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• **Mitsubishi Heavy Industries Compressor Corporation**
Minato-ku
Tokyo 108-0014 (JP)

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(72) Inventors:
• **MASUTANI, Jo**
Tokyo 108-8215 (JP)
• **HIRATA, Daisuke**
Hiroshima-shi
Hiroshima 733-8553 (JP)

(71) Applicants:
• **Mitsubishi Heavy Industries, Ltd.**
Tokyo 108-8215 (JP)

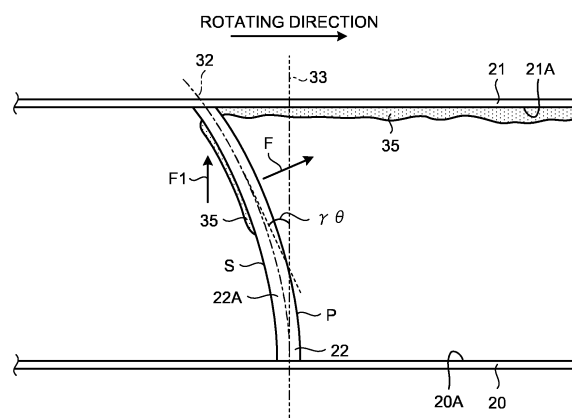
(74) Representative: **Studio Torta S.p.A.**
Via Viotti, 9
10121 Torino (IT)

(54) **CENTRIFUGAL IMPELLER AND CENTRIFUGAL COMPRESSOR**

(57) A centrifugal impeller capable of suppressing the development of a boundary layer and thus fulfilling its performance sufficiently, and a centrifugal compressor are provided.

The impeller includes a hub 20, a shroud 21, and a plurality of blades 22 disposed between the hub 20 and the shroud 21 and blows out fluid in a radial direction by the rotation of a rotary shaft fixed to the hub 20. When an angle made by a projection line 33 that is obtained by projecting a camber line 32 of the blade 22 onto a pre-determined meridional cross section and the camber line 32 is defined as an inclination angle $\gamma\theta$ and an inclination in a direction opposite to a rotating direction of the rotary shaft is defined to be positive, the blade 22 is formed in such a manner that the inclination angle $\gamma\theta$ of a leading edge 22A is zero or positive on the hub 20 side and gradually increasing toward the shroud 21 and the inclination angle is gradually decreasing from the leading edge toward a trailing edge in a flow direction of the fluid.

FIG.6



Description

Field

[0001] The present invention relates to a centrifugal impeller and a centrifugal compressor including the centrifugal impeller.

Background

[0002] Centrifugal compressors for industrial use are generally used in petrochemical plants or natural gas plants, for example. A centrifugal compressor of this type employs a centrifugal impeller for blowing out fluid in a radial direction by the rotation of a rotary shaft, including a hub fixed to the rotary shaft and a plurality of blades disposed in the hub (see Patent Literature 1, for example).

Citation List

Patent Literature

[0003] Patent Literature 1: Japanese Patent Application Laid-Open No. 2004-044473

Summary

Technical Problem

[0004] According to a conventional configuration, when a blade 100 of a centrifugal impeller is viewed from an intake port 101 side, the blade 100 is formed in such a manner that an angle made by a camber line 103 of a leading edge 102 and a straight line 104 extending in a radial direction from the center of rotation is approximately 0° over a region from a wall surface 105 on a hub side to a wall surface 106 on a shroud side as shown in FIG. 11. When the blade 100 is viewed from a blowoff port 107 side, the blade latter half of the blade 100 including a trailing edge 108 inclines obliquely in such a manner that a suction surface S of the blade 100 faces the wall surface 106 on the shroud side as shown in FIG. 12.

[0005] By the way, in the centrifugal impeller of this type, a boundary layer 109 is generated on the wall surface 106 on the shroud side, which constitutes a passage for fluid. The boundary layer 109 develops in a deceleration zone of the wall surface 106 on the shroud side in the first half of the blade. Also on a surface of the blade 100, a boundary layer develops, starting from the leading edge 102, on the suction surface S having larger deceleration than a pressure surface P to which a positive pressure is applied by the rotation. This boundary layer is attracted to a radially upper part by centrifugal force, thereby flowing into and merging with the boundary layer 109 generated on the wall surface 106 on the shroud side. Thus, the boundary layer 109 on the wall surface 106 on the shroud side develops further. The thus devel-

oped boundary layer develops further also in the latter half of the blade, thereby creating a large energy deficit portion on a blade outlet side. Thus, it is expected to deteriorate the performance of the centrifugal impeller.

The conventional configuration, however, has made no contraption for suppressing the boundary layer 109 developed on the wall surface 106 on the shroud side in the first half of the blade, in particular.

[0006] The present invention has been made in view of such circumstances, and it is an object of the present invention to provide a centrifugal impeller capable of suppressing the development of a boundary layer and thus fulfilling its performance sufficiently, and a centrifugal compressor.

Solution to Problem

[0007] According to an aspect of the present invention, a centrifugal impeller comprises: a hub; a shroud; and a plurality of blades disposed between the hub and the shroud, the centrifugal impeller blowing out fluid in a radial direction by rotation of a rotary shaft fixed to the hub. When an angle made by a projection line that is obtained by projecting a camber line of the blade onto a predetermined meridional cross section and the camber line is defined as an inclination angle and an inclination in a direction opposite to a rotating direction of the rotary shaft is defined to be positive, the blade is formed in such a manner that the inclination angle of a leading edge is zero or positive on the hub side and gradually increasing toward the shroud and the inclination angle is gradually decreasing from the leading edge toward a trailing edge in a flow direction.

[0008] According to this configuration, the inclination angle of the leading edge in the blade is zero or positive on the hub side and gradually increasing toward the shroud. Thus, a pressure surface of the blade faces the shroud in a portion of the blade from the leading edge to the first half thereof. Consequently, a boundary layer is pressed against the shroud by force of the pressure surface of the blade, thereby suppressing the development of the boundary layer. On a suction surface of the blade, a boundary layer is pressed against the suction surface by centrifugal force, thereby preventing its movement toward the shroud and thus suppressing the development of the boundary layer. Furthermore, in the flow direction, the blade is formed in such a manner that the inclination angle is gradually decreasing from the leading edge toward the trailing edge. Consequently, the surface area of the blade in the latter half of the blade is reduced, and thus the amount of the boundary layer developed over the blade surface in the latter half of the blade can be reduced. This can suppress the generation of an energy deficit portion on a blade outlet side, thereby allowing the performance of the centrifugal impeller to be fulfilled sufficiently.

[0009] In this configuration, the inclination angle of the trailing edge in the blade is preferably zero or positive on

the hub side and gradually increasing toward the shroud. According to such a configuration, the pressure surface of the blade faces the shroud also in the latter half of the blade. Consequently, the boundary layer is pressed against the shroud by the force of the pressure surface of the blade, thereby suppressing the development of the boundary layer.

[0010] Alternatively, the inclination angle of the trailing edge in the blade is preferably zero or positive over a region from the hub side to the shroud side. Moreover, such a positive value is preferably closer to zero. According to such a configuration, the length of the trailing edge of the blade can be made the shortest distance, thereby minimizing an amount of wake flow due to the thickness of the trailing edge of the blade. Furthermore, the reduced surface area of the blade in the latter half of the blade can reduce the amount of the boundary layer developed over the blade surface in the latter half of the blade as compared to the conventional technique.

[0011] The leading edge of the blade, when projected onto the meridional cross section, preferably has a linear shape from the hub side to the shroud side or a shape protruded toward an upstream side of the flow direction between the hub side and the shroud side. According to such a configuration, the area of a portion of the leading edge of the blade facing the shroud can be increased, thereby more effectively suppressing the development of the boundary layer accordingly.

[0012] The provision of the above-described centrifugal impeller in a centrifugal compressor can suppress the generation of the energy deficit portion on the blade outlet side, thus improving the compression efficiency of the centrifugal compressor.

Advantageous Effects of Invention

[0013] According to the centrifugal impeller of the present invention, the blade is formed in such a manner that the inclination angle of the leading edge is zero or positive on the hub side and gradually increasing toward the shroud and the inclination angle is gradually decreasing from the leading edge toward the trailing edge in the flow direction. Thus, the pressure surface of the blade faces the shroud in the portion of the blade from the leading edge to the first half thereof. This can suppress the development of the boundary layer and thus suppress the generation of the energy deficit portion on the blade outlet side, thereby allowing the performance of the centrifugal impeller to be fulfilled sufficiently.

Brief Description of Drawings

[0014]

FIG. 1 is a longitudinal cross-sectional view of a centrifugal compressor according to the present embodiment.

FIG. 2 is a partial enlarged view illustrating an im-

peller.

FIG. 3 is a diagram for explaining an inclination angle of a blade shown on a meridional cross section.

FIG. 4 is a diagram illustrating the blade projected on the meridional cross section.

FIG. 5 is a diagram illustrating an intake port of the impeller as seen from an axial direction.

FIG. 6 is a schematic view illustrating the shape of a leading edge of the blade of the impeller.

FIG. 7 is a diagram illustrating a blowoff port of the impeller as seen from a radial direction.

FIG. 8 is a diagram illustrating the blowoff port of the impeller as seen from the axial direction.

FIG. 9 is a schematic view illustrating the shape of a trailing edge of the blade of the impeller.

FIG. 10 is an experimental measurement diagram showing changes in the development of boundary layers due to the shapes of blades in a conventional technique and the present embodiment.

FIG. 11 is a schematic view illustrating the shape of a leading edge of a blade in a conventional impeller.

FIG. 12 is a schematic view illustrating the shape of a trailing edge of the blade in the conventional impeller. Description of Embodiments

[0015] An embodiment of the present invention will be described below with reference to the drawings. Note that this invention is not limited by the following embodiment. Note also that elements in the following embodiment encompass those substitutable by and obvious to a person skilled in the art, or substantially the same elements.

[0016] FIG. 1 is a longitudinal cross-sectional view of a centrifugal compressor according to the present embodiment. A centrifugal compressor 1 includes: a casing 2 formed by a combination of a plurality of parts; a rotary shaft 5 supported so as to be rotatable about an axis line L via bearings (not shown) in the casing 2; and closed type impellers 6 fixed to the rotary shaft 5 so as to rotate integrally with the rotary shaft 5. In other words, the centrifugal compressor 1 of the present embodiment is a two-stage centrifugal compressor.

[0017] In the centrifugal compressor 1, the rotary shaft 5 is driven by a driving mechanism (not shown) to rotate the impellers 6. Consequently, fluid, such as gas or air, to be compressed is sucked into the centrifugal compressor 1 via a suction port 10 provided in the casing 2. An intake passage 11 is connected to the suction port 10 via a suction space 10A formed in the casing 2. The intake passage 11 bends along the direction of the axis line L of the rotary shaft 5 (axial direction) and has an opening facing an intake port 6A of the first-stage impeller 6.

[0018] Centrifugal force is imparted to the fluid sucked from the suction port 10 by the rotation of the first-stage impeller 6. The kinetic energy of such fluid is converted to pressure energy by a first-stage vaneless diffuser 12 provided at a blowoff port 6B of the impeller 6. This fluid is further guided to an intake port 6A of the second-stage

impeller 6, which is the next compression stage, via a return bend 14 and a return vane 15.

[0019] Similarly, centrifugal force is imparted to such compressed fluid by the second-stage impeller 6. The kinetic energy of such fluid is converted to pressure energy by a second-stage vaneless diffuser 12 and discharged to a scroll 16 as compressed fluid with a higher pressure. Thereafter, the fluid is sent out from the scroll 16 to a discharge pipe (not shown) via a discharge port 17 provided in the casing 2. Note that the reference numeral 18 in FIG. 1 denotes a balance piston provided for adjusting thrust of the impeller 6. The impeller 6 will be described next.

[0020] FIG. 2 is a partial enlarged view illustrating the impeller. As shown in FIG. 2, the impeller 6 includes: a hub 20 fixed to the rotary shaft 5; a shroud 21 disposed with a space from the hub 20 in a radial direction and the axial direction; and a plurality of blades 22 disposed between the hub 20 and the shroud 21. The blades 22 are disposed radially with a space around the axis line L, although their graphic representation is omitted. A leading edge 22A of the blade 22 is positioned on the intake port 6A side of the impeller 6, and a trailing edge 22B extends to the blowoff port 6B of the impeller 6.

[0021] By the way, a boundary layer is generated on an inner wall surface 21A of the shroud 21, which constitutes a fluid passage together with the hub 20, on the intake port 6A side of the impeller 6. This boundary layer grows (develops) on the inner wall surface 21A of the shroud 21 when the fluid flows from the leading edge 22A of the blade 22 toward the trailing edge 22B. Consequently, a large energy deficit is generated at the blowoff port (blade outlet side) 6B. Thus, it is expected to deteriorate the performance of the impeller. In the present embodiment, the shape of the blade 22 has the following configuration in order to suppress the growth of the boundary layer.

[0022] An inclination angle required to define the shape of the blade 22 of the impeller 6 will be described first. FIG. 3 is a diagram for explaining the inclination angle of the blade shown on a meridional cross section. FIG. 4 is a diagram illustrating the blade projected on the meridional cross section. Since the blade 22 of the impeller 6 has a three-dimensional shape, the inclination angle is expressed with a cylindrical coordinate system shown in FIGS. 3 and 4.

[0023] In FIGS. 3 and 4, the Z-axis represents the axis line L of the rotary shaft 5. An r-Z plane formed by the Z-axis and a straight line r extending from an origin point O at an angle made by a predetermined angle θ from the X-axis represents a predetermined meridional cross section 30. When the blade 22 is projected on the meridional cross section 30, a broken line denoted by the reference numeral 31 is a line (streamline) dividing a meridional passage into equal areas in a blade span direction.

[0024] In FIG. 3, the reference numeral 32 denotes a camber line of the blade (for example, the leading edge) before being projected. When the camber line 32 is pro-

jected on the meridional cross section 30, a projection line (projection line of the camber line of the blade parallel to the meridional cross section 30) 33 is formed. An angle made by the projection line 33 and the camber line 32 is defined as the inclination angle of the blade 22 (inclination angle in a circumferential direction of the blade) $\gamma\theta$ in the present embodiment. Note that the positive or negative sign of the inclination angle $\gamma\theta$ is defined in accordance with the rotating direction of the rotary shaft 5. In the present embodiment, a direction opposite to the rotating direction (counter-rotating direction) is defined to be positive.

[0025] Note that the reference numeral 34 denotes a projection line of a camber line of the blade perpendicular to the meridional cross section 30. An angle γZ made by the above-described projection line 33 and the Z-axis (parallel line Z' translated onto the meridional cross section 30) is defined as an axial tilt angle of the blade projected onto the meridional cross section 30.

[0026] The shape of the blade 22 will be described next. FIG. 5 is a diagram illustrating the intake port of the impeller as seen from the axial direction. FIG. 6 is a schematic view illustrating the shape of the leading edge of the blade of the impeller. As shown in FIG. 6, the leading edge 22A is formed in a curved manner so as to project more on the inner wall surface 21A side of the shroud 21 than on a inner wall surface 20A side of the hub 20. Specifically, the camber line 32 of the leading edge 22A curves in such a manner that the inclination angle $\gamma\theta$ with respect to the projection line 33 formed on the above-described meridional cross section 30 (FIG. 3) is approximately zero or positive on the hub 20 side and gradually increasing toward the shroud 21. In such a configuration, the shroud 21 side of the leading edge 22A of the blade 22 inclines in the counter-rotating direction. Thus, a pressure surface P of the blade 22 is disposed so as to face the inner wall surface 21A of the shroud 21. Furthermore, since the inclination angle $\gamma\theta$ gradually increases toward the shroud 21, the leading edge 22A inclines more on the shroud 21 side, thus facing the inner wall surface 21A of the shroud 21 in a larger degree. Consequently, gradually toward the shroud 21, force F generated by the pressure surface P of the blade 22 is headed to the inner wall surface 21A of the shroud 21. Note that the curve of the leading edge 22A may be a curve along a single arc or a curve made by a combination of arcs.

[0027] According to this configuration, the inclination angle $\gamma\theta$ of the leading edge 22A in the blade 22 is zero or positive on the hub 20 side and gradually increasing toward the shroud 21. Thus, the pressure surface P of the blade 22 faces the inner wall surface 21A of the shroud 21 in a portion of the blade 22 from the leading edge 22A to the first half thereof in a flow direction. Consequently, a boundary layer 35 is pressed against the inner wall surface 21A of the shroud 21 by the force F of the pressure surface P of the blade 22, thereby suppressing the development of the boundary layer 35. On a suction surface S side of the blade 22, a boundary layer 35

generated on the suction surface S is pressed against the suction surface S by centrifugal force F1, thereby preventing its movement toward the shroud 21 and thus suppressing the development of the boundary layer 35.

[0028] The trailing edge 22B side of the blade 22 will be described next. FIG. 7 is a diagram illustrating the blowoff port of the impeller as seen from the radial direction. FIG. 8 is a diagram illustrating the blowoff port as seen from the axial direction. FIG. 9 is a schematic view illustrating the shape of the trailing edge of the blade of the impeller. Unlike the leading edge 22A side, the trailing edge 22B side of the blade 22 is formed in such a manner that the inclination angle $\gamma\theta$ of the camber line 32 with respect to the projection line 33 is approximately zero or positive. Such a positive value is preferably closer to zero. A region between the leading edge 22A and the trailing edge 22B in the blade 22 is formed in such a manner that the inclination angle $\gamma\theta$ gradually decreases (becomes closer to zero) along the flow direction of the fluid. In this configuration, the trailing edge 22B of the blade 22 erects generally perpendicular to the inner wall surface 20A of the hub 20 and the inner wall surface 21A of the shroud 21, thereby making its height (length) in the direction of the axis line L the shortest distance. Thus, an amount of wake flow due to the thickness of the trailing edge 22B of the blade 22 can be minimized.

[0029] Effects of the present embodiment will be described next. FIG. 10 is an experimental measurement diagram showing changes in the development of the boundary layers due to the shapes of the blades in the conventional technique and the present embodiment. In FIG. 10, A to C show changes in the boundary layer in the configuration using the conventional blade 100 (FIGS. 11 and 12). D to F show changes in the boundary layer in the configuration using the blade 22 of the present embodiment. Specifically, A and D each illustrate an amount of the boundary layer at a position before the outflow port of the impeller. Moreover, B and E each illustrate an amount of the boundary layer in midstream to the outflow port of the impeller. Furthermore, C and F each illustrate an amount of the boundary layer in a middle portion of the length of the blade in the flow direction.

[0030] In the conventional configuration, an amount of the boundary layer 109 (a portion with a particularly large pressure loss in an accumulated development portion of the boundary layer) increases along the flow direction of the fluid (C $\rightarrow$ B $\rightarrow$ A). In the present embodiment, on the other hand, while an amount of the boundary layer 35 (a portion with a particularly large pressure loss in an accumulated development portion of the boundary layer) slightly increases along the flow direction of the fluid (F $\rightarrow$ E $\rightarrow$ D), the amount of the boundary layer is reduced significantly as compared to the conventional configuration. Thus, it can be understood that the growth of the boundary layer (the portion with a particularly large pressure loss in the accumulated development portion of the boundary layer) can be suppressed.

[0031] As described above, the impeller 6 according

to the present embodiment is configured to include the hub 20, the shroud 21, and the plurality of blades 22 disposed between the hub 20 and the shroud 21 and blow out the fluid in the radial direction by the rotation of the rotary shaft 5 fixed to the hub 20. When the angle made by the projection line 33 that is obtained by projecting the camber line 32 of the blade 22 onto the predetermined meridional cross section 30 and the camber line 32 is defined as the inclination angle $\gamma\theta$ and an inclination in the direction opposite to the rotating direction of the rotary shaft 5 is defined to be positive, the inclination angle $\gamma\theta$ of the leading edge 22A in the blade 22 is zero or positive on the hub 20 side and gradually increasing toward the shroud 21. Thus, the pressure surface P of the blade 22 faces the inner wall surface 21A of the shroud 21 in the portion of the blade 22 from the leading edge 22A to the first half thereof. Consequently, the boundary layer 35 is pressed against the inner wall surface 21A of the shroud 21 by the force F of the pressure surface P of the blade 22, thereby suppressing the development of the boundary layer 35. On the suction surface S of the blade 22, the boundary layer 35 is pressed against the suction surface S by the centrifugal force F1, thereby preventing its movement toward the shroud 21 and thus suppressing the development of the boundary layer 35.

[0032] Furthermore, in the flow direction of the fluid, the blade 22 is formed in such a manner that the inclination angle $\gamma\theta$ is gradually decreasing from the leading edge 22A toward the trailing edge 22B. Consequently, the surface area of the blade 22 in the latter half of the blade 22 is reduced, and thus the amount of the boundary layer developed over the blade surface in the latter half of the blade 22 can be reduced. This can suppress the generation of the energy deficit portion on the blade outlet side, thereby allowing the performance of the impeller 6 to be fulfilled sufficiently.

[0033] Moreover, the inclination angle $\gamma\theta$ of the trailing edge 22B in the blade 22 is zero or positive over the region from the hub 20 side to the shroud 21 side according to the present embodiment. Thus, the height

[0034] (length) of the trailing edge 22B of the blade 22 in the direction of the axis line L can be made the shortest distance. Consequently, the amount of the wake flow due to the thickness of the trailing edge 22B of the blade 22 can be minimized. Furthermore, the reduced surface area of the blade 22 in the latter half of the blade 22 can significantly reduce the amount of the boundary layer developed over the blade surface in the latter half of the blade 22 as compared to the conventional technique.

[0035] Moreover, the provision of the above-described impeller 6 in the centrifugal compressor 1 of the present embodiment can suppress the generation of the energy deficit portion on the outlet side of the blade 22, thus improving the compression efficiency of the centrifugal compressor 1.

[0036] While the embodiment of the present invention has been described above, the present invention is not

limited by the above details. For example, the above-described embodiment has described the configuration in which the inclination angle $\gamma\theta$ of the trailing edge 22B in the blade 22 is zero or positive over a region from the hub 20 side to the shroud 21 side. However, the inclination angle $\gamma\theta$ of the trailing edge in the blade 22 may be zero or positive on the hub 20 side and may be gradually increasing toward the shroud 21. According to such a configuration, the pressure surface P of the blade 22 faces the inner wall surface 21A of the shroud 21 also in the latter half of the blade 22. Consequently, the boundary layer 35 is pressed against the shroud 21 by the force of the pressure surface P of the blade 22, thereby suppressing the development of the boundary layer 35 more effectively.

[0037] Moreover, the leading edge 22A of the blade 22, when projected onto the meridional cross section, has the shape in which the hub 20 and the shroud 21 are generally straight lines in the above-described embodiment. However, the present invention is not limited thereto. The leading edge 22A may have a protruding shape protruded toward the upstream side in the flow direction of the fluid between the hub 20 and the shroud 21. According to such a configuration, the area of a portion of the leading edge 22A of the blade 22 facing the shroud 21 can be increased, thereby more effectively suppressing the development of the boundary layer 35 accordingly.

[0038] Moreover, while the leading edge of the blade 22 in the present embodiment is configured such that the inclination angle $\gamma\theta$ curves with a gradually larger degree from the hub 20 side toward the shroud 21, the present invention is not limited thereto. The inclination may be configured to increase (bend) sharply so as to turn outwardly (configuration provided with a discontinuous portion somewhere in the span direction). In this case, not a single but a plurality of bent portions (discontinuous portions) may be provided.

[0039] Moreover, while the impeller 6 in the present embodiment is provided in the two-stage centrifugal compressor 1, the impeller 6 can be applied to a single-stage centrifugal compressor or a multistage centrifugal compressor including three or more stages as long as the compressor includes an impeller.

Reference Signs List

[0040]

- 1 centrifugal compressor
- 2 casing
- 5 rotary shaft
- 6 impeller (rotary impeller)
- 6A intake port
- 6B blowoff port
- 10 suction port
- 10A suction space
- 11 intake passage

- 12 vaneless diffuser
- 14 return bend
- 15 return vane
- 16 scroll
- 17 discharge port
- 18 balance piston
- 20 hub
- 20A inner wall surface
- 21 shroud
- 21A inner wall surface
- 22 blade
- 22A leading edge
- 22B trailing edge
- 30 meridional cross section
- 32 camber line
- 33 projection line
- 35 boundary layer (a portion with a particularly large pressure loss in an accumulated development portion of the boundary layer)
- 100 blade
- 101 intake port
- 102 leading edge
- 103 camber line
- 104 straight line
- 105 wall surface
- 106 wall surface
- 107 blowoff port
- 108 trailing edge
- 109 boundary layer (a portion with a particularly large pressure loss in an accumulated development portion of the boundary layer)
- L axis line
- O origin point
- P pressure surface
- S suction surface
- Z' parallel line
- r straight line
- $\gamma\theta$ inclination angle

Claims

1. A centrifugal impeller comprising: a hub; a shroud; and a plurality of blades disposed between the hub and the shroud, the centrifugal impeller blowing out fluid in a radial direction by rotation of a rotary shaft fixed to the hub, wherein
when an angle made by a projection line that is obtained by projecting a camber line of the blade onto a predetermined meridional cross section and the camber line is defined as an inclination angle and an inclination in a direction opposite to a rotating direction of the rotary shaft is defined to be positive, the blade is formed in such a manner that the inclination angle of a leading edge is zero or positive on a hub side and gradually increasing toward the shroud and the inclination angle is gradually decreasing from the leading edge toward a trailing edge

in a flow direction.

2. The centrifugal impeller according to claim 1, wherein the inclination angle of the trailing edge in the blade is zero or positive on the hub side and gradually increasing toward the shroud. 5
3. The centrifugal impeller according to claim 1, wherein the inclination angle of the trailing edge in the blade is zero or positive over a region from the hub side to the shroud side. 10
4. The centrifugal impeller according to any one of claims 1 to 3, wherein the leading edge of the blade, when projected onto the meridional cross section, has a linear shape from the hub side to the shroud side or a shape protruded toward an upstream side of the flow direction between the hub side and the shroud side. 15
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5. A centrifugal compressor comprising the centrifugal impeller according to any one of claims 1 to 4. 25

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FIG.1

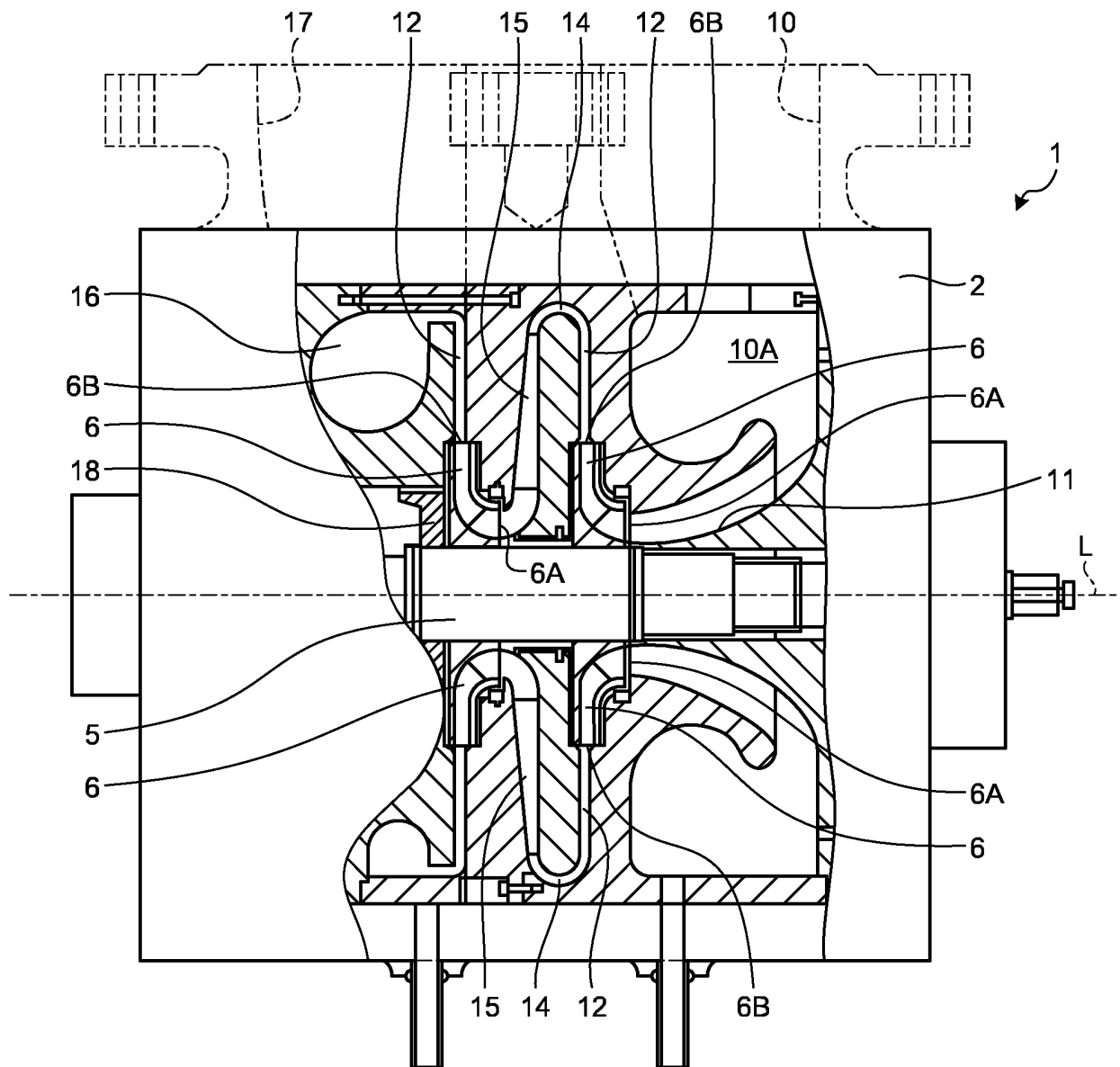


FIG.2

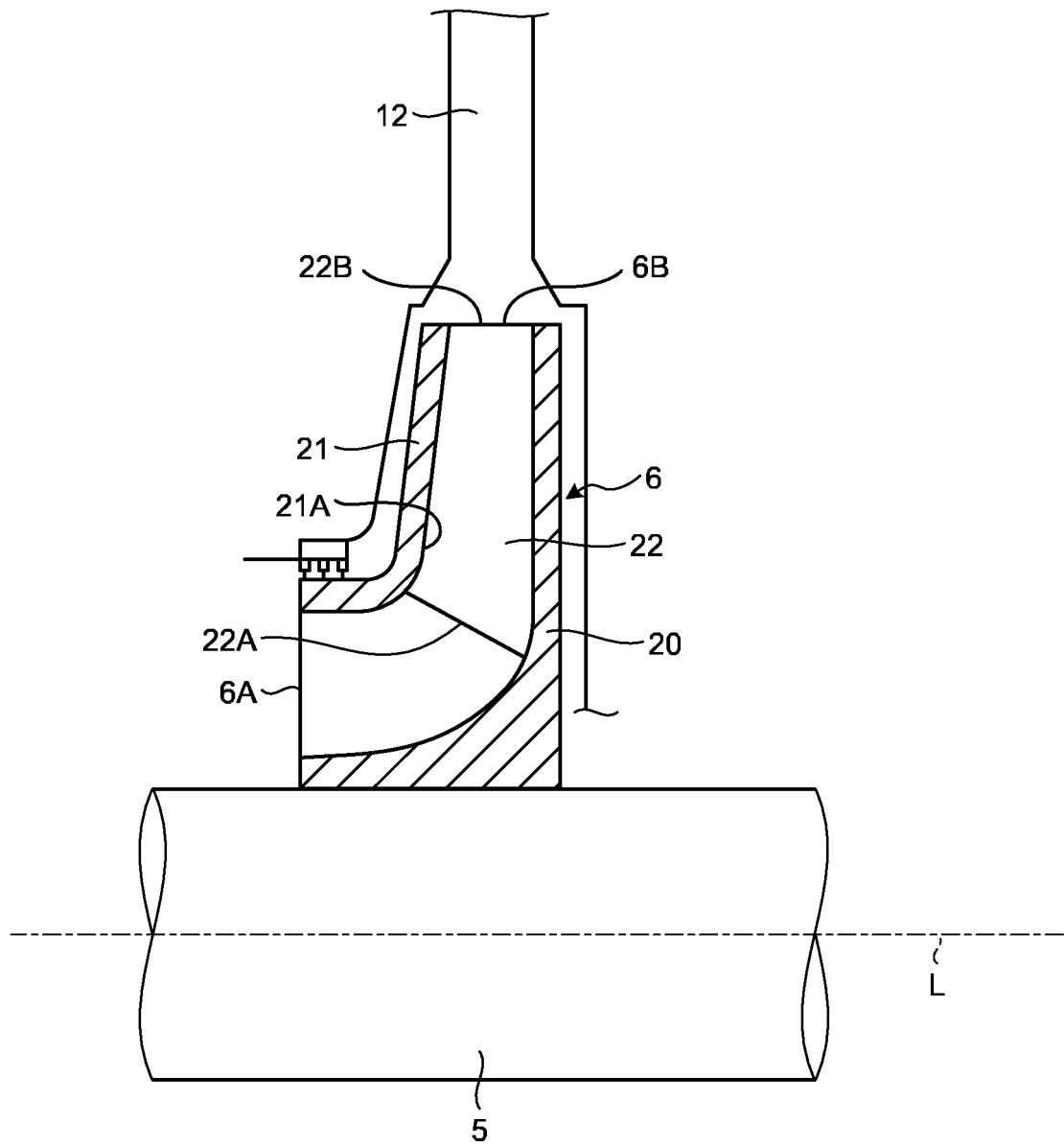


FIG.3

LINE DIVIDING MERIDIONAL PASSAGE
INTO EQUAL AREAS IN BLADE SPAN
DIRECTION ($\hat{=}$ STREAMLINE)

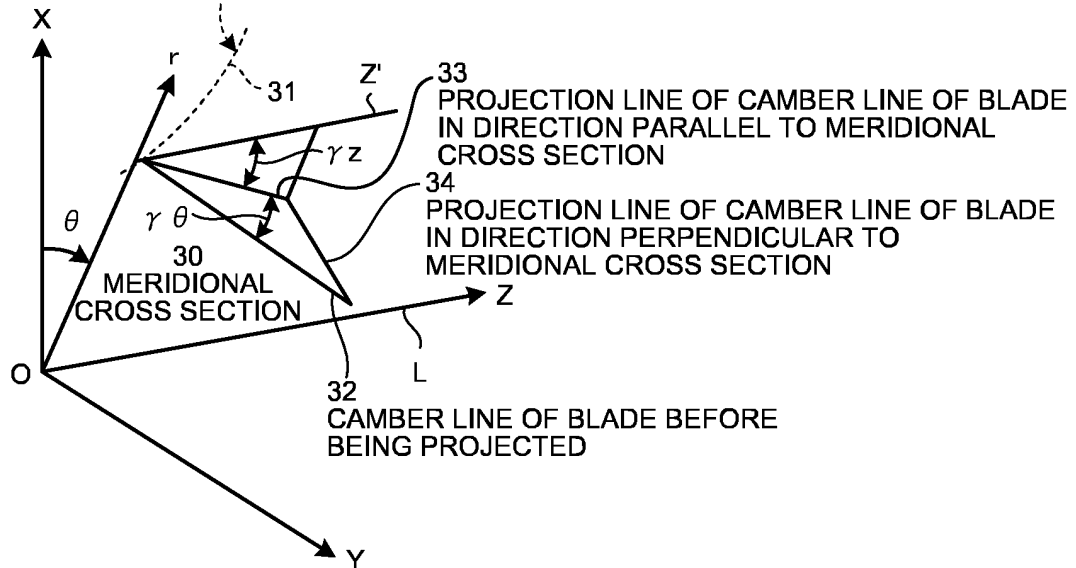


FIG.4

LINE DIVIDING MERIDIONAL PASSAGE
INTO EQUAL AREAS IN BLADE SPAN
DIRECTION ($\hat{=}$ STREAMLINE)

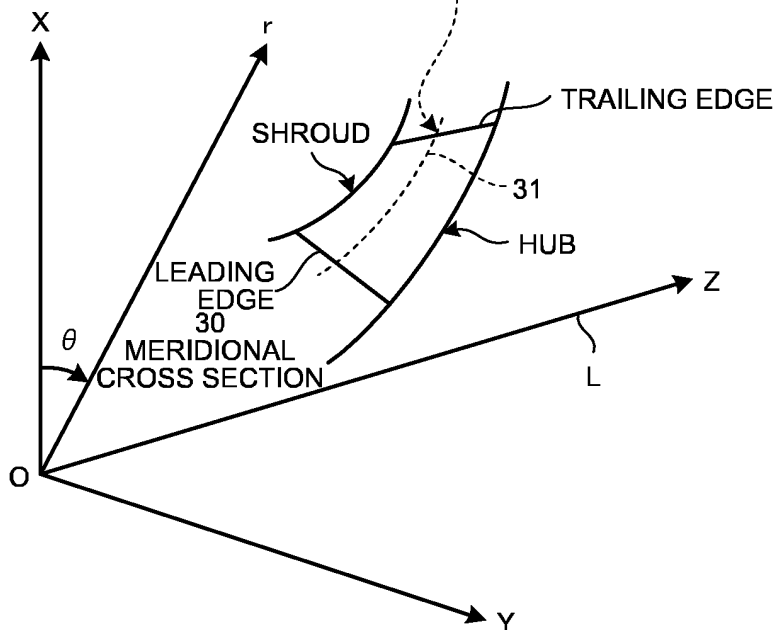


FIG.5

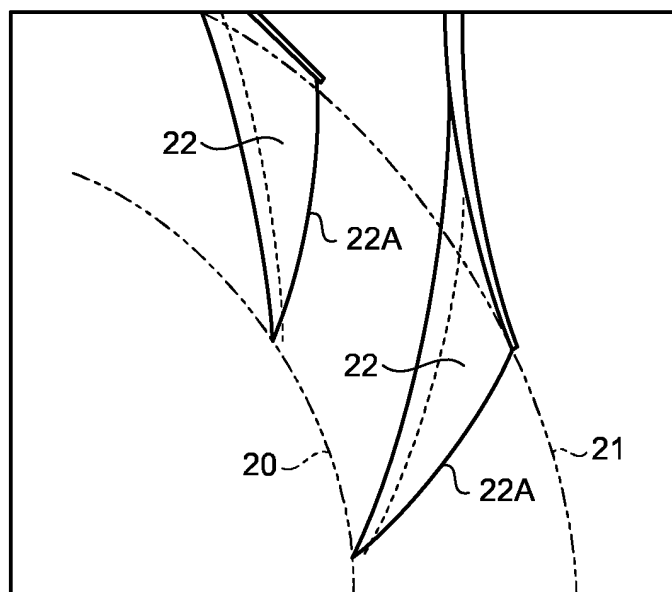


FIG.6

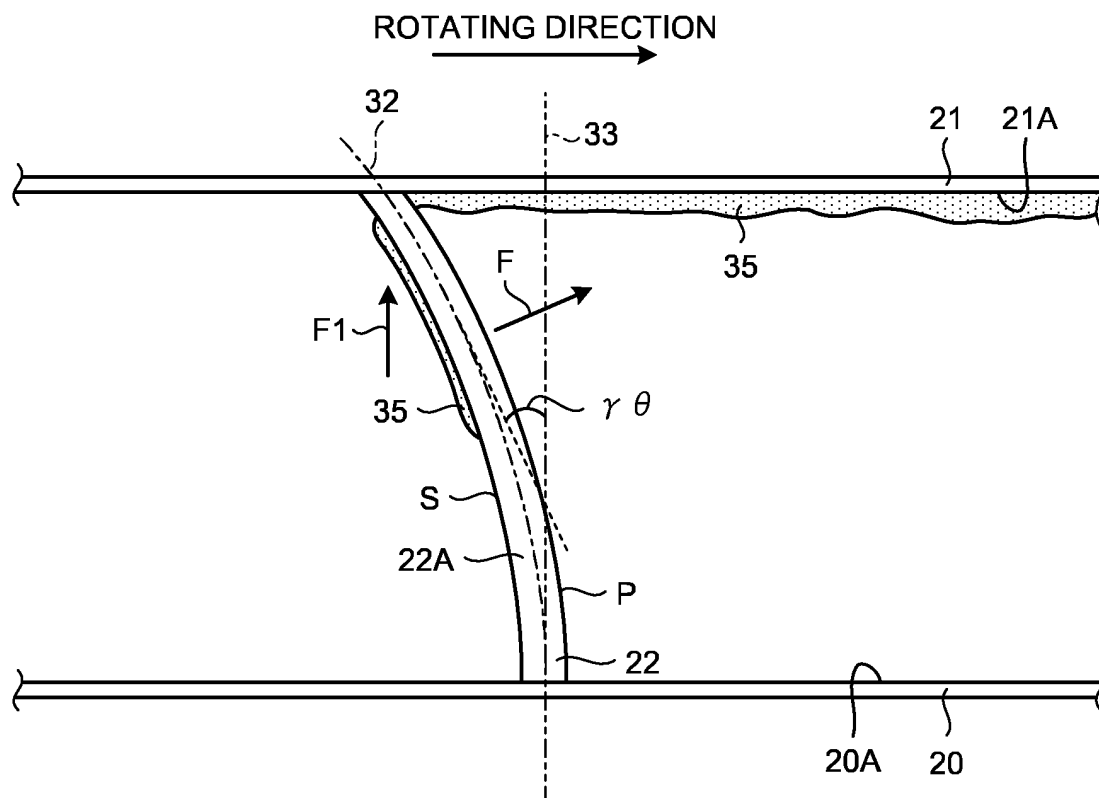


FIG.7

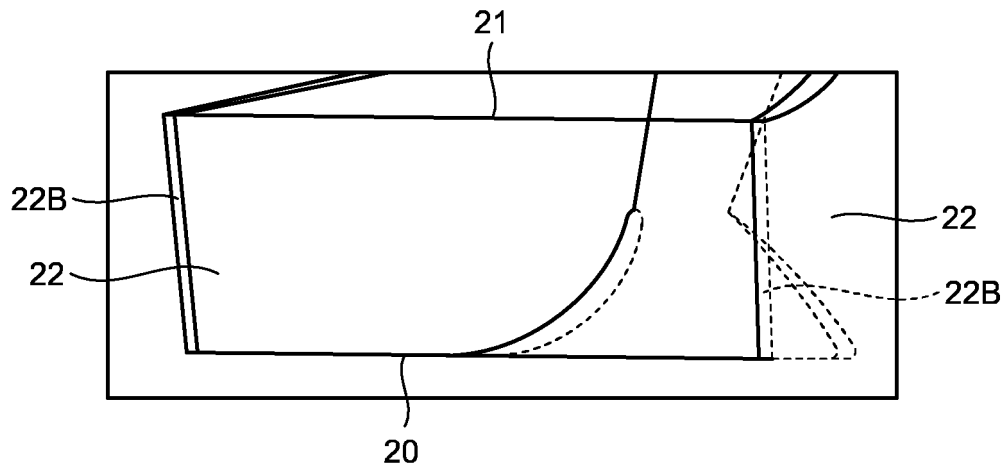


FIG.8

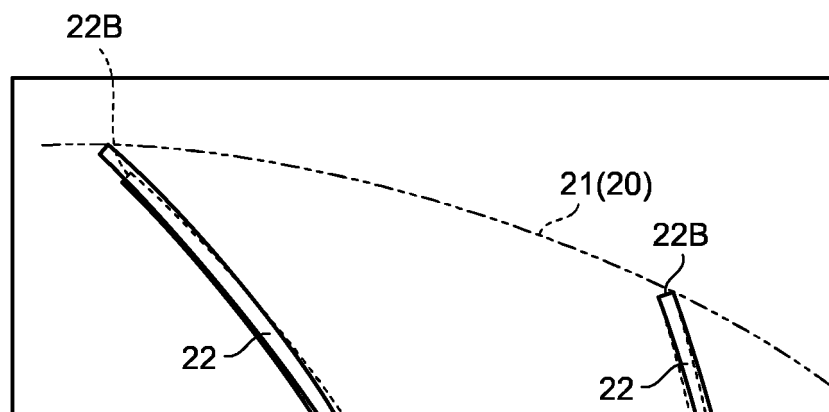


FIG.9

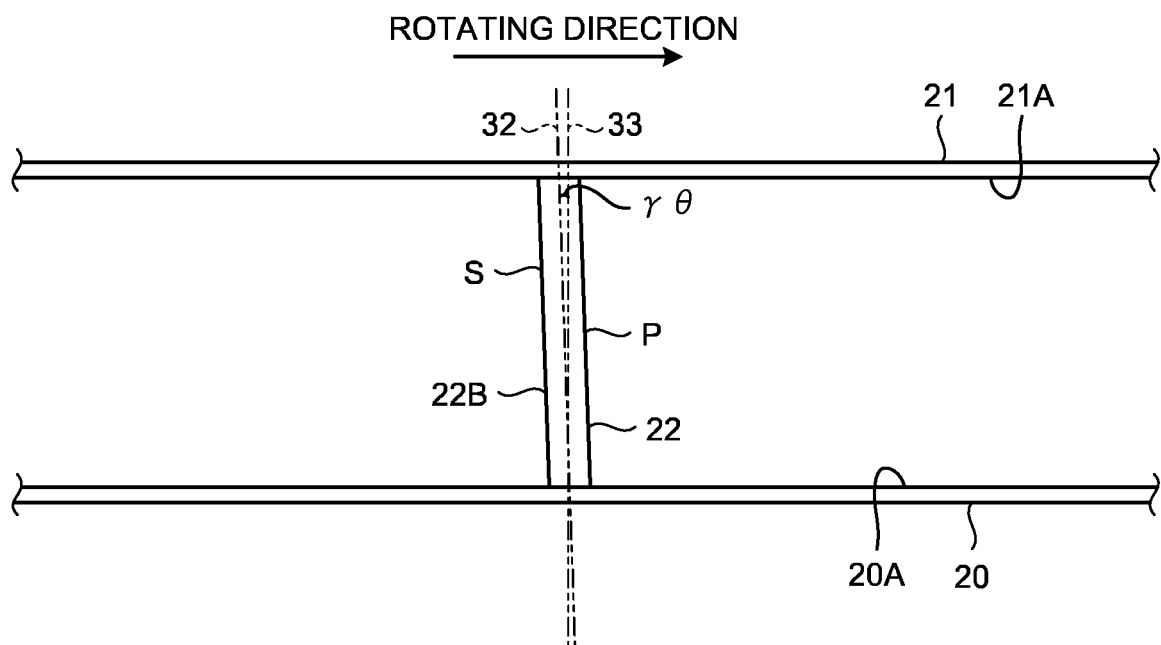


FIG. 10

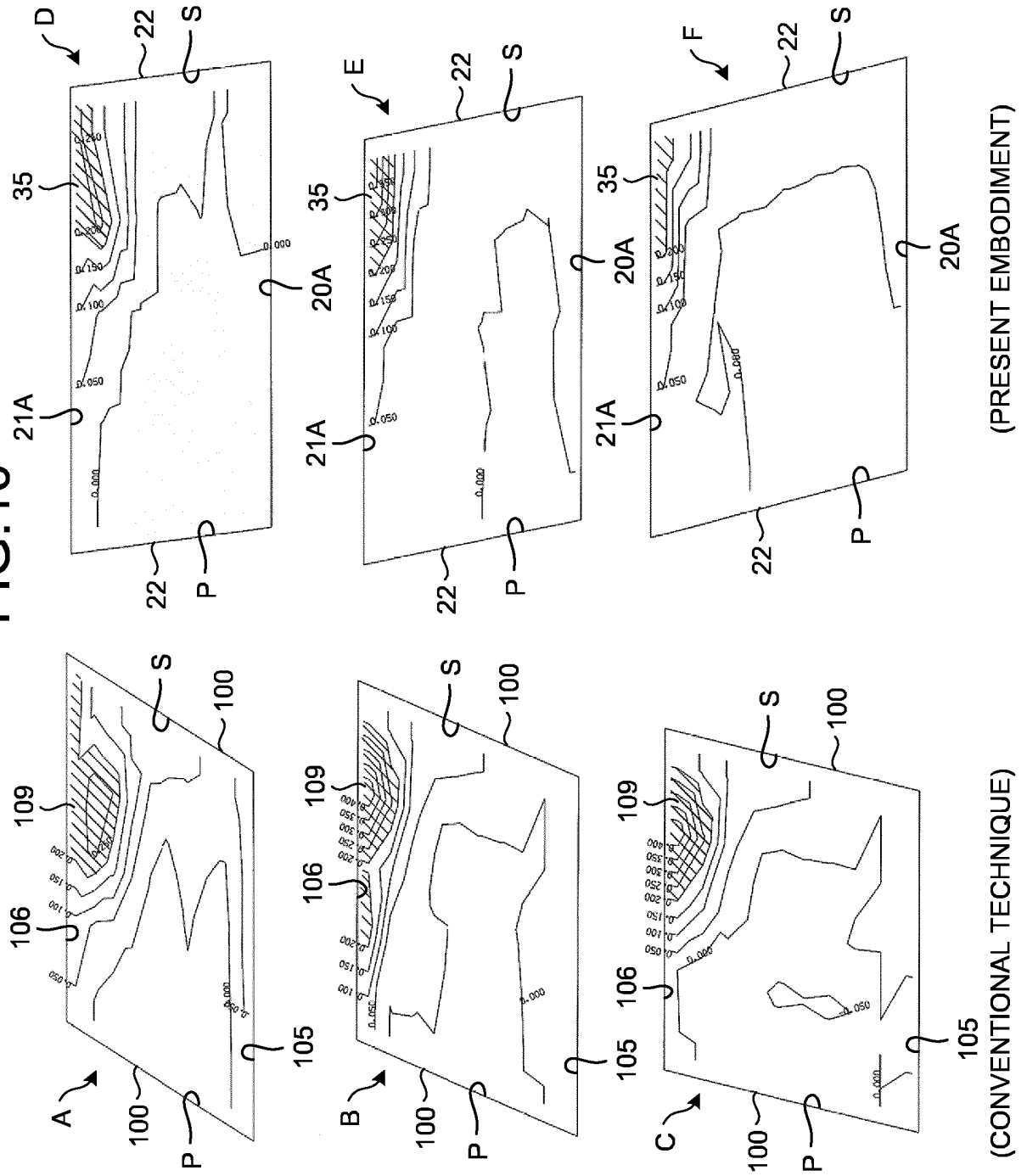


FIG.11

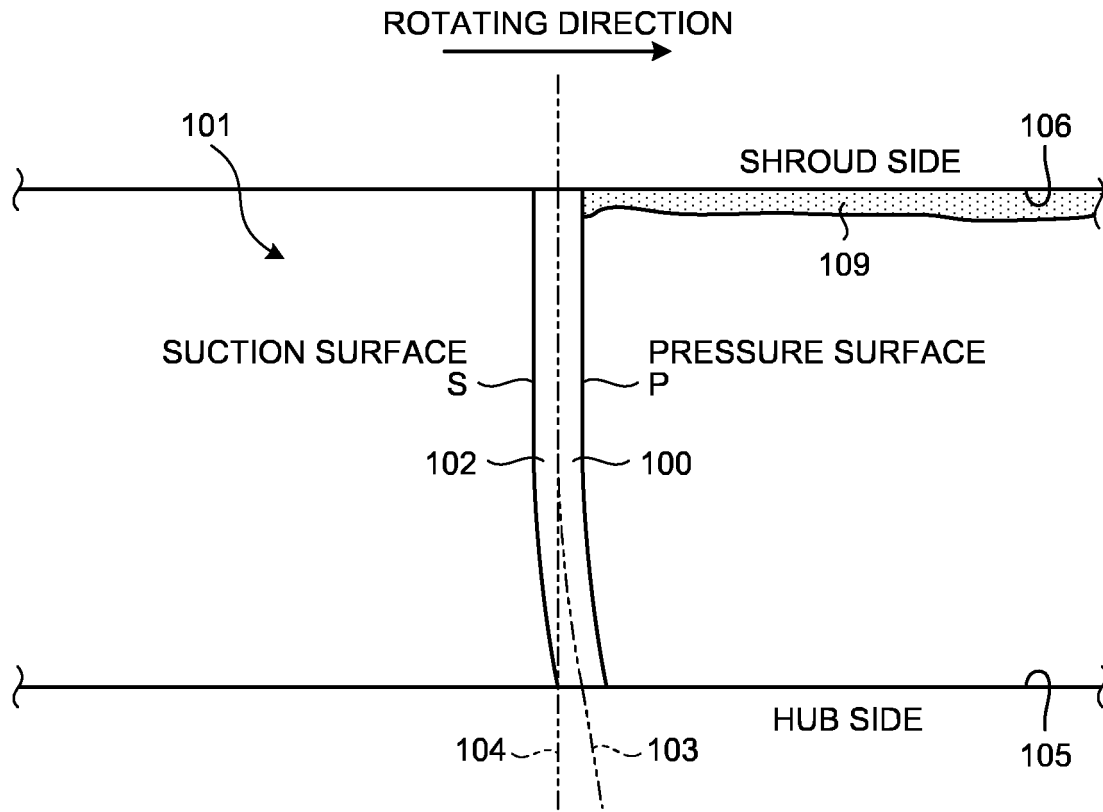
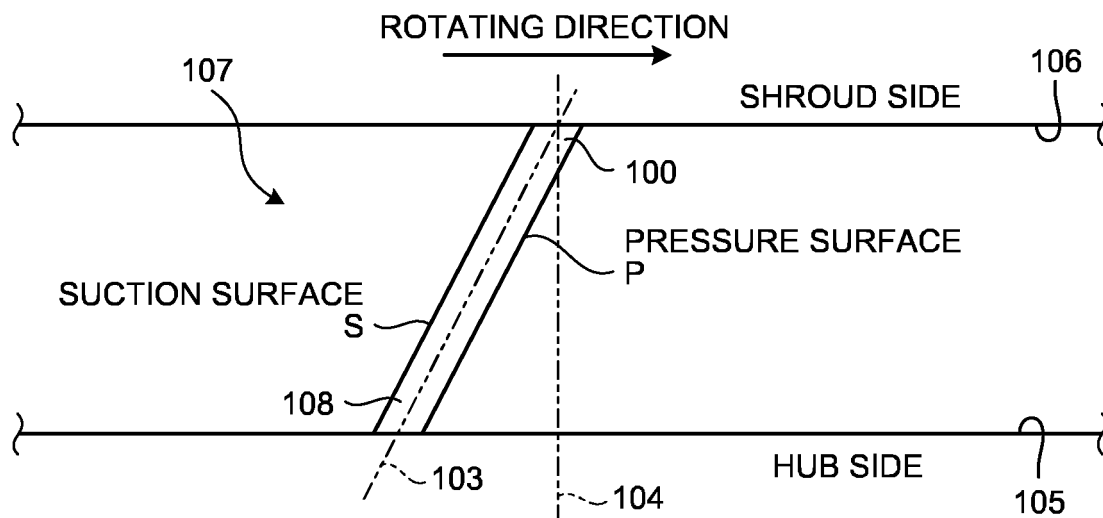


FIG.12



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/059344

A. CLASSIFICATION OF SUBJECT MATTER

F04D29/30(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)

F04D29/30

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 1996-2015

Kokai Jitsuyo Shinan Koho 1971-2015 Toroku Jitsuyo Shinan Koho 1994-2015

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 Y	JP 36-22175 B1 (Shin Mitsubishi Jukogyo Kabushiki Kaisha), 16 November 1961 (16.11.1961), page 1, left column, line 10 to right column, line 35; fig. 1 to 6 (Family: none)	1-4 5
Y	JP 2007-509268 A (York International Corp.), 12 April 2007 (12.04.2007), paragraph [0002] & US 2005/0076656 A1	5
A	US 2013/0149157 A1 (Hirofumi SHOJI), 13 June 2013 (13.06.2013), paragraphs [0023] to [0062]; fig. 1 to 11 (Family: none)	1-5

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

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"&" document member of the same patent family

Date of the actual completion of the international search
22 June 2015 (22.06.15)Date of mailing of the international search report
30 June 2015 (30.06.15)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2015/059344

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2011-64072 A (Mitsubishi Electric Corp.), 31 March 2011 (31.03.2011), paragraph [0035]; fig. 9 (Family: none)	1-5
A	JP 2006-2585 A (Samsung Electronics Co., Ltd.), 05 January 2006 (05.01.2006), paragraphs [0025] to [0036]; fig. 1 to 5 & KR 10-2005-0119071 A	1-5

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2004044473 A [0003]