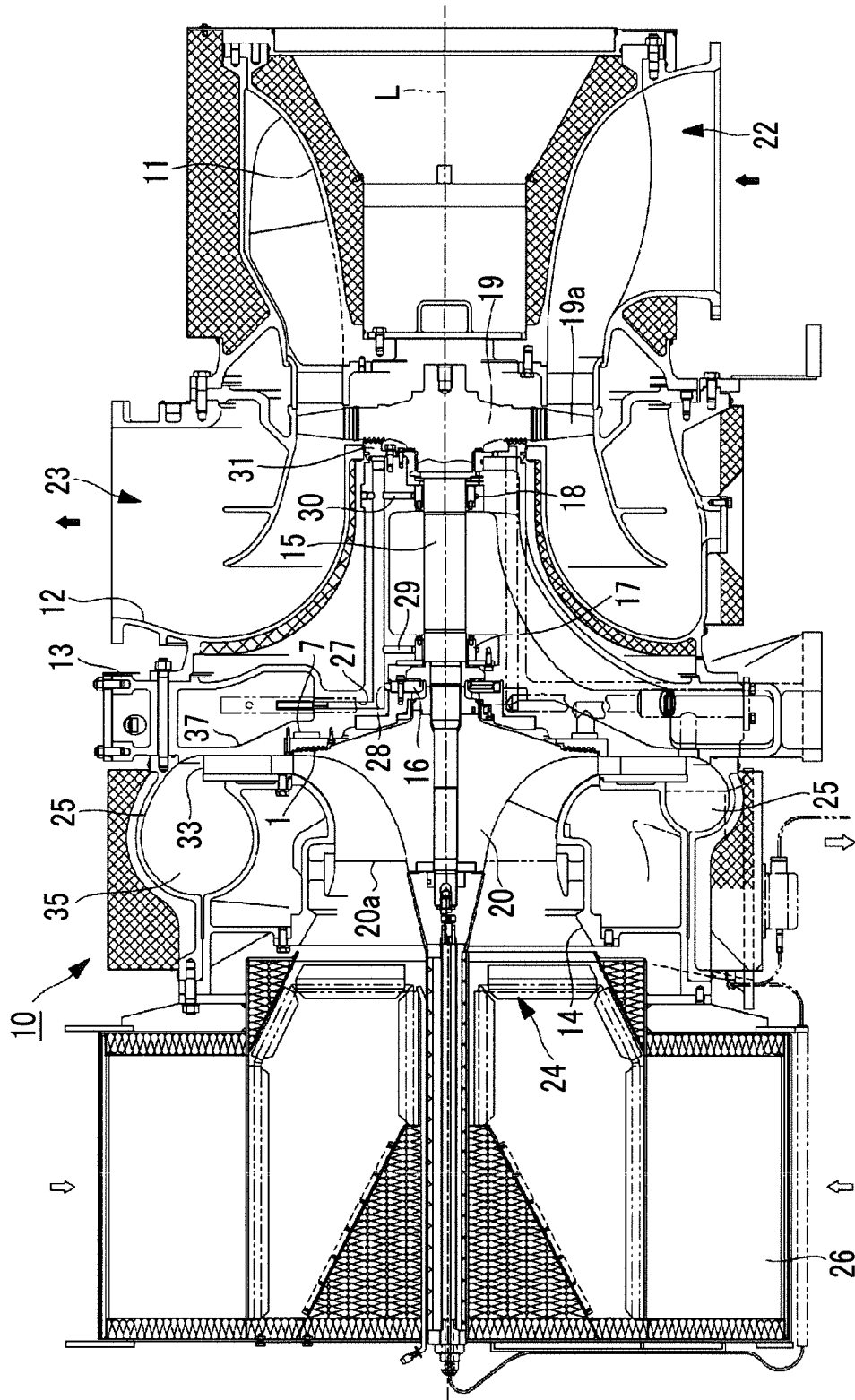


FIG. 2

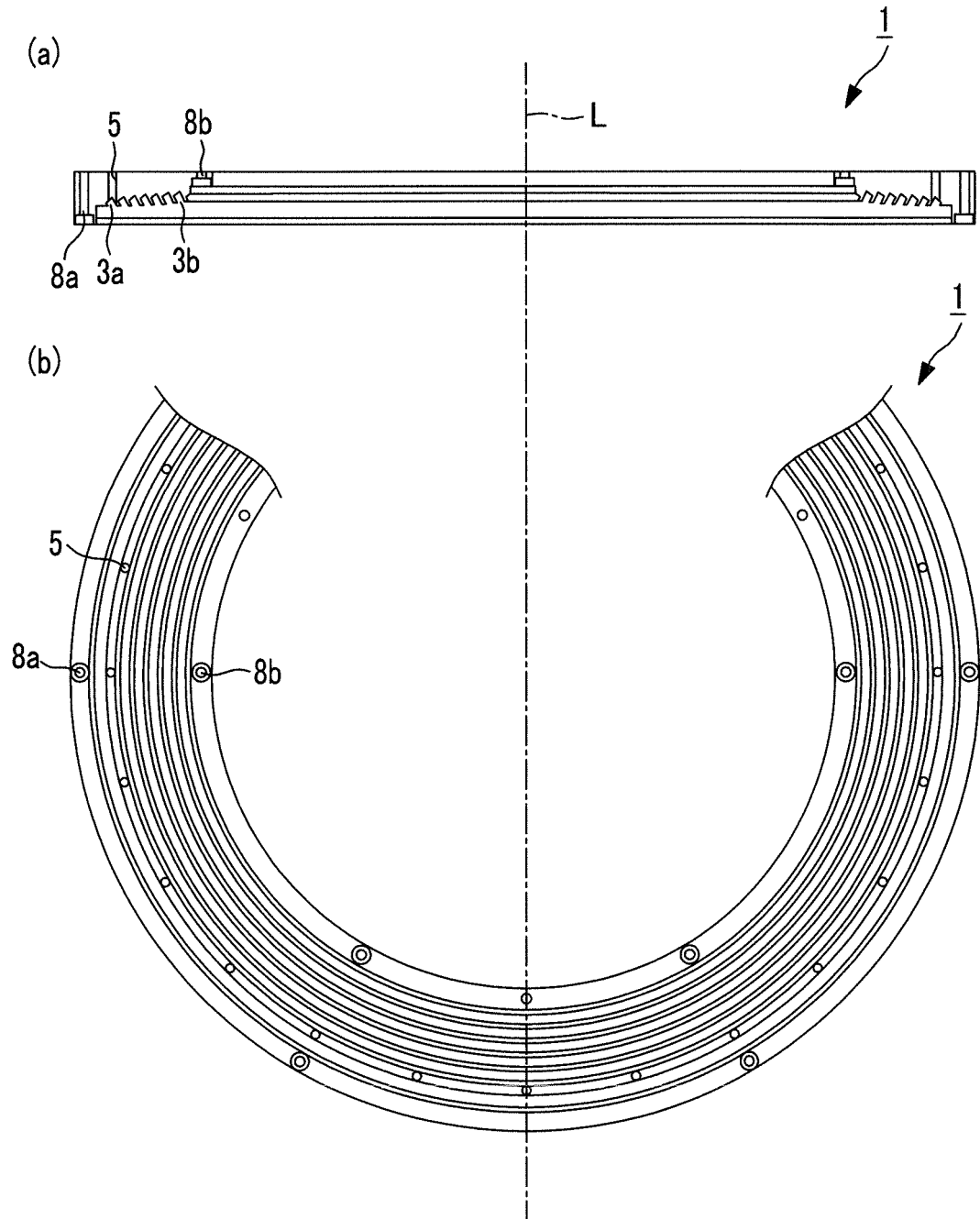


FIG. 3

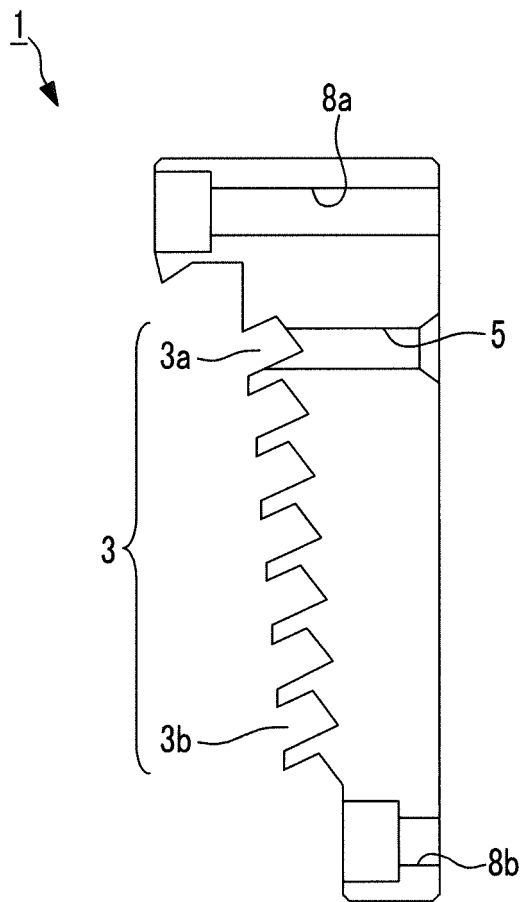


FIG. 4

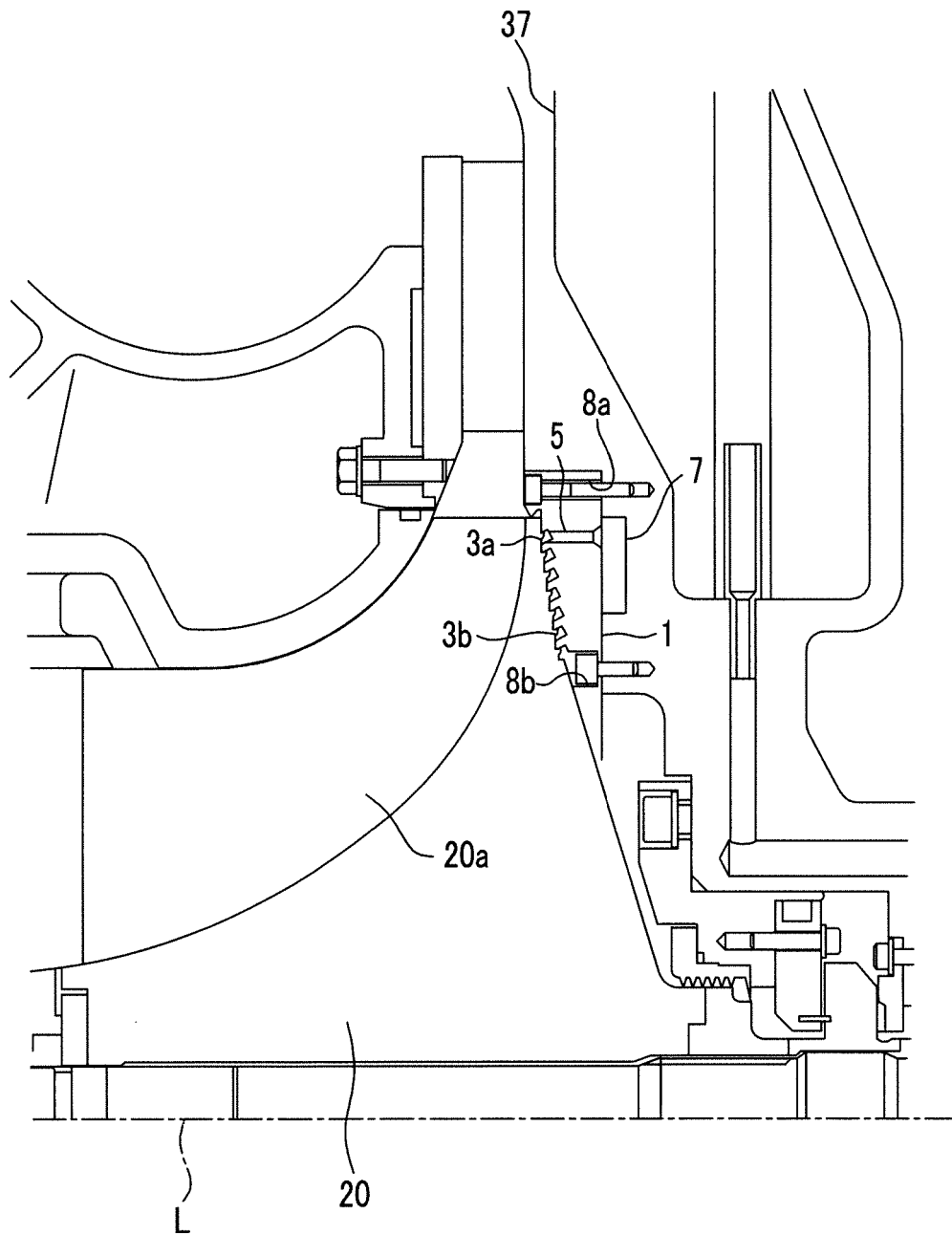
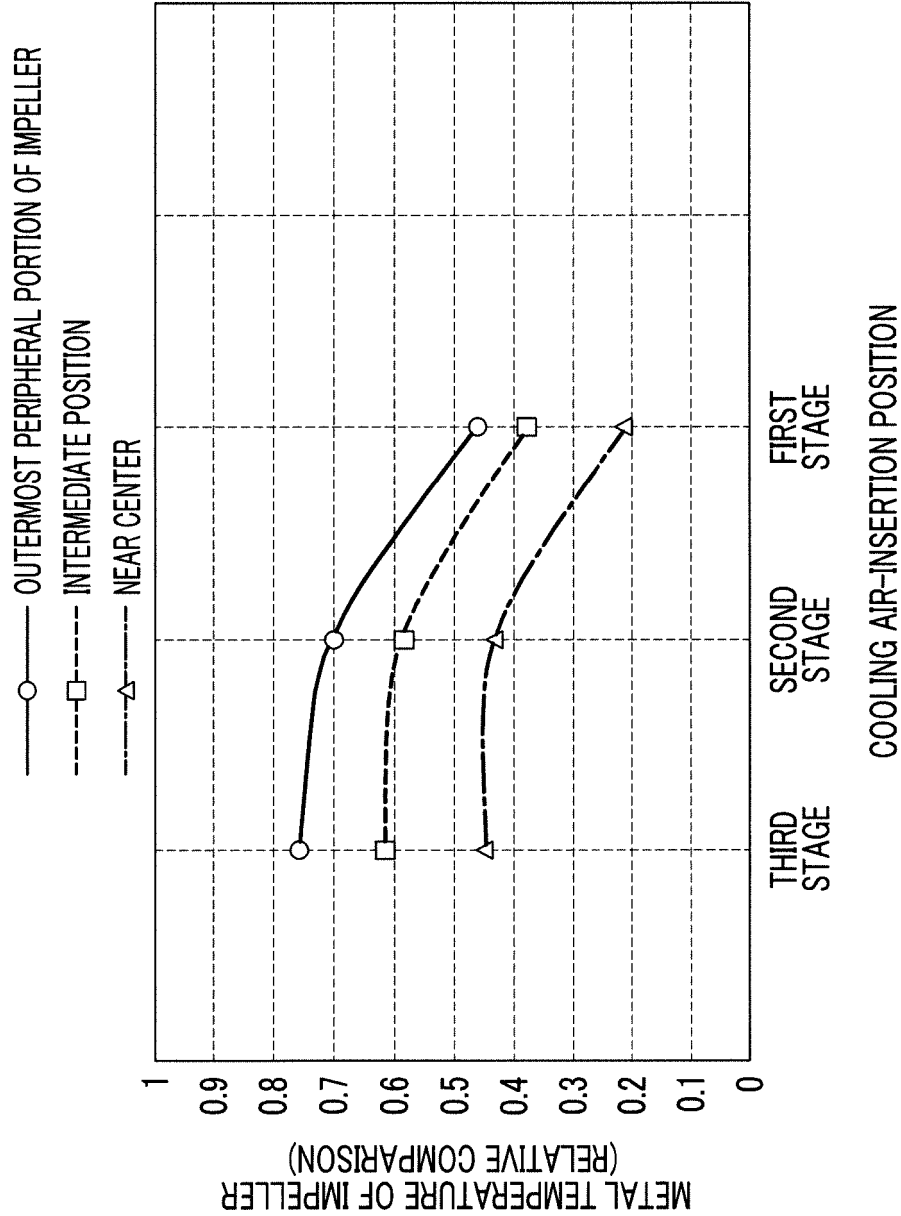


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2013/082346

A. CLASSIFICATION OF SUBJECT MATTER

F04D29/08(2006.01)i, F04D29/58(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)

F04D29/08, F04D29/58

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 1996-2014

Kokai Jitsuyo Shinan Koho 1971-2014 Toroku Jitsuyo Shinan Koho 1994-2014

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.
X	JP 2010-506091 A (MAN Diesel SE),	1-3
Y	25 February 2010 (25.02.2010), paragraphs [0023], [0044]; fig. 4 & WO 2008/043539 A1 & DE 102006048784 A & CH 698234 B & KR 10-2009-0082890 A & CN 101631940 A	4-6
Y	JP 2008-45425 A (Mitsubishi Heavy Industries, Ltd.), 28 February 2008 (28.02.2008), paragraph [0012] (Family: none)	4-6

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

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Date of the actual completion of the international search

16 January, 2014 (16.01.14)

Date of mailing of the international search report

28 January, 2014 (28.01.14)

Name and mailing address of the ISA/
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Patent documents cited in the description

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- JP 4503726 B [0005]