



(11) **EP 2 752 622 A1**

(12) **EUROPEAN PATENT APPLICATION**  
published in accordance with Art. 153(4) EPC

(43) Date of publication:  
**09.07.2014 Bulletin 2014/28**

(51) Int Cl.:  
**F23R 3/42 (2006.01) F01D 9/02 (2006.01)**  
**F23R 3/16 (2006.01)**

(21) Application number: **12832651.9**

(86) International application number:  
**PCT/JP2012/073298**

(22) Date of filing: **12.09.2012**

(87) International publication number:  
**WO 2013/039095 (21.03.2013 Gazette 2013/12)**

(84) Designated Contracting States:  
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**

- **TSUKAGOSHI, Keizo**  
Tokyo 108-8215 (JP)
- **YURI, Masanori**  
Tokyo 108-8215 (JP)
- **KISHIDA, Hiroaki**  
Tokyo 108-8215 (JP)
- **TORII, Shunsuke**  
Tokyo 108-8215 (JP)

(30) Priority: **16.09.2011 JP 2011203016**

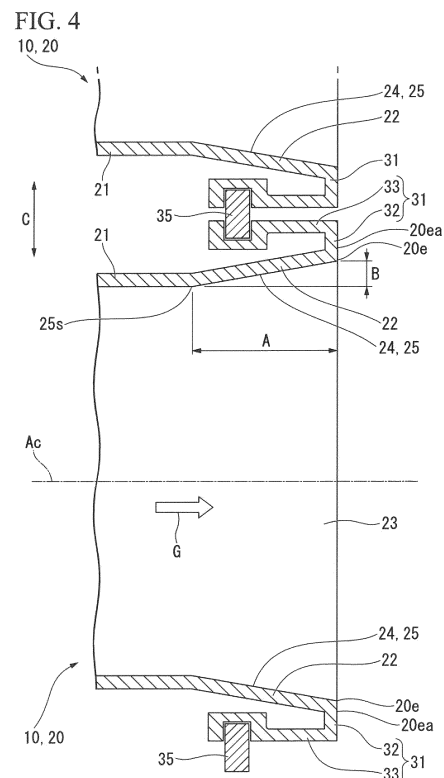
(71) Applicant: **Mitsubishi Heavy Industries, Ltd.**  
**Tokyo 108-8215 (JP)**

(74) Representative: **Henkel, Breuer & Partner**  
**Patentanwälte**  
**Maximiliansplatz 21**  
**80333 München (DE)**

(72) Inventors:  
• **SAKAMOTO, Yasuro**  
Tokyo 108-8215 (JP)  
• **MATSUYAMA, Keisuke**  
Tokyo 108-8215 (JP)

(54) **GAS TURBINE**

(57) In this gas turbine, at a downstream part of a tail pipe of a combustor, the inner surfaces of a pair of lateral walls facing each other in the circumferential direction of a turbine rotor form inclination surfaces that, going in the downstream axial direction of the tail pipe, incline in a direction approaching the tail pipe of an adjacent other combustor that gradually draws closer, until the inclination surfaces reach the downstream end of the tail pipe.



**EP 2 752 622 A1**

**Description**

## Technical Field

5 **[0001]** The present invention relates to a gas turbine including a plurality of combustors configured to mix and combust fuel with compressed air to generate combustion gas, and a turbine having a rotor that is rotated by the combustion gas from the plurality of combustors, and particularly, to a transition piece of a combustor.

**[0002]** Priority is claimed on Japanese Patent Application No. 2011-203016, filed September 16, 2011, the content of which is incorporated herein by reference.

10

## Background Art

**[0003]** Gas turbines include a compressor that brings in the outside air to generate compressed air, a plurality of combustors that mix and combust fuel with the compressed air to generate combustion gas, and a turbine having a rotor that is rotated by the combustion gas from the plurality of combustors. The plurality of combustors are annularly arranged with a rotor as a center. Each combustor has a transition piece through which combustion gas is flowed to a gas inlet of the turbine.

15

**[0004]** If the combustion gas flows out of the transition piece of the combustor, the combustion gas enters a combustion gas flow channel of the turbine from the gas inlet of the turbine. In this case, a Karman's vortex street may be formed in the flow of the combustion gas immediately after flowing out of the transition piece, an unsteady pressure fluctuation that has this Karman's vortex street as a vibration source may resonate at an acoustic eigenvalue, and a large pressure fluctuation may occur, which leads to an operating load.

20

**[0005]** Thus, in the technique described in the following PTL 1, a large pressure fluctuation is suppressed by limiting a dimension in an axis direction between a downstream end of a transition piece and an upstream end of a first stage turbine vane, a dimension in a circumferential direction between the upstream end of the first stage turbine vane and the center between transition pieces that are adjacent to each other in the circumferential direction centered on a rotor, or the like to specific ranges.

25

## Citation List

30

## Patent Literature

**[0006]** [PTL 1]: Japanese Unexamined Patent Application, First Publication No. 2009-197650

## 35 Summary of Invention

## Problem to be Solved by the Invention

**[0007]** The technique described in the above PTL 1 can reliably suppress a large pressure fluctuation at the downstream portion of the transition piece. However, it is desired to further suppress the pressure fluctuation at the downstream portion of the transition piece and to further enhance the gas turbine efficiency.

40

**[0008]** Thus, an object of the invention is to provide a gas turbine that can further suppress pressure fluctuation at a downstream portion of a transition piece of a combustor and can further enhance gas turbine efficiency, so as to meet such requests.

45

## Means for Solving the Problem

**[0009]** (1) A gas turbine according to a first aspect of the invention includes a plurality of combustors configured to mix and combust fuel with compressed air to generate combustion gas; and a turbine having a rotor that is rotated by the combustion gas from the plurality of combustors. The plurality of combustors are annularly arranged with the rotor as a center and have a transition piece through which combustion gas is flowed to a gas inlet of the turbine. An inner surface of at least one lateral wall of a pair of lateral walls that constitute a downstream portion of the transition piece of the combustor and face each other in a circumferential direction of the rotor forms an inclination surface that inclines down to a downstream end of the transition piece in a direction approaching the transition piece of another adjacent combustor that gradually draws closer as it goes to the downstream side of the transition piece in an axis direction.

50

55

**[0010]** Even after the combustion gas that flows toward the downstream side through the inside of the transition piece has flowed out of the inside of the transition piece, the combustion gas tends to flow in a direction along the inner surfaces of the lateral walls. Therefore, a Karman's vortex street may be formed on the downstream side of a downstream end

surface of the transition piece.

**[0011]** In the gas turbine, the inner surfaces of the lateral walls on the downstream side of the transition piece form inclination surfaces down to the downstream end of the transition piece. Therefore, flows along the inner surfaces of the lateral walls of the transition piece of the combustor that are adjacent to each other join each other at an angle on the downstream side of the downstream end surface of the transition piece. Therefore, formation of the Karman's vortex street on the downstream side of the downstream end surface of the transition piece can be suppressed, and the pressure fluctuation of the downstream portion of the transition piece can be suppressed.

**[0012]** (2) In the gas turbine of the above (1), the turbine may include a plurality of first stage turbine vanes arranged annularly along the gas inlet with the rotor as a center, and each of the first stage turbine vanes may be formed such that a chord direction in which a chord extends inclines with respect to the circumferential direction. Where a side to which a downstream end of the first stage turbine vane is located with respect to an upstream end of the first stage turbine vane in the circumferential direction is defined as a blade inclination side, at least one lateral wall of the transition piece may be a lateral wall on the blade inclination side out of the pair of lateral walls of the transition piece facing each other in the circumferential direction.

**[0013]** Where the inner surface of only the lateral wall on the blade inclination side out of the pair of lateral walls of the transition piece facing each other in the circumferential direction is the inclination surface, the flow direction of the combustion gas guided by the inclination surface and the flow direction of the combustion gas guided by the first stage turbine vane are almost the same. As a result, the flow of the combustion gas from the transition piece to the first stage turbine vane becomes smooth. For this reason, even if the inner surface of only the lateral wall on the blade inclination side is the inclination surface, the pressure fluctuation of the downstream portion of the transition piece can be effectively suppressed. In addition, the chord is a line segment that connects the upstream end and downstream end of a turbine vane.

**[0014]** (3) In the gas turbine of the above (1), both of the inner surfaces of the pair of lateral walls of the transition piece facing each other in the circumferential direction may form the inclination surfaces.

**[0015]** In the gas turbine, formation of the Karman's vortex street on the downstream side of the respective downstream end surfaces of the transition piece connected from the inner surfaces of the pair of lateral walls of the transition piece can be suppressed.

**[0016]** (4) In the gas turbine of any one of the above (1) to (3), a ratio A/B of a dimension A in the axis direction from an upstream end of the inclination surface to a downstream end thereof, to a dimension B in the circumferential direction from the upstream end of the inclination surface to the downstream end thereof, may be 1 to 8.

**[0017]** (5) In the gas turbine according to any one of the above (1) to (4), the inclination surface may include a curved surface, which swells toward the axis of the transition piece and toward the downstream side, in at least a portion thereof.

**[0018]** (6) In the gas turbine of any one of the above (1) to (5), the ratio of the number of the combustors to the number of the first stage turbine vanes may be an odd number that is equal to or more than 2:3, and a ratio S/P of a dimension S in the circumferential direction from an intermediate point between the transition piece of the combustor and the transition piece of the other combustor to the upstream end of the first stage turbine vane nearest to the intermediate point in the circumferential direction, to a pitch dimension P of the plurality of first stage turbine vanes, may be equal to or less than 0.05, between 0.2 to 0.55, or between 0.7 to 1.0.

**[0019]** In the gas turbine, any first stage turbine vanes are present relatively closely in the circumferential direction, even at the respective downstream ends of the transition piece connected from the respective inner surfaces of the pair of lateral walls of the transition piece of any combustor. Therefore, pressure fluctuation on the downstream side of the respective transition pieces can be suppressed due to the presence of the first stage turbine vanes.

**[0020]** (7) In the gas turbine of any one of the above (1) to (6), a ratio L/P of a dimension L in the axis direction from the downstream end of the transition piece to the upstream end of the first stage turbine vane, to a pitch dimension P of the plurality of first stage turbine vanes, may be equal to or less than 0.2.

**[0021]** In the gas turbine, the first stage turbine vane is present relatively closely in the axis direction of the transition piece on the downstream end of the transition piece. Therefore, pressure fluctuation on the downstream side of the respective transition piece can be suppressed due to the presence of the first stage turbine vane.

#### Effects of the Invention

**[0022]** In the invention, formation of the Karman's vortex street on the downstream side of the downstream end surface of the transition piece can be suppressed, and pressure fluctuation of the downstream portion of the transition piece can be suppressed. For this reason, according to the invention, gas turbine efficiency can be enhanced.

#### Brief Description of the Drawings

**[0023]**

FIG. 1 is an overall side view in which main portions of a gas turbine in an embodiment related to the invention are cut out.

FIG. 2 is a cross-sectional view of the circumference of a combustor of a gas turbine in one embodiment related to the invention.

FIG. 3 is a perspective view of a transition piece in the embodiment related to the invention.

FIG. 4 is a cross-sectional view of a downstream side of the transition piece in the embodiment related to the invention.

FIG. 5 is a graph showing the relationship between the inclination rate of an inclination surface and pressure fluctuation range in the embodiment related to the invention.

FIG. 6 is an explanatory view showing the positional relationship between the transition piece and first stage turbine vanes in the embodiment related to the invention.

FIG. 7 is an explanatory view showing pressure fluctuations on the downstream side of the transition piece in the embodiment related to the invention, FIG. 7(a) shows a case where a circumferential ratio is 10%, FIG. 7(b) shows a case where the circumferential ratio is 22.5%, FIG. 7(c) shows a case where the circumferential ratio is 35%, and FIG. 7(d) shows a case where the circumferential ratio is 47.5%.

FIG. 8 is a graph showing the relationship between the pressure fluctuation range and the circumferential ratio on the downstream side of the transition piece of the embodiment related to the invention.

FIG. 9 is a cross-sectional view on the downstream side of the transition piece for showing modification examples of an inclination surface of the embodiment related to the invention, FIG. 9(a) shows a first modification example of the inclination surface, and FIG. 9(b) shows a second modification example of the inclination surface.

FIG. 10 is an explanatory view showing the positional relationship between an inclination surface of a transition piece and first stage turbine vanes in a modification example of one embodiment related to the invention.

#### Description of Embodiments

**[0024]** Hereinafter, an embodiment of a gas turbine related to the invention will be described in detail with reference to the drawings.

**[0025]** As shown in FIG 1, the gas turbine of the present embodiment includes a compressor 1 that compresses the outside air to generate compressed air, a plurality of combustors 10 configured to mix and combust the fuel from a fuel supply source with the compressed air to generate combustion gas, and a turbine 2 that is driven by the combustion gas.

**[0026]** The turbine 2 includes a casing 3, and a turbine rotor 5 that rotates within the casing 3. The turbine rotor 5 has a rotor body 6 configured such that a plurality of rotor disks are stacked, and a plurality of turbine blades 7 that extend in a radial direction from the rotor disks for each rotor disk. That is, the turbine rotor 5 has a multi-stage turbine blade configuration.

**[0027]** For example, a generator (not shown) that generates electricity by the rotation of the turbine rotor 5 is connected to the turbine rotor 5. Additionally, a plurality of turbine vanes 4 that extend in a direction approaching the rotor body 6 from an inner peripheral surface of the casing are respectively fixed to the casing 3 on the upstream side of the turbine blade 7 of each stage.

**[0028]** The plurality of combustors 10 are fixed to the casing 3 at equal intervals from each other in the circumferential direction with a rotation axis  $A_r$  of the turbine rotor 5 as a center.

**[0029]** As shown in FIG. 2, the combustor 10 includes a transition piece 20 through which high-temperature and high-pressure combustion gas G is flowed from a gas inlet 9 of the turbine 2 into a gas flow passage 8 of the turbine 2, and a fuel supply device 11 that supplies fuel and compressed air Air into the transition piece 20. The turbine blades 7 and the turbine vanes 4 of the turbine 2 are arranged in the gas flow passage 8. The fuel supply device 11 includes a pilot burner 12 that supplies pilot fuel X into the transition piece 20 to form a diffusion flame in the transition piece 20, and a plurality of main nozzles 13 that premix main fuel Y and the compressed air Air to supply premixed gas into the transition piece 20 and forms a premixed flame in the transition piece 20.

**[0030]** As shown in FIGS. 2 and 3, the transition piece 20 has a trunk 21 that forms a tubular shape and has the combustion gas G flowing on an inner peripheral side thereof, and an outlet flange 31 that is provided at a downstream end portion of the trunk 21 and spreads in a direction away from the axis  $A_c$  of the transition piece 20.

**[0031]** The cross-sectional shape of the trunk 21 on the downstream side has an oblong shape, and the trunk 21 has, at a downstream portion, a pair of lateral walls 22 facing each other in a circumferential direction C centered on the rotation axis  $A_r$  of the turbine rotor 5, and a pair of lateral walls 23 facing each other in a radial direction centered on the rotation axis  $A_r$ .

**[0032]** As shown in FIG. 4, the outlet flange 31 provided at the downstream end portion of the trunk 21 has a flange body portion 32 that spreads in the direction away from the downstream end of the trunk 21 with respect to the axis  $A_c$  of the transition piece 20, and a facing portion 33 that extends toward the upstream side from an outer edge of the flange body portion 32. A downstream end surface of the flange body portion 32 forms a downstream end surface 20ea of the transition piece 20. Additionally, a seal member 35 that seals a space between the transition pieces of the adjacent

combustors 10 is provided between this facing portion 33 and the facing portion 33 of the transition piece 20 of an adjacent combustor 10 in the circumferential direction C. In addition, in the present embodiment, the portion of the trunk 21 on the downstream side, that is, the lateral walls 22 and 23 of the downstream portion of the trunk 21, and the flange body portion 32 are formed from an integrally molded article.

**[0033]** Respective inner surfaces 24 of the pair of lateral walls 22 facing each other in the circumferential direction C form inclination surfaces 25 that incline down to a downstream end 20e of the transition piece 20 in the direction approaching the transition piece 20 of another adjacent combustor 10 that gradually draws closer as it goes to the downstream side in the direction of the axis Ac of the transition piece 20. That is, the downstream ends of the inclination surfaces 25 are downstream ends 20e of the transition piece 20.

**[0034]** Even after the combustion gas G that flows toward the downstream side through the inside of the transition piece 20 has flowed out of the inside of the transition piece 20, the combustion gas tends to flow in a direction along the inner surfaces 24 of the lateral walls 22. Therefore, a Karman's vortex street may be formed on the downstream side of the downstream end surface 20ea of the flange body portion 32.

**[0035]** In the present embodiment, since the inner surfaces 24 of the lateral walls 22 of the downstream portion of the transition piece 20 form the inclination surfaces 25, the angle formed by the downstream end surface 20ea of the flange body portion 32 and the inner surfaces 24 of the lateral walls 22 is smaller than that in a case where the inner surfaces 24 do not form the inclination surfaces 25. Hence, in the present embodiment, formation of the Karman's vortex street on the downstream side of the downstream end surface 20ea of the flange body portion 32 can be suppressed, and pressure fluctuation of the downstream portion of the transition piece 20 can be suppressed.

**[0036]** Here, since the pressure fluctuation range of the downstream portion of the transition piece 20 when changing the inclination rate of each inclination surface 25 was simulated, the results of this simulation will be described. In addition, in this simulation, as shown in FIG. 4, the ratio A/B of a dimension A in the direction of the axis Ac from the upstream end 25s to the downstream end 20e, to a dimension B in the circumferential direction C from an upstream end 25s of the inclination surface 25 to a downstream end 20e (= the downstream end of the transition piece 20) thereof, is defined as the inclination rate of the inclination surface 25.

**[0037]** As a result of this simulation, as shown in FIG 5, it can be understood that, when the inclination rate A/B is 1 to 8, a pressure fluctuation range  $\Delta P$  of the downstream portion of the combustor 10 is small. This is because, where the inclination rate A/B is less than 1 and more than 8, the inclination is too steep or too gentle and therefore, the effect as the inclination surface 25 cannot be sufficiently obtained. Moreover, it can also be understood that, if the inclination rate A/B of the inclination surface 25 is 2 to 6, the pressure fluctuation range  $\Delta P$  is extremely small. In addition, as the flow velocity of the combustion gas G that flows through the inside of the transition piece 20 becomes higher, the pressure fluctuation range  $\Delta P$  also becomes larger. However, the relationship between the inclination rate A/B of the inclination surface 25 and the pressure fluctuation range  $\Delta P$  is fundamentally the same even if the flow velocity of the combustion gas G that flows through the inside of the transition piece 20 changes.

**[0038]** For this reason, it can be said that the preferable range Ra of the inclination rate A/B of the inclination surface 25 is 1 to 8, and the more preferable range Rb is 2 to 6.

**[0039]** Moreover, here, since the pressure fluctuation range at the downstream portion of the combustor 10 when changing the relative positions between the transition piece 20 and the first stage turbine vanes 4a was also simulated herein, the results of this simulation will also be described. Specifically, as shown in FIG 6, the relationship between the pressure fluctuation range  $\Delta P$ , and the ratio S/P (hereinafter referred to as a circumferential ratio S/P) of a dimension S in the circumferential direction C from an intermediate point M between the transition piece 20 of a specific combustor 10a and the transition piece 20 of another adjacent combustor 10b adjacent to the specific combustor on one side in the circumferential direction C to an upstream end 4s of the first stage turbine vane 4a nearest to the intermediate point on one side in the circumferential direction C, to a pitch dimension P in the circumferential direction C of the plurality of first stage turbine vanes 4a, was simulated.

**[0040]** In addition, this simulation was performed with the ratio of the number Nc of the combustors 10 and the number Ns of the first stage turbine vanes 4a being 2:3 and with the inclination rate A/B of the inclination surface 25 of the transition piece 20 being 2.75. Moreover, this simulation was performed with the ratio L/P (hereinafter referred to as an axis-direction ratio L/P) of a dimension L in the direction of the axis Ac from the downstream end 20e of the transition piece 20 to the upstream end 4s of the first stage turbine vane 4a to the pitch dimension P being 12%.

**[0041]** As shown in FIG. 8, where the axis-direction ratio L/P is 12%, there is almost no unsteady pressure fluctuation with the circumferential ratio S/P being 0% to 5%. However, where the circumferential ratio S/P exceeds 5%, a large pressure fluctuation range  $\Delta P$  begins to be seen, and where the circumferential ratio S/P reaches 10%, the pressure fluctuation range  $\Delta P$  becomes larger.

**[0042]** As shown in FIG. 7(a), where the circumferential ratio S/P is 10%, an unsteady pressure fluctuation is not seen on the downstream side between the transition piece 20 of a specific combustor 10a and the transition piece 20 of another combustor 10b that is adjacent to the specific combustor on one side in the circumferential direction C. However, on the downstream side between the transition piece 20 of the specific combustor 10a and the transition piece 20 of

another combustor 10c that is adjacent to the specific combustor on the other side in the circumferential direction C, the Karman's vortex street V is generated and a relatively large unsteady pressure fluctuation occurs. It is considered that this is because the dimension in the circumferential direction C from a position between the transition piece 20 of the specific combustor 10a and the transition piece 20 of the other combustor 10c that is adjacent to the specific combustor on the other side in the circumferential direction C to the upstream end 4s of the first stage turbine vane 4a nearest to the position in the circumferential direction C becomes large. In addition, thin lines in FIG. 7 indicate isostatic lines.

**[0043]** Hence, it is be considered that, where the circumferential ratio S/P reaches 10%, the pressure fluctuation range  $\Delta P$  becomes large. However, in this simulation, since the inclination rate A/B of the inclination surface 25 is 2.75 that is in a more preferable range Rb (2 to 6), the pressure fluctuation range  $\Delta P$  is smaller than that in a case where the inclination surface 25 is not formed, or the like.

**[0044]** The pressure fluctuation range  $\Delta P$  becomes drastically small as shown in FIG. 8 if the circumferential ratio S/P reaches 20%, and an unsteady pressure fluctuation is hardly seen where the circumferential ratio S/P reaches 22.5%. As shown in FIG. 7(b), where the circumferential ratio S/P is 22.5%, an unsteady pressure fluctuation is hardly seen on the downstream side between the transition piece 20 of the specific combustor 10a and the transition piece 20 of the other combustor 10b that is adjacent to the specific combustor on one side in the circumferential direction C and even on the downstream side between the transition piece 20 of the specific combustor 10a and the transition piece 20 of the other combustor 10c that is adjacent to the specific combustor on the other side in the circumferential direction C.

**[0045]** The unsteady pressure fluctuation, as shown in FIG. 7(c) and FIG. 7(d), are hardly seen even where the circumferential ratios S/P are 35 and 47.5%. However, as shown in FIG. 8, where the circumferential ratio S/P exceeds 55%, a large pressure fluctuation range  $\Delta P$  begins to be seen again, and where the circumferential ratio S/P reaches 60%, the pressure fluctuation range  $\Delta P$  becomes larger. It is considered that this is because the dimension in the circumferential direction C from the position between the transition piece 20 of the specific combustor 10a and the transition piece 20 of the other combustor 10b that is adjacent to the specific combustor on one side in the circumferential direction C to the upstream end 4s of the first stage turbine vane 4a nearest to the position in the circumferential direction C is large. That is, it is considered that, where circumferential ratio S/P is 60%, the same phenomenon occurs for the reason that is fundamentally the same as that where the circumferential ratio S/P is 10%.

**[0046]** The pressure fluctuation range  $\Delta P$  becomes drastically small where the circumferential ratio S/P reaches 70%, and an unsteady pressure fluctuation is hardly seen where the circumferential ratio S/P becomes 72.5%. An unsteady pressure fluctuation is hardly seen thereafter until the circumferential ratio S/P reaches 100%.

**[0047]** As described above, it can be understood that, when where the circumferential ratios S/P are 0 to 5%, 20 to 55%, and 70 to 100%, an unsteady pressure fluctuation is hardly seen, and the pressure fluctuation range  $\Delta P$  of the downstream portion of the transition piece 20 becomes extremely small. That is, it can be understood that the preferable ranges Rc of the circumferential ratio S/P are 0 to 5%, 20 to 55%, and 70 to 100%.

**[0048]** Moreover, here, the axis-direction ratio L/P was changed and the relationship between the circumferential ratio S/P and the pressure fluctuation range  $\Delta P$  was simulated similarly to the above.

**[0049]** As shown in FIG 8, even where the axis-direction ratios L/P are 18%, 20%, and 27%, the same tendency as that where the aforementioned axis-direction ratio L/P is 12% is seen as the changes in the pressure fluctuation range  $\Delta P$  to the changes in the circumferential ratio S/P. That is, it can be understood that, when the circumferential ratios S/P are 0 to 5%, 20 to 55%, and 70 to 100% similar to a case where the aforementioned axis-direction ratio L/P is 12%, the pressure fluctuation range  $\Delta P$  of the downstream portion of the combustor 10 is relatively small compared to cases where the circumferential ratios S/P are 5 to 20% and 55 to 70%.

**[0050]** However, it can be understood that, in cases where the circumferential ratios S/P are 0 to 5%, 20 to 55%, and 70 to 100% where the axis-direction ratios L/P are 18% and 20%, an unsteady pressure fluctuation is hardly seen and the absolute value of the pressure fluctuation range  $\Delta P$  is small similar to when the aforementioned axis-direction ratio L/P is 12%, but even in cases where the circumferential ratios S/P are 0 to 5%, 20 to 55%, and 70 to 100% where the axis-direction ratio L/P is 27%, the absolute value of the pressure fluctuation range  $\Delta P$  is large.

**[0051]** That is, it can be understood that the pressure fluctuation range  $\Delta P$  becomes small as the axis-direction ratio L/P is made equal to or less than 20%.

**[0052]** Additionally, the above-described simulation results are results in a case where the ratio of the number Nc of the combustor 10 and the number Ns of the first stage turbine vanes 4a is 2:3. However, it is considered that, even in the cases of Nc:Ns = 2:5, Nc:Ns = 2:7, and Nc:Ns = 2:9 or more, the same results as in the above are obtained regarding the relationship between the relative positions of the transition piece 20 and the first stage turbine vanes 4a and the pressure fluctuation range  $\Delta P$  on the downstream portion of the transition piece 20. However, as the number Ns of the first stage turbine vanes 4a becomes larger than the number Nc of the combustors 10, the absolute value of the pressure fluctuation range  $\Delta P$  when the pressure fluctuation range  $\Delta P$  becomes large becomes smaller at any value of the circumferential ratio S/P or the axis-direction ratio L/P. As a result, it is considered that, where the number Ns of the first stage turbine vanes 4a becomes larger, an unsteady pressure fluctuation is hardly seen at any value of the circumferential ratio S/P or the axis-direction ratio L/P.

**[0053]** In addition, where the number  $N_c$  of the combustors 10 and the number  $N_s$  of the first stage turbine vanes 4a is 1:natural number, the upstream end 4s of the first stage turbine vane 4a can be arranged directly below the position between the transition piece 20 of each combustor 10 and the other transition piece 20 that is adjacent to the combustor of each combustor. Therefore, an unsteady pressure fluctuation can be almost eliminated by arranging the first stage turbine vanes 4a in this way.

**[0054]** Next, various modification examples of the inclination surface 25 of the transition piece 20 will be described.

**[0055]** In the inclination surface 25 of the above embodiment, the whole surface from the upstream end 25s of the inclination surface to the downstream end 20e thereof is a planar surface. However, the inclination surface 25 does not need to be a planar surface as a whole, and may also include curved surfaces in at least portions thereof.

**[0056]** Specifically, the curved surfaces, as shown in FIG. 9, are curved surfaces 26a, 26b, and 26c that swell smoothly toward the axis  $A_c$  of the transition piece 20 and toward the downstream side. For example, as for the curved surface 26a, as shown in FIG. 9a, in a boundary region 26a between the inclination surface 25 and the downstream end surface 20ea of the flange body portion 32, that is, a downstream end of the curved surface 26a coincides with the downstream end 20e of the inclination surface 25. Additionally, as for the curved surface 26b, an upstream end of the curved surface 26b coincides with the upstream end 25s of the inclination surface 25. Additionally, as shown in FIG. 9(b), the whole inclination surface 25 is the curved surface 26c.

**[0057]** If the curved surfaces are adopted in at least a portion of the inclination surface 25 in this way, a place where the flow direction of the combustion gas G changes drastically is eliminated. Therefore, formation of the Karman's vortex street on the downstream side of the downstream end surface 20ea of the transition piece 20 can be further suppressed, and the pressure fluctuation of the downstream portion of the transition piece 20 can be more effectively suppressed. For this reason, when the curved surfaces are adopted in at least a portion of the inclination surface 25, the preferable range  $R_a$  of the inclination rate  $A/B$  of the inclination surface 25 becomes wider than the range of 1 to 8 that is described above.

**[0058]** Additionally, in the above embodiment, the respective inner surfaces 24 of the pair of lateral walls 22 facing each other in the circumferential direction C form the inclination surfaces 25. However, even if only one inner surface 24 forms the inclination surface 25, the pressure fluctuation of the downstream portion of the transition piece 20 can be suppressed. In this case, as shown in FIG. 10, where the side to which the downstream end 4e of a first stage turbine vane 4a is located with respect to the upstream end 4s of the first stage turbine vane 4a in the circumferential direction C is defined as a blade inclination side  $C_a$ , it is preferable that the inner surface 24 of the lateral wall 22 (22b in the case of FIG. 10) on the blade inclination side  $C_a$  out of the pair of lateral walls 22 (22a and 22b in the case of FIG. 10) facing each other in the circumferential direction C forms the inclination surface 25. This is because the flow direction of the combustion gas G guided by the inclination surface 25, and the direction of a chord that is a line segment that connects the upstream end 4s and the downstream end 4e of the first stage turbine vane 4a, that is, the flow direction of the combustion gas G guided by the first stage turbine vane 4a, are almost the same, and consequently, the flow of the combustion gas G from the transition piece 20 to the first stage turbine vane 4a becomes smooth and the pressure fluctuation of the downstream portion of the transition piece 20 can be effectively suppressed.

**[0059]** In addition, as described above, even if only the inner surface 24 of any one lateral wall 22 (22a or 22b in the case of FIG. 10) out of the pair of lateral walls 22 facing each other in the circumferential direction C forms the inclination surface 25, the relationship between the relative positions of the transition piece 20 and the first stage turbine vanes 4a and the pressure fluctuation range  $\Delta P$  at the downstream portion of the transition piece 20 is fundamentally the same as in the above simulation results.

Reference Signs List

**[0060]**

- 1: COMPRESSOR
- 2: TURBINE
- 3: CASING
- 4: TURBINE VANE
- 4a: FIRST STAGE TURBINE VANE
- 4s: UPSTREAM END (OF TURBINE VANE)
- 4e: DOWNSTREAM END (OF TURBINE VANE)
- 5: TURBINE ROTOR
- 6: ROTOR BODY
- 7: TURBINE BLADE
- 8: GAS FLOW PASSAGE
- 9: GAS INLET

10:	COMBUSTOR
20:	TRANSITION PIECE
20e:	DOWNSTREAM END (OF TRANSITION PIECE OR INCLINATION SURFACE)
20ea:	DOWNSTREAM END SURFACE (OF TRANSITION PIECE OR FLANGE BODY PORTION)
5 21:	TRUNK
22, 22a, 22b, 23:	LATERAL WALL
24:	INNER SURFACE
25:	INCLINATION SURFACE
25s:	UPSTREAM END (OF INCLINATION SURFACE)
10 26a, 26b, 26c:	CURVED SURFACE

**Claims**

- 15 **1.** A gas turbine comprising:
- a plurality of combustors configured to mix and combust fuel with compressed air to generate combustion gas; and
- 20 a turbine having a rotor that is rotated by the combustion gas from the plurality of combustors, wherein the plurality of combustors are annularly arranged with the rotor as a center and have a transition piece through which combustion gas is flowed to a gas inlet of the turbine, and wherein, at a downstream portion of the transition piece of the combustor, an inner surface of at least one lateral wall out of a pair of lateral walls facing each other in a circumferential direction of the rotor forms an inclination surface that inclines down to a downstream end of the transition piece in a direction approaching the transition piece of another adjacent combustor that gradually draws closer as it goes to the downstream side of the transition piece in an axis direction.
- 25 **2.** The gas turbine according to Claim 1, wherein the turbine includes a plurality of first stage turbine vanes arranged annularly along the gas inlet with the rotor as a center, and each of the first stage turbine vanes are formed such that a chord direction in which a chord extends inclines with respect to the circumferential direction, and wherein where the side to which a downstream end of the first stage turbine vane is located with respect to an upstream end of the first stage turbine vane in the circumferential direction is defined as a blade inclination side, at least one lateral wall of the transition piece is a lateral wall on the blade inclination side out of the pair of lateral walls of the transition piece facing each other in the circumferential direction.
- 30 **3.** The gas turbine according to Claim 1, wherein both of the inner surfaces of the pair of lateral walls of the transition piece facing each other in the circumferential direction form the inclination surfaces.
- 35 **4.** The gas turbine according to any one of Claims 1 to 3, wherein a ratio A/B of a dimension A in the axis direction from an upstream end of the inclination surface to a downstream end thereof, to a dimension B in the circumferential direction from the upstream end of the inclination surface to the downstream end thereof, is 1 to 8.
- 40 **5.** The gas turbine according to any one of Claims 1 to 4, wherein the inclination surface includes a curved surface, which swells toward the axis of the transition piece and toward the downstream side, in at least a portion thereof.
- 45 **6.** The gas turbine according to any one of Claims 1 to 5, wherein the ratio of the number of the combustors and the number of the first stage turbine vanes is an odd number that is equal to or more than 2:3, and wherein a ratio S/P of a dimension S in the circumferential direction from an intermediate point between the transition piece of the combustor and the transition piece of the other combustor to the upstream end of the first stage turbine vane nearest to the intermediate point in the circumferential direction, to a pitch dimension P of the plurality of first stage turbine vanes, is equal to or less than 0.05, between 0.2 to 0.55, or between 0.7 to 1.0.
- 50 **7.** The gas turbine according to any one of Claims 1 to 6,
- 55

**EP 2 752 622 A1**

wherein a ratio  $L/P$  of a dimension  $L$  in the axis direction from the downstream end of the transition piece to the upstream end of the first stage turbine vane, to a pitch dimension  $P$  of the plurality of first stage turbine vanes, is equal to or less than 0.2.

5

10

15

20

25

30

35

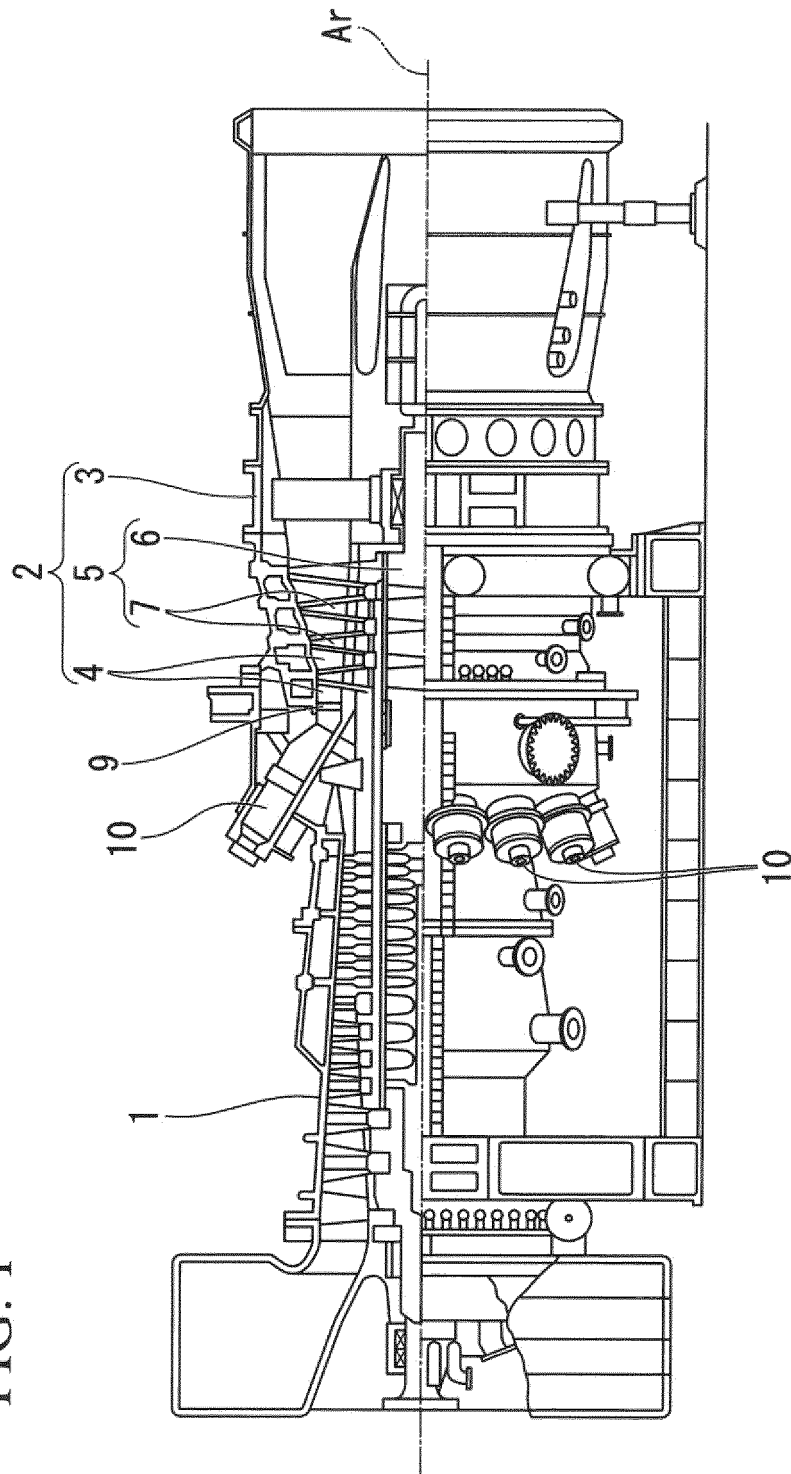
40

45

50

55

FIG. 1



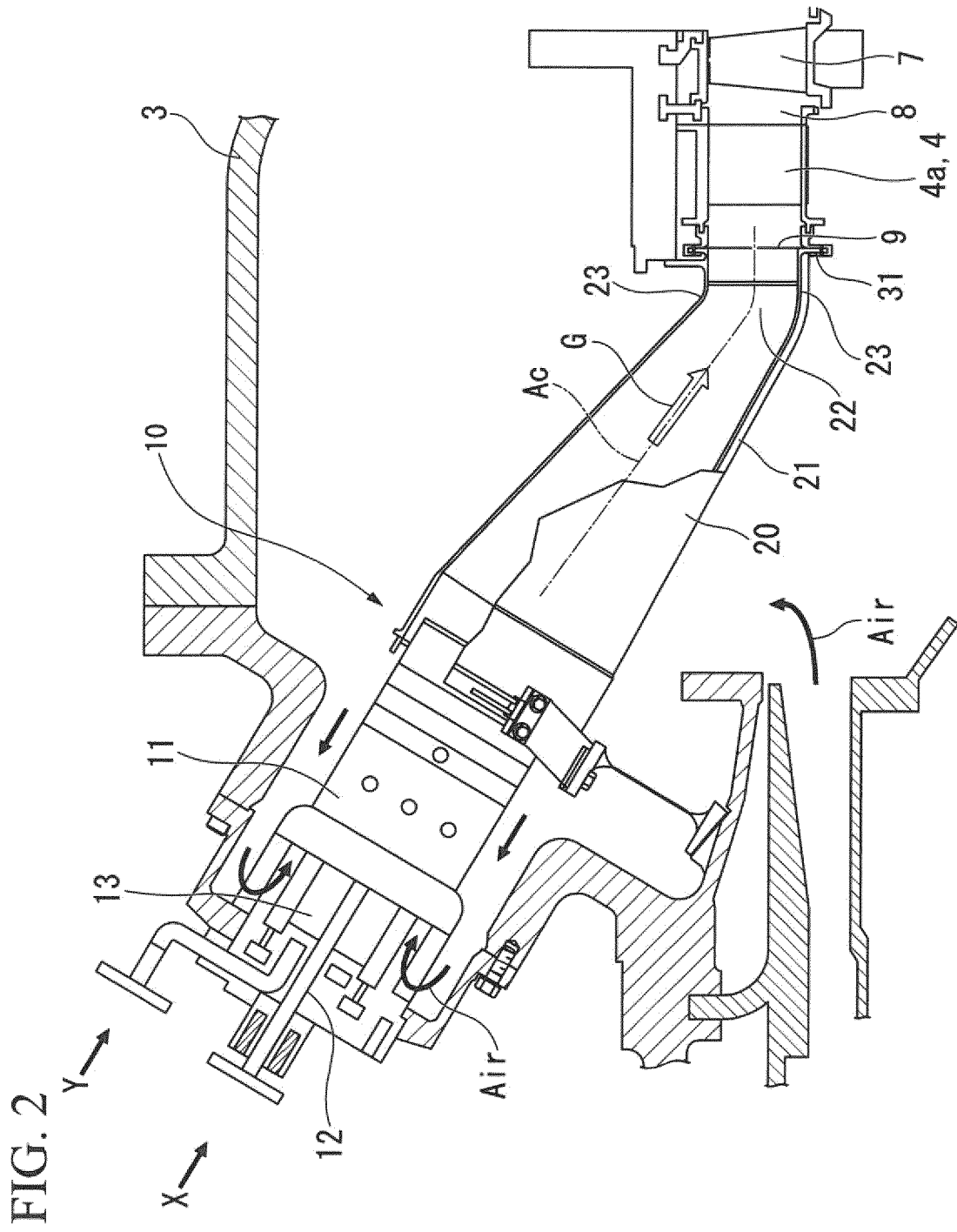


FIG. 3

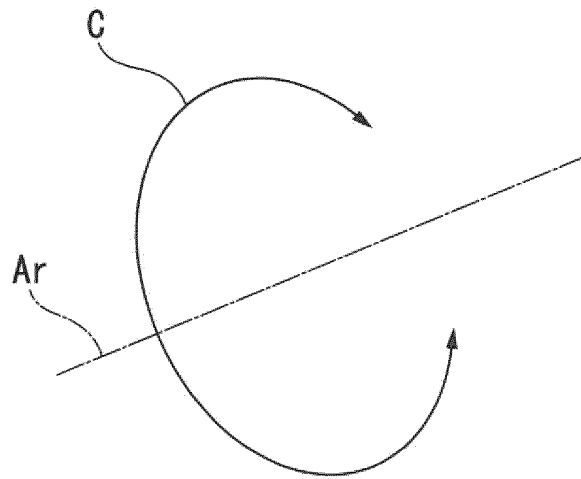
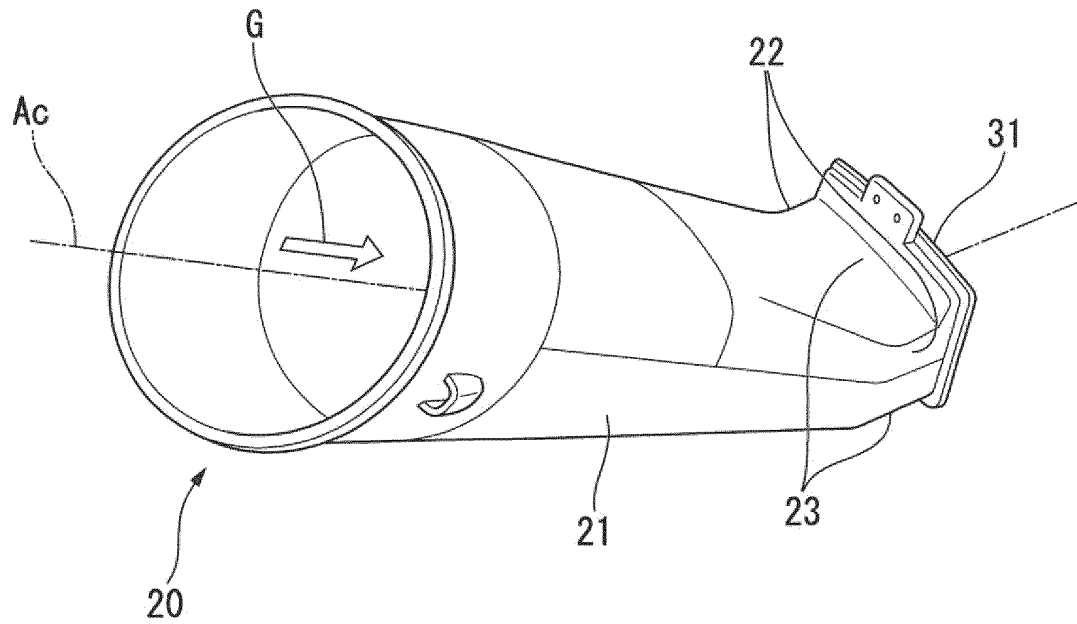


FIG. 4

10, 20

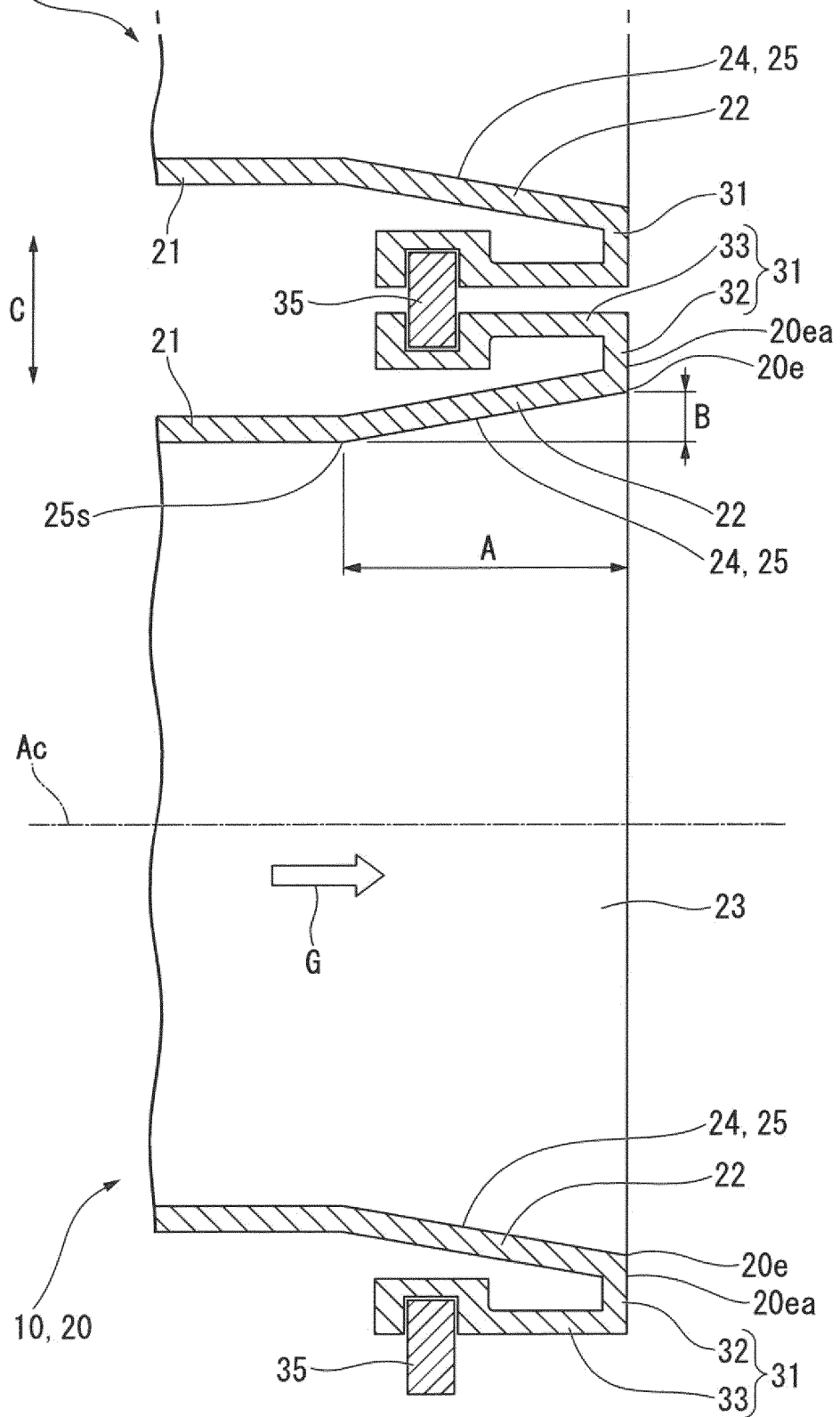


FIG. 5

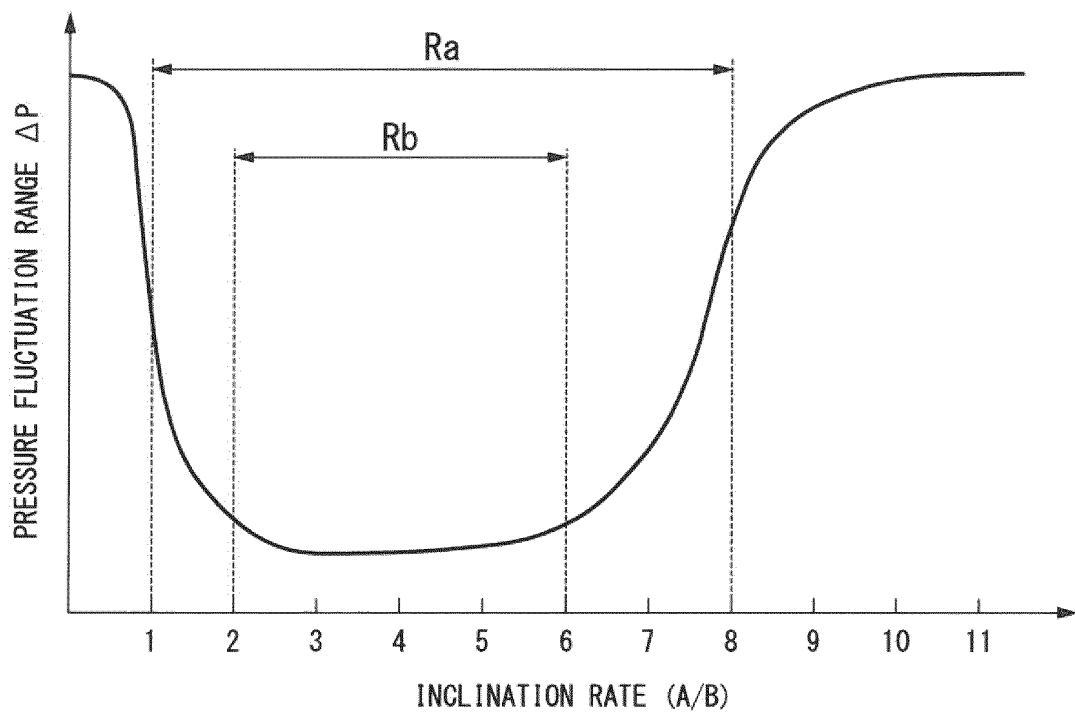


FIG. 6

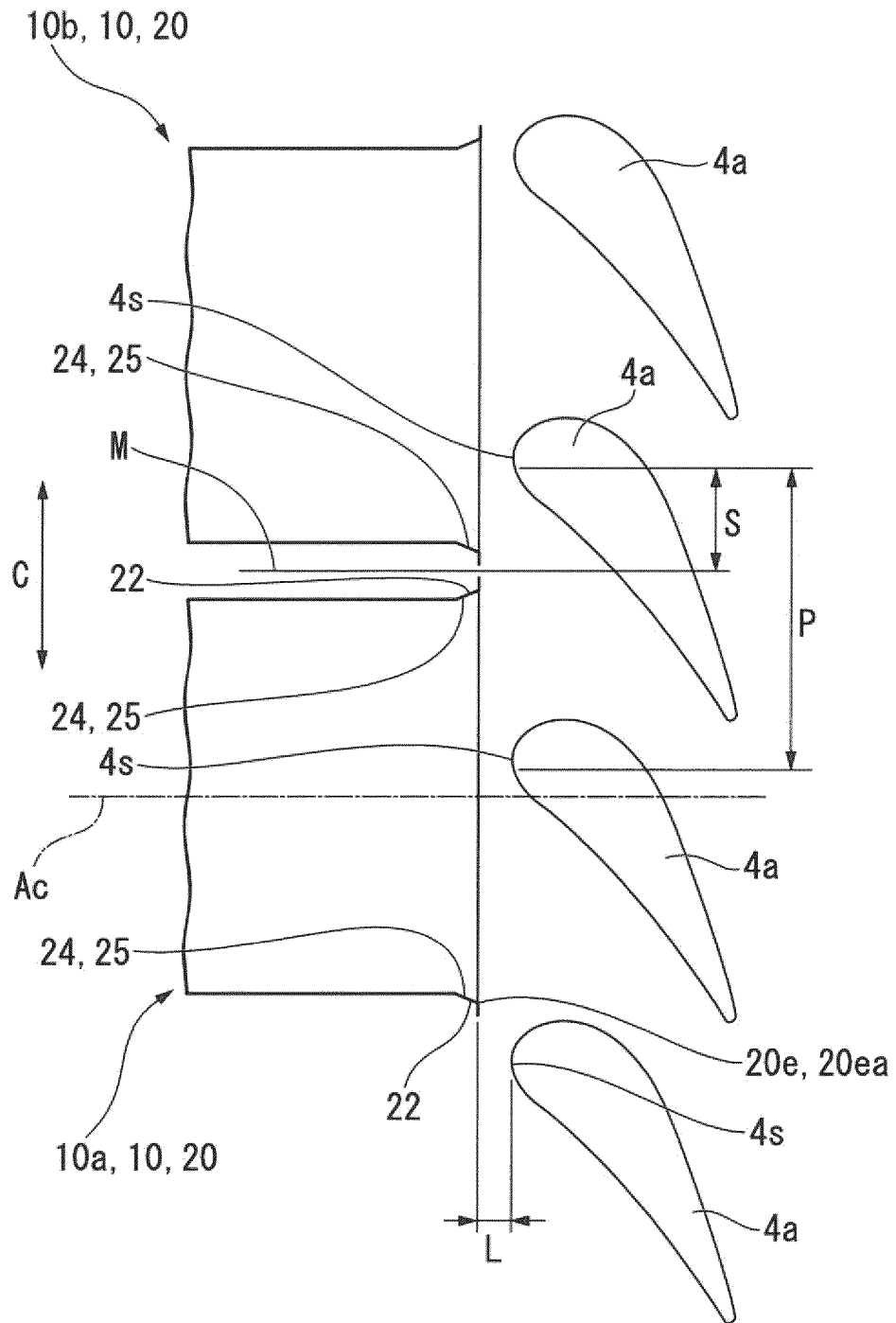


FIG. 7

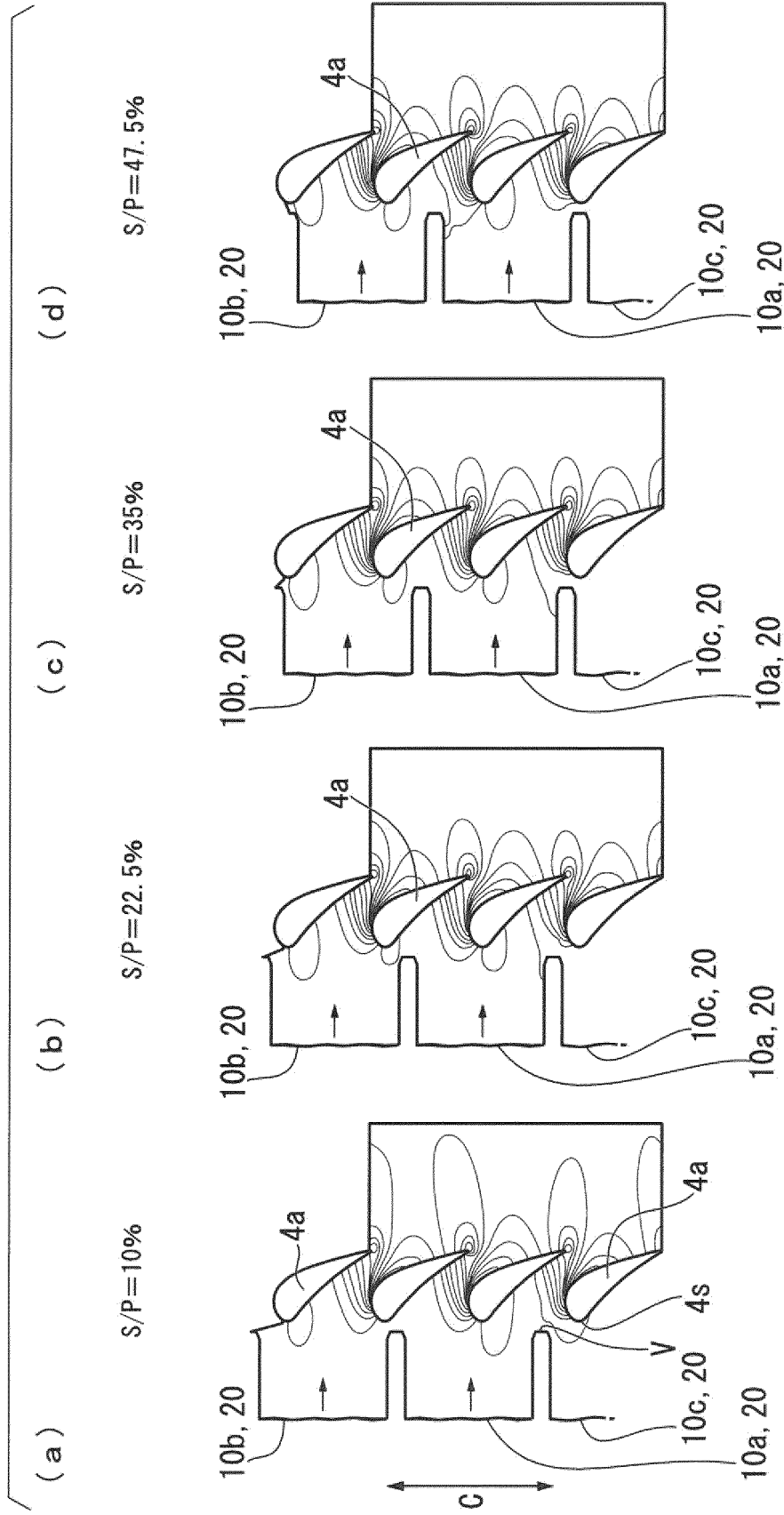


FIG. 8

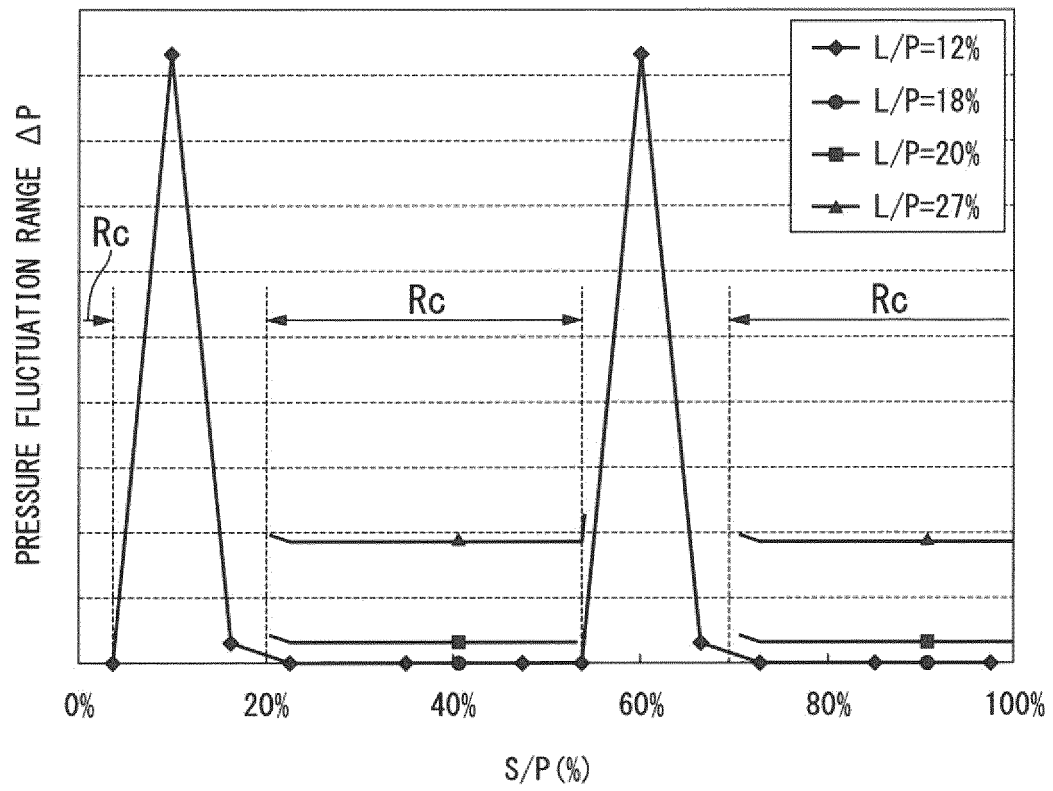


FIG. 9

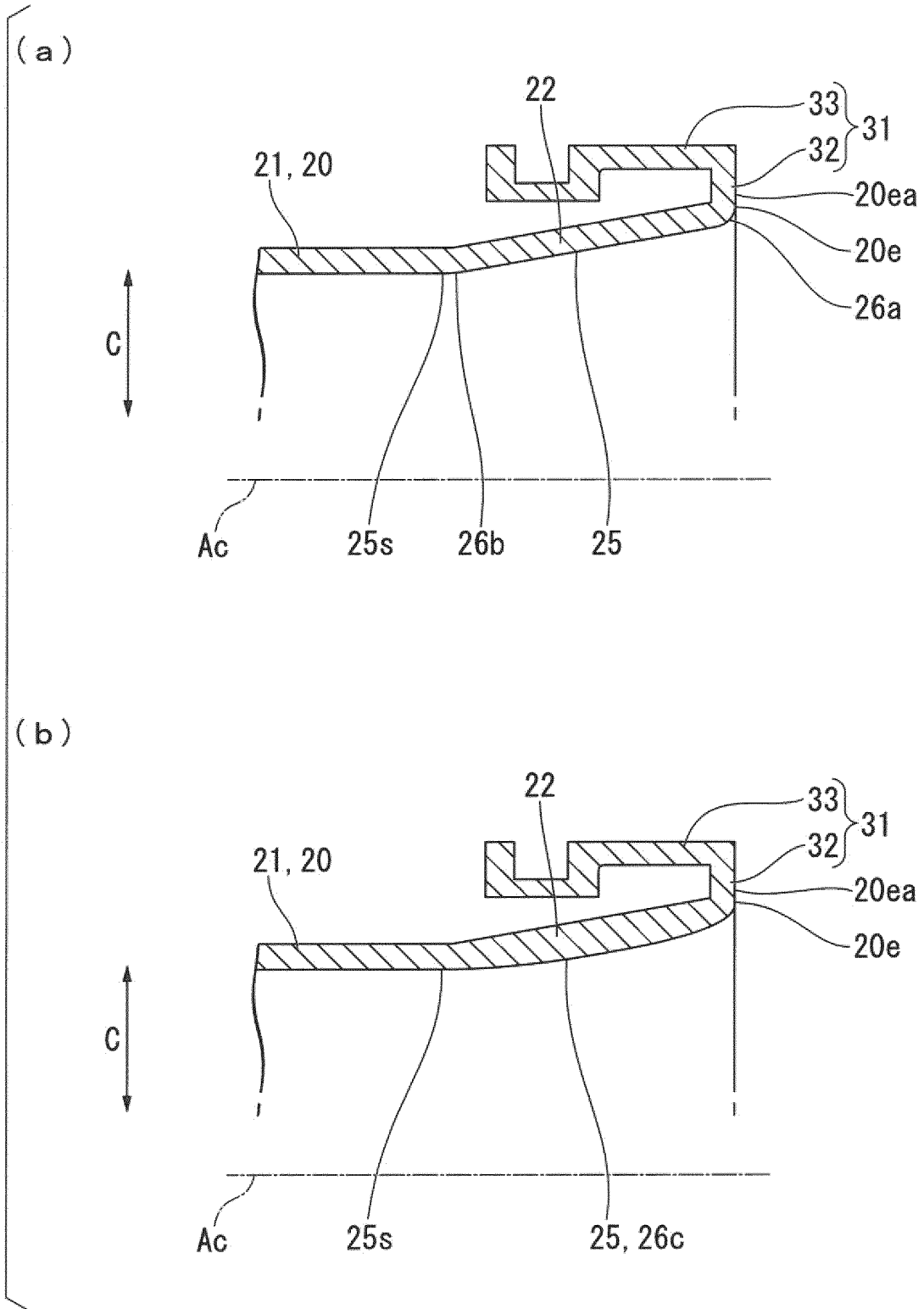
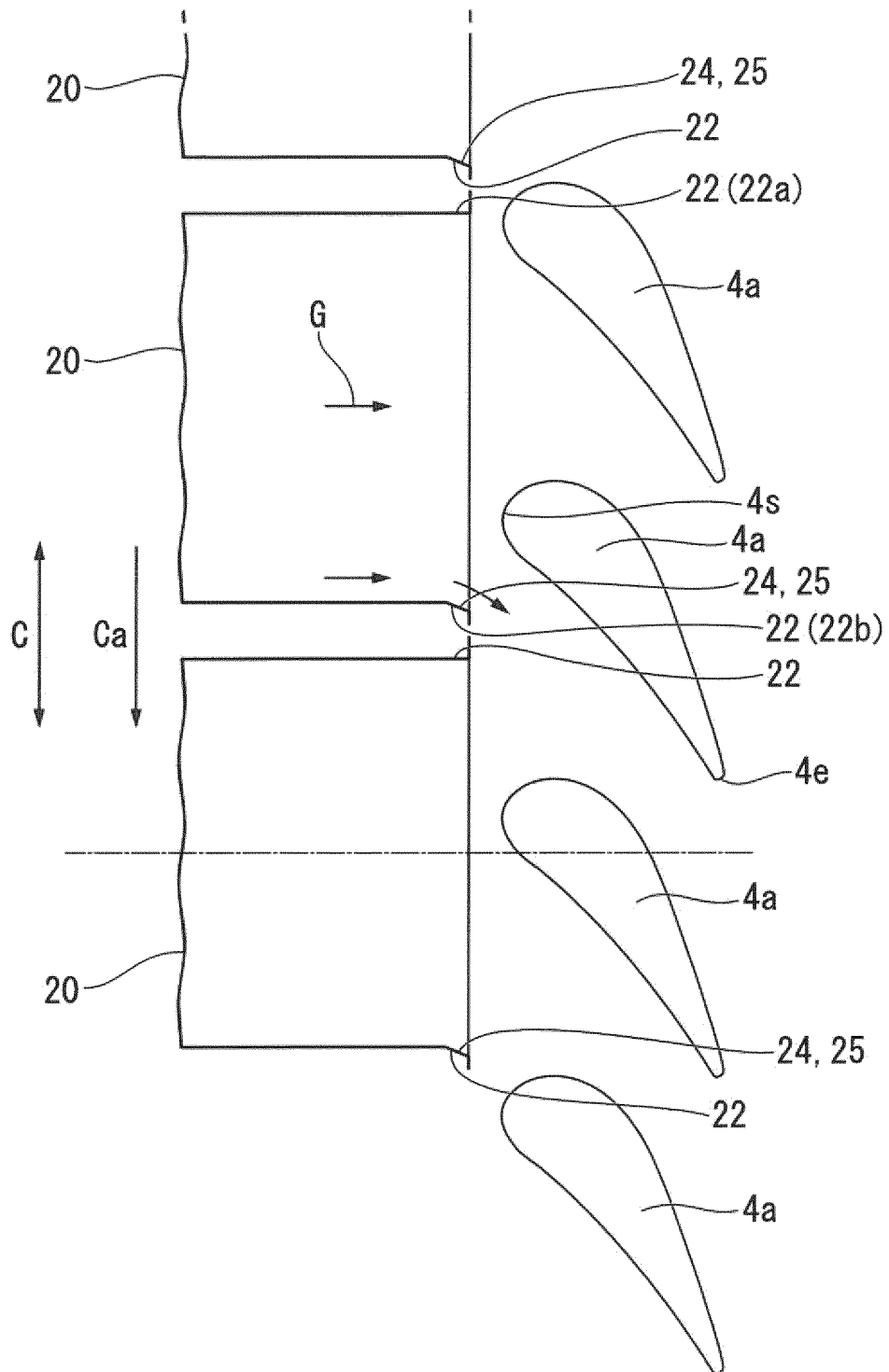


FIG. 10



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/073298

A. CLASSIFICATION OF SUBJECT MATTER F23R3/42(2006.01)i, F01D9/02(2006.01)i, F23R3/16(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) F23R3/42, F01D9/02, F23R3/16		
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.
Y A	JP 2009-197650 A (Mitsubishi Heavy Industries, Ltd.), 03 September 2009 (03.09.2009), paragraphs [0019] to [0030]; fig. 1, 2 & US 2010/0313567 A1 & EP 2251530 A1 & WO 2009/104317 A1 & KR 10-2010-0102213 A & CN 101946063 A	1-4, 7 5, 6
Y	JP 2004-116992 A (General Electric Co.), 15 April 2004 (15.04.2004), fig. 5, 6 & US 2004/0060298 A1 & EP 1403582 A2 & KR 10-2004-0027401 A & CN 1497217 A	1-4, 7
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 19 November, 2012 (19.11.12)		Date of mailing of the international search report 27 November, 2012 (27.11.12)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

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

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2012/073298

5

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
10 Y	JP 62-121835 A (Director General, Agency of Industrial Science and Technology), 03 June 1987 (03.06.1987), fig. 2 (Family: none)	1-4,7
15 Y	US 3609968 A (George M.MIERLEY, SR.), 29 April 1970 (29.04.1970), fig. 1 to 3 & GB 1299684 A & DE 2119113 A & FR 2086462 A & BE 766326 A & NL 7105761 A & CA 929464 A	1-4,7
20 A	JP 2006-52910 A (Mitsubishi Heavy Industries, Ltd.), 23 February 2006 (23.02.2006), entire text; all drawings (Family: none)	1-7
25 A	JP 2001-289003 A (Mitsubishi Heavy Industries, Ltd.), 19 October 2001 (19.10.2001), entire text; all drawings (Family: none)	1-7
30 A	US 2010/0037619 A1 (Richard CHARRON), 18 February 2010 (18.02.2010), entire text; all drawings & EP 2324292 A & WO 2010/019174 A2 & CN 102171413 A	1-7
35 A	JP 2010-117124 A (General Electric Co.), 27 May 2010 (27.05.2010), entire text; all drawings & US 2010/0115953 A1 & DE 102009044513 A & CN 101737801 A	1-7
40 A	JP 58-208519 A (Hitachi, Ltd.), 05 December 1983 (05.12.1983), entire text; all drawings (Family: none)	1-7
45 A	JP 2008-111652 A (Siemens Power Generation, Inc.), 15 May 2008 (15.05.2008), entire text; all drawings & EP 1903184 A2 & CA 2603130 A1	1-7
50		
55		

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

**REFERENCES CITED IN THE DESCRIPTION**

*This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.*

**Patent documents cited in the description**

- JP 2011203016 A [0002]
- JP 2009197650 A [0006]