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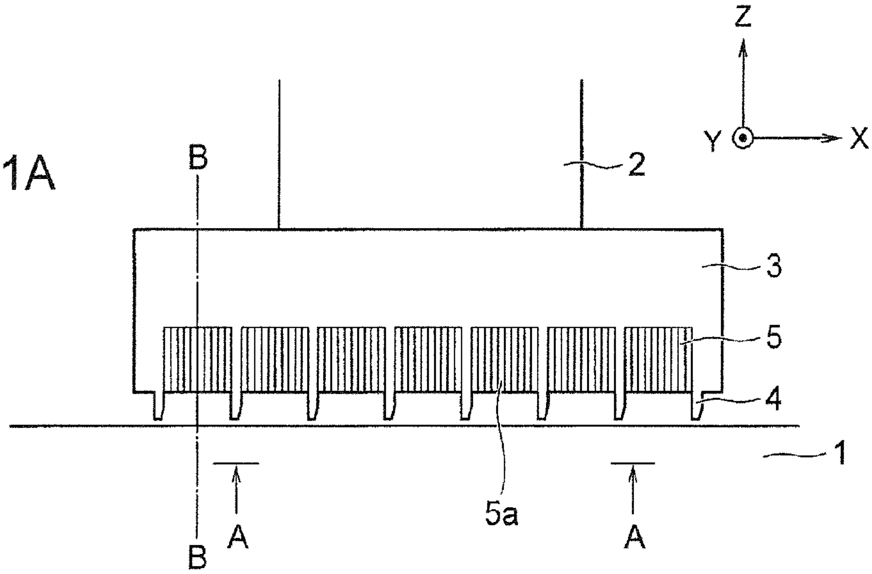
# (54) Sealing device, axial turbine and power plant

(57) In one embodiment, a sealing device includes seal fins provided on an inner circumferential surface of a stationary body or an outer circumferential surface of a rotating body so as to be adjacent to each other in an axial direction of the rotating body in a gap between the outer circumferential surface of the rotating body and the inner circumferential surface of the stationary body. The device further includes at least one opening member provided on the inner circumferential surface of the stationary body, the opening member being provided at a position between seal fins adjacent to each other in the axial direction, and having holes opened on a side of the inner circumferential surface of the stationary body. Corresponding axial turbine and power plant are also provided.

FIG.1A

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## Description

### FIELD

**[0001]** Embodiments described herein relate to a sealing device, an axial turbine and a power plant.

### BACKGROUND

**[0002]** An axial turbine includes a rotor in a casing for closing a working fluid, a rotor vane on a side of an outer circumferential surface of the rotor, and a stator vane on a side of an inner circumferential surface of the casing. A sealing device for sealing the working fluid is provided in a gap between the outer circumferential surface of the rotor and an inner circumferential surface of the stator vane or in a gap between the inner circumferential surface of the casing and an outer circumferential surface of the rotor vane. In a turbo machine used in a large power plant and the like, a labyrinth sealing device is generally used as the sealing device.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0003]**

FIGS. 1A to 1C are sectional views and an arrow view showing a structure of a sealing device of a first embodiment;
FIGS. 2A to 2C are sectional views and an arrow view showing a structure of a sealing device of a second embodiment;
FIGS. 3A and 3B are a sectional view and an arrow view showing a structure of a sealing device of a third embodiment;
FIGS. 4A and 4B are a sectional view and an arrow view showing a structure of a sealing device of a fourth embodiment;
FIGS. 5A and 5B are sectional views showing a structure of a sealing device of a fifth embodiment;
FIGS. 6A and 6B are sectional views showing a structure of a sealing device of a sixth embodiment;
FIG. 7 is a sectional view showing a structure of a sealing device of a seventh embodiment;
FIG. 8 is a sectional view showing a structure of a sealing device of an eighth embodiment;
FIGS. 9A and 9B are a sectional view and an arrow view showing a structure of a sealing device of a ninth embodiment;
FIG. 10 is a sectional view showing a structure of a sealing device of a tenth embodiment;
FIG. 11 is a sectional view showing a structure of a sealing device of an eleventh embodiment;
FIG. 12 is a sectional view showing a structure of a $CO_2$ turbine of a twelfth embodiment; and
FIG. 13 is a schematic view showing a configuration of a thermal power generation system of a thirteenth embodiment.

### DETAILED DESCRIPTION

**[0004]** Embodiments will now be explained with reference to the accompanying drawings.

**[0005]** In the sealing device, when the rotor is displaced in a radial direction in a state that a leakage flow rate of the seal has a circumferential component, circumferential pressure distribution in the seal is unbalanced, and a fluid force of destabilizing the rotor (hereinafter, called as the "destabilizing fluid force") is generated. The destabilizing fluid force causes unstable vibration of the rotor at worst. Particularly, in a case where the rotor is rotated at high speed or in a case where a differential pressure is large between an inlet and an outlet of the sealing device, the destabilizing fluid force is larger.

**[0006]** In a case where a honeycomb sealing device including a honeycomb member on the side of the inner circumferential surface of the casing or the stator vane is used instead of the labyrinth sealing device, an effect of damping the destabilizing fluid force is larger than the labyrinth sealing device. Therefore, it is known that the honeycomb sealing device can stabilize the unstable vibration of the rotor. However, due to a large pressure decrease in the axial direction in the honeycomb sealing device, there is a possibility that honeycomb holes of the honeycomb member are damaged. Particularly, in a case where the axial turbine is a steam turbine or a $CO_2$ turbine which are driven by a high-pressure working fluid, the honeycomb holes are more easily damaged.

**[0007]** In one embodiment, a sealing device includes seal fins provided on an inner circumferential surface of a stationary body or an outer circumferential surface of a rotating body so as to be adjacent to each other in an axial direction of the rotating body in a gap between the outer circumferential surface of the rotating body and the inner circumferential surface of the stationary body. The device further includes at least one opening member provided on the inner circumferential surface of the stationary body, the opening member being provided at a position between seal fins adjacent to each other in the axial direction, and having holes opened on a side of the inner circumferential surface of the stationary body.

(First Embodiment)

**[0008]** FIGS. 1A to 1C are sectional views and an arrow view showing a structure of a sealing device of a first embodiment.

**[0009]** FIGS. 1A to 1C show the sealing device provided in an axial turbine as an example. An example of this axial turbine includes a steam turbine and a $CO_2$ turbine. FIG. 1A is a meridional sectional view showing the structure of the sealing device. FIG. 1B is an arrow view in which the sealing device is seen in the A direction of FIG. 1A. FIG. 1C is a sectional view along line B-B of FIG. 1A.

**[0010]** FIGS. 1A to 1C show a rotor 1, a stator vane 2, a stator vane inner ring 3, a plurality of seal fins 4, and a plurality of honeycomb members 5 as components of the sealing device.

[0011] The rotor 1 is a rotation shaft for transmitting rotation energy to a power generator. FIGS. 1A to 1C show a X direction which is parallel to the axial direction of the rotor 1, and Y and Z directions which are perpendicular to the axial direction of the rotor 1. On a side of an outer circumferential surface of the rotor 1, a rotor vane (not shown) is attached. The rotor 1 is an example of a rotating body of the disclosure.

[0012] The stator vane 2 is attached on a side of an inner circumferential surface of a casing (not shown). On a side of an inner circumferential surface of the stator vane 2, the stator vane inner ring 3 integrated with the stator vane 2 or formed as a separate body is provided. The stator vane 2 and the stator vane inner ring 3 are examples of a stationary body of the disclosure.

[0013] The sealing device of FIG. 1 is provided in a gap between the outer circumferential surface of the rotor 1 and an inner circumferential surface of the stator vane inner ring 3. A sealing device provided in a gap between the inner circumferential surface of the casing and an outer circumferential surface of a shroud cover of the rotor vane or the like will be described later.

[0014] The seal fins 4 are members for sealing a working fluid, and are provided on the inner circumferential surface of the stator vane inner ring 3 in a gap between the rotor 1 and the stator vane inner ring 3. The seal fins 4 extend in the circumferential direction of the rotor 1 along the outer circumferential surface of the rotor 1, and are arranged adjacently to each other in the axial direction of the rotor 1. Radial length of the seal fins 4 is set so as to have a minute gap from the rotor 1. By such seal fins 4, leakage of the working fluid from the upstream side to the downstream side of the sealing device is reduced. The seal fins 4 are integrated with the stator vane inner ring 3 or formed as separate bodies.

[0015] The honeycomb members 5 are attached to the inner circumferential surface of the stator vane inner ring 3, and have a large number of honeycomb holes 5a opened on the side of the inner circumferential surface of the stator vane inner ring 3. Each of the honeycomb holes 5a has a hexagonal cylinder shape with a dead end. Members forming bottom surfaces of the honeycomb holes 5a may be the honeycomb members 5 or the stator vane inner ring 3. The honeycomb members 5 of the present embodiment has a large number of regularly arranged honeycomb holes 5a, and specifically has plural rows of honeycomb holes 5a, in each of which the honeycomb holes 5a are placed in one line in the circumferential direction. The honeycomb members 5 and the honeycomb holes 5a are examples of at least one opening member and holes of the disclosure, respectively.

[0016] The sealing device of the present embodiment is provided not only with a plurality of seal fins 4 but also a plurality of honeycomb members 5. Each honeycomb member 5 is arranged at a position between seal fins 4 adjacent to each other in the axial direction on the inner circumferential surface of the stator vane inner ring 3. A distance between an inner circumferential surface of the honeycomb member 5 and the outer circumferential surface of the rotor 1 is set to be longer than a distance between front ends of the seal fins 4 and the outer circumferential surface of the rotor 1.

[0017] Hereinafter, effects of the first embodiment will be described.

[0018] In general, when a fluid passes through a minute gap between a seal fin 4 and an opposite surface to the seal fin 4 in the sealing device, a pressure decrease is generated, so that a pressure difference is generated between the upstream side and the downstream side of the seal fin 4. Therefore, when a honeycomb member 5 is installed on the opposite surface, a pressure in the honeycomb holes 5a on the downstream side of the seal fin 4 is lower than a pressure in the honeycomb holes 5a on the upstream side of the seal fin 4, so that the honeycomb holes 5a receive a force in the axial direction. As a result, there is a possibility that the honeycomb holes 5a are damaged. Particularly, in the sealing device installed in a turbine step where the pressure difference of the working fluid is large, the pressure difference between the upstream side and the downstream side of the seal fin 4 is large, so that a risk that the honeycomb holes 5a are damaged is increased.

[0019] Meanwhile, in the present embodiment, the honeycomb members 5 are not installed on the opposite surfaces to the seal fins 4, but installed at the positions between the seal fins 4 adjacent to each other in the axial direction, on the inner circumferential surface of the stator vane inner ring 3 which is the same side as the seal fins 4. Although the pressure difference between the upstream side and the downstream side of a seal fin 4 is large, there is almost no pressure difference in a region between the seal fins 4 adjacent to each other in the axial direction. Therefore, according to the present embodiment, a possibility that the honeycomb holes 5a receive an excessive force in the axial direction can be reduced, so that the risk that the honeycomb holes 5a are damaged can be decreased.

[0020] According to the present embodiment, by installing the honeycomb members 5 in the regions surrounded by the adjacent seal fins 4, unbalance of circumferential pressure distribution can be eased by a damper effect by the honeycomb members 5. Therefore, according to the present embodiment, a destabilizing fluid force that destabilizes the rotor 1 can be reduced.

[0021] According to the present embodiment, since the honeycomb holes 5a with dead ends work as resistances against a circumferential flow rate of the fluid, a swirling flow rate in a cavity serving as a generation source of the unbalance of the circumferential pressure distribution of the fluid can be reduced. Therefore, according to the present embodiment, the destabilizing fluid force that destabilizes the rotor 1 can further be reduced.

[0022] As described above, in the present embodiment, the honeycomb members 5 are installed at the positions between the seal fins 4 adjacent to each other in the axial direction of the rotor 1. Therefore, according to the present embodiment, damage to the honeycomb holes 5a can be suppressed while reducing the destabilizing fluid force by the honeycomb members 5.

(Second Embodiment)

**[0023]** FIGS. 2A to 2C are sectional views and an arrow view showing a structure of a sealing device of a second embodiment.

**[0024]** FIGS. 2A to 2C are a meridional sectional view, an A-direction arrow view, and a B-B sectional view corresponding to FIGS. 1A to 1C, respectively.

**[0025]** In the present embodiment, the seal fins 4 are provided not on the inner circumferential surface of the stator vane inner ring 3 but on the outer circumferential surface of the rotor 1. The seal fins 4 may be integrated with the rotor 1 or formed as separate bodies from the rotor 1.

**[0026]** In the present embodiment, the inner circumferential surface of the stator vane inner ring 3 has first surfaces $S_1$ which are the inner circumferential surfaces of the honeycomb members 5, and second surfaces $S_2$ placed between the honeycomb members 5 adjacent to each other in the axial direction, placed on the upstream side of the most upstream honeycomb member 5, or placed on the downstream side of the most downstream honeycomb member 5. The first surfaces $S_1$ have a hollow structure having a large number of honeycomb holes 5a, whereas the second surfaces $S_2$ have a solid structure having no such holes.

**[0027]** In the present embodiment, the seal fins 4 are provided at positions facing the second surfaces $S_2$ on the outer circumferential surface of the rotor 1. As a result, the honeycomb members 5 are arranged at positions between the seal fins 4 adjacent to each other in the axial direction on the inner circumferential surface of the stator vane inner ring 3.

**[0028]** Hereinafter, effects of the second embodiment will be described.

**[0029]** As described above, in the present embodiment, as well as the first embodiment, the honeycomb members 5 are installed at the positions between the seal fins 4 adjacent to each other in the axial direction of the rotor 1. Therefore, according to the present embodiment, as well as the first embodiment, the damage to the honeycomb holes 5a can be suppressed while reducing the destabilizing fluid force by the honeycomb members 5.

**[0030]** In the present embodiment, by providing the seal fins 4 on the side of the rotor 1, for example, free-polished member layers (not shown) can be formed on the second surfaces $S_2$. Thereby, the minute gaps between the seal fins 4 and the stator vane inner ring 3 are downsized, so that a seal leakage flow rate can be reduced.

**[0031]** In the present embodiment, when the rotor 1 is rotated and by any chance the seal fins 4 are brought into contact with the second surfaces $S_2$, due to a large surface area of the rotor 1, heat easily escapes from the rotor 1. Thereby, a risk of unstable vibration or the like due to thermal deformation of the rotor 1 can be avoided.

**[0032]** In the present embodiment, due to thermal expansion of the rotor 1 during a turbine operation for example, a position of the rotor 1 may sometimes be displaced in the axial direction. Therefore, in a case where a width in the axial direction of the second surfaces $S_2$ is narrow, when the position of the rotor 1 is displaced in the axial direction, there is a fear that positions of the seal fins 4 are displaced from the positions facing the second surfaces $S_2$ to positions facing the first surfaces $S_1$. In the present embodiment, the width in the axial direction of the second surfaces $S_2$ is desirably set to be such sufficient width that the seal fins 4 continue to face the second surfaces $S_2$ even when the position of the rotor 1 is displaced.

(Third Embodiment)

**[0033]** FIGS. 3A and 3B are a sectional view and an arrow view showing a structure of a sealing device of a third embodiment.

**[0034]** FIGS. 3A and 3B are a meridional sectional view and an A-direction arrow view corresponding to FIGS. 1A and 1B, respectively.

**[0035]** In the present embodiment, as well as the first embodiment, the seal fins 4 are provided on the inner circumferential surface of the stator vane inner ring 3, and the honeycomb members 5 are arranged at the positions between the seal fins 4 adjacent to each other in the axial direction on the inner circumferential surface of the stator vane inner ring 3 (FIG. 3A). However, each honeycomb member 5 of the present embodiment is divided into a plurality of members 5b and 5c in the circumferential direction of the rotor 1 as shown in FIG. 3B, and include a reinforcing member 6 between the divided members 5b and 5c adjacent to each other in the circumferential direction.

**[0036]** Hereinafter, effects of the third embodiment will be described.

**[0037]** Since there is a pressure difference between an upstream side surface $S_3$ and a downstream side surface $S_4$ of a seal fin 4, the seal fin 4 receives a force from the upstream side surface $S_3$ to the downstream side surface $S_4$ within a range from a height of an outer circumferential surface of the honeycomb members 5 to a height of the inner circumferential surface of the honeycomb members 5. In the present embodiment, the reinforcing member 6 for reinforcing the seal fins 4 in the axial direction is installed between the divided members 5b and 5c adjacent to each other in the circumferential direction so as to be brought into contact with side surfaces of the seal fins 4. Therefore, in the present embodiment, since the reinforcing member 6 receives the force from the upstream side surface $S_3$ to the downstream side surface $S_4$, deformation and breakage of the seal fin 4 is suppressed, so that reliability of the seal fin 4 can be improved.

**[0038]** In the present embodiment, the division number of dividing each honeycomb member 5 in the circumferential direction may be any number. For example, in a case where each honeycomb member 5 is divided into four members in the circumferential direction, four reinforcing members 6 are installed between these divided members. The direction and the shape of the reinforcing members 6 are not limited to those shown in FIG. 3B but the direction of the reinforcing members 6 may be the direction which is not parallel to the X direction, and the shape of the reinforcing members 6 may be a shape which is other than a rod shape, for example. Each reinforcing member 6 may be in contact with seal fins 4 on both the sides or may be in contact with only a seal fin 4 on one side.

(Fourth Embodiment)

**[0039]** FIGS. 4A and 4B are a sectional view and an arrow view showing a structure of a sealing device of a fourth embodiment.

**[0040]** FIGS. 4A and 4B are a meridional sectional view and an A-direction arrow view corresponding to FIGS. 2A and 2B, respectively.

**[0041]** In the present embodiment, as well as the second embodiment, the seal fins 4 are provided on the outer circumferential surface of the rotor 1, and the honeycomb members 5 are arranged at the positions between the seal fins 4 adjacent to each other in the axial direction on the outer circumferential surface of the stator vane inner ring 3 (FIG. 4A). However, each honeycomb member 5 of the present embodiment is divided into the plurality of members 5b and 5c in the circumferential direction of the rotor 1 as shown in FIG. 4B, and include the reinforcing member 6 between the divided members 5b and 5c adjacent to each other in the circumferential direction. This is the same as the third embodiment.

**[0042]** Hereinafter, effects of the fourth embodiment will be described.

**[0043]** Since there is a pressure difference between an upstream side surface $S_5$ and a downstream side surface $S_6$ of a wall between the honeycomb members 5 adjacent to each other in the axial direction, the wall receives a force from the upstream side surface $S_5$ to the downstream side surface $S_6$ within the range from the height of the outer circumferential surface of the honeycomb members 5 to the height of the inner circumferential surface of the honeycomb members 5. In the present embodiment, the reinforcing member 6 for reinforcing the wall in the axial direction is installed between the members 5b and 5c adjacent to each other in the circumferential direction so as to be brought into contact with side surfaces of the wall. Therefore, in the present embodiment, since the reinforcing members 6 receive the force from the upstream side surfaces $S_5$ to the downstream side surfaces $S_6$, deformation and breakage of the wall is suppressed, so that reliability of the honeycomb members 5 can be improved.

(Fifth Embodiment)

**[0044]** FIGS. 5A and 5B are sectional views showing a structure of a sealing device of a fifth embodiment.

**[0045]** FIGS. 5A and 5B are a meridional sectional view and a B-B sectional view corresponding to FIGS. 1A and 1C, respectively.

**[0046]** An arrow C of FIG. 5B indicates the rotation direction of the rotor 1. An arrow D indicates the inward normal direction on the inner circumferential surface of the stator vane inner ring 3. An arrow E indicates the direction from bottom regions to opening regions of the honeycomb holes 5a.

**[0047]** In the present embodiment, the direction E from the bottom regions to the opening regions of the honeycomb holes 5a is inclined opposite to the rotation direction C of the rotor 1 with respect to the normal direction D at the same position. Thereby, in comparison to a case where the direction E from the bottom regions to the opening regions of the honeycomb holes 5a is the same as the normal direction D, a resistance given to the circumferential flow rate of the fluid by the honeycomb holes 5a is increased. Therefore, according to the present embodiment, the swirling flow rate can be more reduced and the destabilizing fluid force can further be reduced.

(Sixth Embodiment)

**[0048]** FIGS. 6A and 6B are sectional views showing a structure of a sealing device of a sixth embodiment.

**[0049]** FIGS. 6A and 6B are a meridional sectional view and a B-B sectional view corresponding to FIGS. 1A and 1C, respectively.

**[0050]** As shown in FIG. 6B, each honeycomb member 5 of the present embodiment alternately includes first regions 5d and second regions 5e in which heights of inner circumferential surfaces are different from each other along the circumferential direction of the rotor 1. As a result, each honeycomb member 5 of the present embodiment has steps 7 between the first regions 5d and the second regions 5e in the circumferential direction of the rotor 1. According to the present embodiment, since the steps 7 work as resistances against the circumferential flow rate of the fluid, the swirling flow rate can be more reduced and the destabilizing fluid force can further be reduced.

**[0051]** The steps 7 may be provided on a border between segments of the stator vane inner ring 3, for example. In this case, the individual segment includes any one of the first region 5d and the second region 5e. Each honeycomb member 5 may have the steps 7 by including three or more types of regions in which heights of inner circumferential surfaces are different from each other.

(Seventh Embodiment)

**[0052]** FIG. 7 is a sectional view showing a structure of a sealing device of a seventh embodiment. FIG. 7 is a meridional sectional view corresponding to FIG. 1A.

**[0053]** In the present embodiment, slits 8 extending in the circumferential direction of the rotor 1 is provided on the inner circumferential surfaces of the honeycomb members 5. According to the present embodiment, since the slits 8 work as resistances against the circumferential flow rate of the fluid, the swirling flow rate can be more reduced and the destabilizing fluid force can further be reduced.

**[0054]** Each slit 8 may be provided on the entire circumference in the circumferential direction on the inner circumferential surface of a honeycomb member 5 (i.e., 360 degree range of the circumference), or may be provided only on a part on the circumference in the circumferential direction on the inner circumferential surface of a honeycomb member 5. The slits 8 can pass through the honeycomb members 5 or not pass through. However, from a view point to extend an installment area of the honeycomb members 5 as far as possible, the slits 7 do desirably not pass through.

(Eighth Embodiment)

**[0055]** FIG. 8 is a sectional view showing a structure of a sealing device of an eighth embodiment. FIG. 8 is a meridional sectional view corresponding to FIG. 1A.

**[0056]** The sealing device of FIG. 8 is provided with an upstream side honeycomb member 9 and a downstream side honeycomb member 10 in addition to the components shown in FIGS. 1A to 1C. The upstream side honeycomb member 9 is provided at a position on the upstream side of the most upstream seal fin 4 on the inner circumferential surface of the stator vane inner ring 3, and has a large number of honeycomb holes 9a opened on the side of the inner circumferential surface of the stator vane inner ring 3. The downstream side honeycomb member 10 is provided at a position on the downstream side of the most downstream seal fin 4 on the inner circumferential surface of the stator vane inner ring 3, and has a large number of honeycomb holes 10a opened on the side of the inner circumferential surface of the stator vane inner ring 3. The upstream side honeycomb member 9 and the downstream side honeycomb member 10 are examples of at least one outside opening member of the disclosure.

**[0057]** According to the present embodiment, by providing the upstream side honeycomb member 9 and the downstream side honeycomb member 10 on the inner circumferential surface of the stator vane inner ring 3 in addition to the honeycomb members 5, the damper effect can further be enhanced and generation of the destabilizing fluid force can further be reduced. The sealing device of the present embodiment may be provided with only one of the upstream side honeycomb member 9 and the downstream side honeycomb member 10.

(Ninth Embodiment)

**[0058]** FIGS. 9A and 9B are a sectional view and an arrow view showing a structure of a sealing device of a ninth embodiment.

**[0059]** FIGS. 9A and 9B are a meridional sectional view and an A-direction arrow view corresponding to FIGS. 1A and 1B, respectively.

**[0060]** In the present embodiment, the honeycomb members 5 are replaced with opening members 11. Each opening member 11 is provided at a position between seal fins 4 adjacent to each other in the axial direction on the inner circumferential surface of the stator vane inner ring 3, and has a large number of holes 11a opened on the side of the inner circumferential surface of the stator vane inner ring 3. Each hole 11a has a cylindrical shape with a dead end.

**[0061]** According to the present embodiment, by installing the opening members 11 at the positions between the seal fins 4 adjacent to each other in the axial direction, the damage to the holes 11a can be suppressed while reducing the destabilizing fluid force by the opening members 11 as well as the first to eighth embodiments. The shape of the holes 11a may be a shape other than a cylindrical shape (for example, a square pillar shape).

(Tenth Embodiment)

**[0062]** FIG. 10 is a sectional view showing a structure of a sealing device of a tenth embodiment. FIG. 10 is a meridional sectional view corresponding to FIG. 1A. FIG. 10 shows the sealing device provided in an axial turbine as one example.

**[0063]** FIG. 10 shows a casing 12, a rotor vane 13, a shroud cover 14, the plurality of seal fins 4, and the plurality of honeycomb members 5 as components of the sealing device.

**[0064]** The casing 12 is configured to close the working fluid. The rotor 1 described above is provided in this casing 12. The casing 12 is an example of the stationary body of the disclosure.

**[0065]** The rotor vane 13 is attached on the side of the outer circumferential surface of the rotor 1 described above. The shroud cover 14 integrated with the rotor vane 13 or formed as a separate body is provided on the side of an outer circumferential surface of the rotor vane 13. The rotor vane 13 and the shroud cover 14 are examples of the rotating body of the disclosure.

**[0066]** The sealing device of FIG. 10 is provided in a gap between an inner circumferential surface of the casing 12 and an outer circumferential surface of the shroud cover 14.

**[0067]** The seal fins 4 are provided on the inner circumferential surface of the casing 12 in a gap between the casing 12 and the shroud cover 14. The seal fins 4 extend in the circumferential direction along the outer circumferential surface of the shroud cover 14 and are arranged adjacently to each other in the axial direction. The seal fins 4 are integrated with the casing 12 or formed as separate bodies.

**[0068]** The honeycomb members 5 are attached to the inner circumferential surface of the casing 12. Specifically, the honeycomb members 5 are arranged at the positions between the seal fins 4 adjacent to each other in the axial direction on the inner circumferential surface of the casing 12.

**[0069]** According to the present embodiment, by installing the honeycomb members 5 at the positions between the seal fins 4 adjacent to each other in the axial direction, the damage to the honeycomb holes 5a can be suppressed while reducing the destabilizing fluid force by the honeycomb members 5 as well as the first embodiment and the like.

(Eleventh Embodiment)

**[0070]** FIG. 11 is a sectional view showing a structure of a sealing device of an eleventh embodiment. FIG. 11 is a meridional sectional view corresponding to FIG. 1A.

**[0071]** In the present embodiment, the seal fins 4 are provided not on the inner circumferential surface of the casing 12 but on the outer circumferential surface of the shroud cover 14. The seal fins 4 may be integrated with the shroud cover 14 or formed as separate bodies from the shroud cover 14.

**[0072]** In the present embodiment, the inner circumferential surface of the casing 12 has the first surfaces $S_1$ which are the inner circumferential surfaces of the honeycomb members 5, and the second surfaces $S_2$ placed between the honeycomb members 5 adjacent to each other in the axial direction, placed on the upstream side of the most upstream honeycomb member 5, or placed on the downstream side of the most downstream honeycomb member 5. The first surfaces $S_1$ have a hollow structure having a large number of honeycomb holes 5a, whereas the second surfaces $S_2$ have a solid structure having no such holes.

**[0073]** In the present embodiment, the seal fins 4 are provided at positions facing the second surfaces $S_2$ on the outer circumferential surface of the shroud cover 14. As a result, the honeycomb members 5 are arranged at the positions between the seal fins 4 adjacent to each other in the axial direction on the inner circumferential surface of the casing 12.

**[0074]** According to the present embodiment, by installing the honeycomb members 5 at the positions between the seal fins 4 adjacent to each other in the axial direction, the damage to the honeycomb holes 5a can be suppressed while reducing the destabilizing fluid force by the honeycomb members 5 as well as the second embodiment and the like.

**[0075]** The sealing devices of the first to eleventh embodiments may be installed in a place other than the gap between the outer circumferential surface of the rotor 1 and the inner circumferential surface of the stator vane inner ring 3, and the gap between the inner circumferential surface of the casing 12 and the outer circumferential surface of the shroud cover 14. The sealing devices may be installed in a ground packing of the axial turbine for example.

(Twelfth Embodiment)

**[0076]** FIG. 12 is a sectional view showing a structure of a $CO_2$ turbine 101 of a twelfth embodiment. The $CO_2$ turbine 101 of FIG. 12 is an example of an axial turbine of the disclosure.

**[0077]** Rotor vanes 105 are arranged at fixed intervals in an annular form on the outer side in the radial direction from a turbine rotor 103. These rotor vanes 105 are also arranged at predetermined intervals in the axial direction, and a stator vane 106 is arranged between the rotor vanes 105 adjacent to each other in the axial direction. The stator vanes 106 are arranged at fixed intervals in an annular form. Base parts of the rotor vanes 105 are planted on an outer circumferential surface of the turbine rotor 103.

**[0078]** Although FIG. 12 shows an example of a five-step configuration in which five rotor vanes 105 and five stator vanes 106 are alternately arranged in the axial direction, there is no particular limit in the step number of the rotor vanes 105 and the stator vanes 106.

**[0079]** The $CO_2$ turbine 101 of FIG. 12 drives the turbine rotor 103 by using $CO_2$ in a supercritical state as the working fluid, and circulates and charges $CO_2$ discharged from the $CO_2$ turbine 101 into the $CO_2$ turbine 101 so as to use $CO_2$ for cooling the parts.

**[0080]** A critical point of $CO_2$ is at 31°C and 7.4 MPa, and the $CO_2$ turbine 101 of FIG. 12 is based on the assumption that $CO_2$ is used at a higher temperature and a higher pressure than this critical point.

**[0081]** A sleeve pipe 107 is provided on the upstream side of the $CO_2$ turbine 101 of FIG. 12, and a $CO_2$ gas in a supercritical state is charged from this sleeve pipe 107 into the turbine as the working fluid. The charged $CO_2$ gas flows from the upstream side to the downstream side along the axial direction and is discharged from a discharge pipe (not shown).

**[0082]** The turbine rotor 103 is rotated and driven by using a force in which the fluid collides with the rotor vanes 105, and there is a need for providing a gap between outer circumferential surfaces of the rotor vanes 105 and a facing inner circumferential surface of an inside casing 102 and between inner circumferential surfaces of the stator vanes 106 and the facing inner circumferential surface of the turbine rotor 103. Therefore, a part of the fluid is leaked out through the gap on the side of the outer circumferential surfaces of the rotor vanes 105 and the gap on the side of the inner circumferential surfaces of the stator vanes 106. In order to suppress this leakage, sealing devices 108 are respectively arranged on the side of the outer circumferential surfaces of the rotor vanes 105 and on the side of the inner circumferential surfaces of the stator vanes 106.

**[0083]** Each sealing device 108 is configured that seal fins 109 are arranged at predetermined intervals on at least one of the outer circumferential surfaces of the rotor vanes 105 on the side of the turbine rotor 103 and the opposite surfaces of the inside casing 102, and the inner circumferential surfaces of the stator vanes 106 and the opposite surfaces of the turbine rotor 103, and thereby the gaps are narrowed down, so that the fluid is not easily leaked out.

**[0084]** The sealing devices 108 are provided not only on the circumferential surfaces of the rotor vanes 105 or the stator vanes 106 and the opposite surfaces thereof, but also on a ground packing 111 on the upper step side of the uppermost stator vane 106.

**[0085]** In a case where honeycomb members 110 are provided in this sealing device 108, the honeycomb members 110 of the structure of the first to eleventh embodiments (honeycomb members 5) are desirably adopted.

(Thirteenth Embodiment)

**[0086]** FIG. 13 is a schematic view showing a configuration of a thermal power generation system 120 of a thirteenth embodiment. The thermal power generation system of FIG. 13 is an example of a power plant of the disclosure.

**[0087]** As shown in FIG. 13, the $CO_2$ turbine 101 of FIG. 12 can be assembled into the thermal power generation system 120 capable of generating power and separating and collecting $CO_2$ at the same time. The thermal power generation system 120 of FIG. 13 is provided with an oxygen production apparatus 121, a combustor 122, the $CO_2$ turbine 101 shown in FIG. 12, a power generator 123, a regenerative heat exchanger 124, a cooler 125, a moisture separator 126, and a $CO_2$ pump 127.

**[0088]** The oxygen production apparatus 121 removes nitrogen contained in the air and extracts only oxygen. The combustor 122 generates a high-temperature combustion gas by using the oxygen extracted in the oxygen production apparatus 121, fuel and $CO_2$. Components of this combustion gas are $CO_2$ and water. A natural gas not using nitrogen such as a methane gas is used as the fuel used by the combustor 122.

**[0089]** The high-temperature and high-pressure $CO_2$ gas generated in the combustor 122 is charged into the $CO_2$ turbine 101 shown in FIG. 12 and used for rotating and driving the turbine rotor 103. The power generator 123 is connected to a rotation shaft of the turbine rotor 103, and the power generator 123 generates the power by using a rotation driving force of the turbine rotor 103.

**[0090]** $CO_2$ and water vapor discharged from the $CO_2$ turbine 101 are cooled down in the regenerative heat exchanger 124 and then further cooled down in the cooler 125. After that, water is removed in the moisture separator 126, and only $CO_2$ is extracted. This $CO_2$ is compressed and its pressure is boosted in the $CO_2$ pump 127.

**[0091]** A temperature of a part of the high-pressure $CO_2$ whose pressure is boosted in the $CO_2$ pump 127 is increased to about 400°C in the regenerative heat exchanger 124. The $CO_2$ discharged from the regenerative heat exchanger 124 is used for cooling the $CO_2$ turbine 101 as cooling $CO_2$ and also supplied to the combustor 122.

**[0092]** Among the high-pressure $CO_2$ whose pressure is boosted in the $CO_2$ pump 127, extra $CO_2$ other than the $CO_2$ used for power generation via the regenerative heat exchanger 124 is collected to be stored or used for other purposes (for example, used for increasing an oil drilling amount).

**[0093]** As described above, the power generation system 120 of the present embodiment generates power by using only $CO_2$ generated by combustion and water, and circulates and re-uses most parts of $CO_2$. Therefore, there is no fear that $NO_X$ which is a harmful gas is discharged, and there is no need for separately providing facilities for separating and collecting $CO_2$. Further, extra $CO_2$ can be collected in a highly-pure state straightaway, which is easily used for various uses other than power generation.

**[0094]** While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel devices, turbines and plants described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the devices, turbines and plants described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

## Claims

**1.** A sealing device comprising:

seal fins (4) provided on an inner circumferential surface of a stationary body (2, 3) or an outer circumferential surface of a rotating body (1) so as to be adjacent to each other in an axial direction of the rotating body in a gap between the outer circumferential surface of the rotating body and the inner circumferential surface of the stationary body; and

at least one opening member (5) provided on the inner circumferential surface of the stationary body, the opening member being provided at a position between seal fins adjacent to each other in the axial direction, and having holes opened on a side of the inner circumferential surface of the stationary body.

**2.** The device of Claim 1, wherein

the seal fins (4) are provided on the outer circumferential surface of the rotating body (1),
the inner circumferential surface of the stationary body has a first surface which is an inner circumferential surface of the opening member (5), and a second surface placed between opening members adjacent to each other in the axial direction, placed on an upstream side of the most upstream opening member, or placed on an downstream side of the most downstream opening member, and
the seal fins (4) are provided at positions facing the second surface on the outer circumferential surface of the rotating body.

3. The device of Claim 1 or 2, wherein the opening member (5) is divided into a plurality of members (5b, 5c) in a circumferential direction of the rotating body, and includes a reinforcing member (6) between the divided members adjacent to each other in the circumferential direction.

4. The device of any one of the preceding claims, wherein a direction from bottom regions to opening regions of the holes (5a) of the opening member (5) is inclined opposite to a rotation direction of the rotating body with respect to an inward normal direction (D) of the inner circumferential surface of the stationary body.

5. The device of any one of the preceding claims, wherein an inner circumferential surface of the opening member has a step (7) in a circumferential direction of the rotating body.

6. The device of any one of the preceding claims, wherein a slit (8) extending in a circumferential direction of the rotating body is provided on an inner circumferential surface of the opening member.

7. The device of any one of the preceding claims, comprising at least one outside opening member (11) provided on the inner circumferential surface of the stationary body, the outside opening member being provided at one or both of a position on a upstream side of the most upstream seal fin and a position on a downstream side of the most downstream seal fin, and having holes (11a) opened on the side of the inner circumferential surface of the stationary body.

8. An axial turbine comprising:

a stationary body (2, 3) including a casing for closing a working fluid and a stator vane provided on a side of an inner circumferential surface of the casing;
a rotating body (1) including a rotor provided in the casing and a rotor vane provided on a side of an outer circumferential surface of the rotor;
and a sealing device according to any one of the preceding claims provided in a gap between an outer circumferential surface of the rotating body and an inner circumferential surface of the stationary body so as to seal the working fluid.

9. The turbine of Claim 8 and configured to operate by using carbon dioxide in a supercritical state as the working fluid.

10. A power plant comprising:

a combustor configured to generate the carbon dioxide to be used as the working fluid;
the axial turbine of Claim 8 or 9 configured to operate by using the carbon dioxide as the working fluid; and
a power generator connected to the axial turbine.

FIG.1A

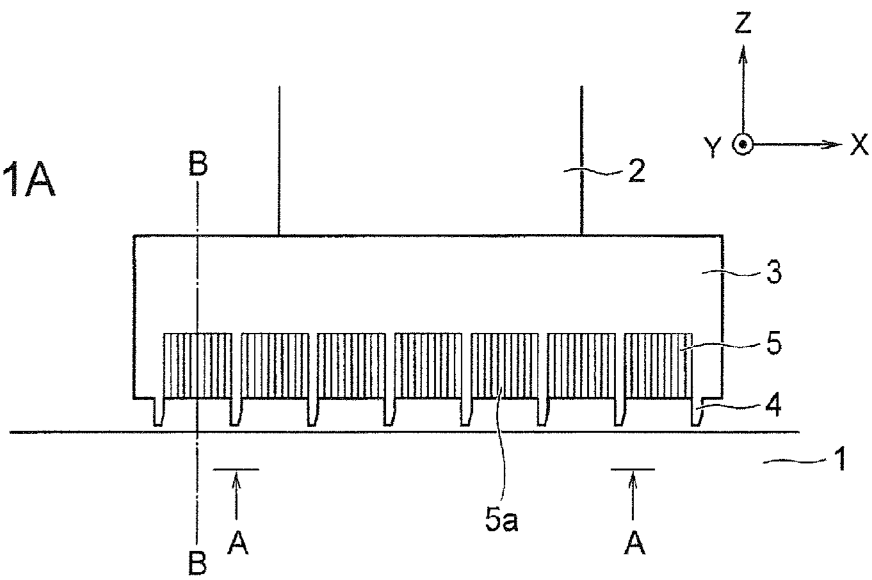



FIG.1B

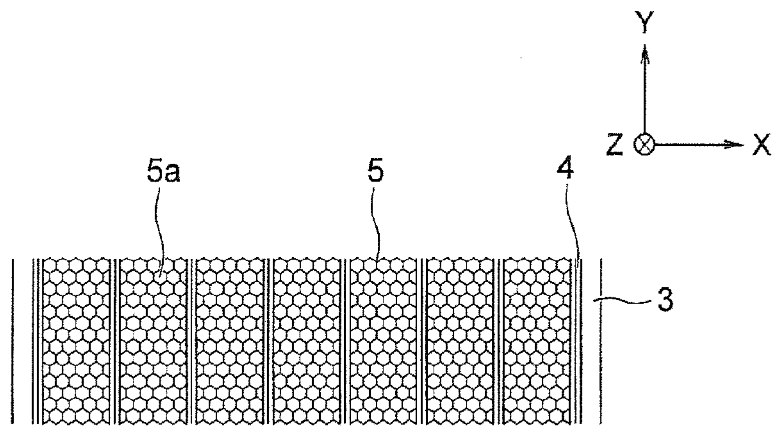



FIG.1C

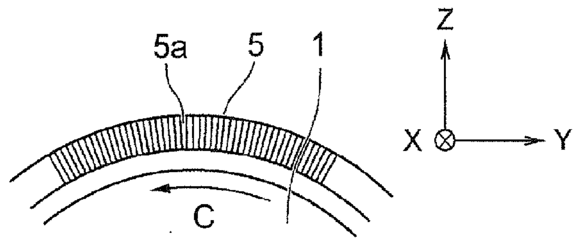


FIG.2A

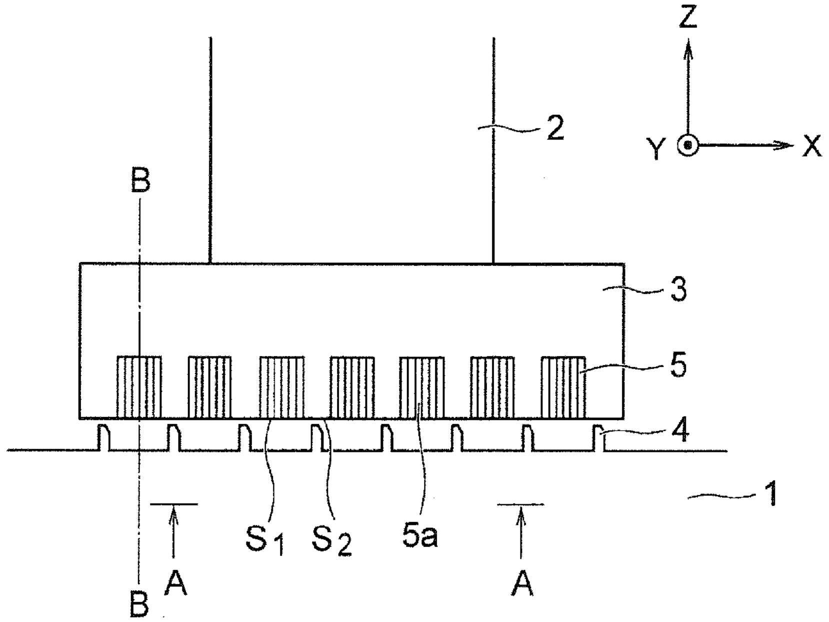



FIG.2B

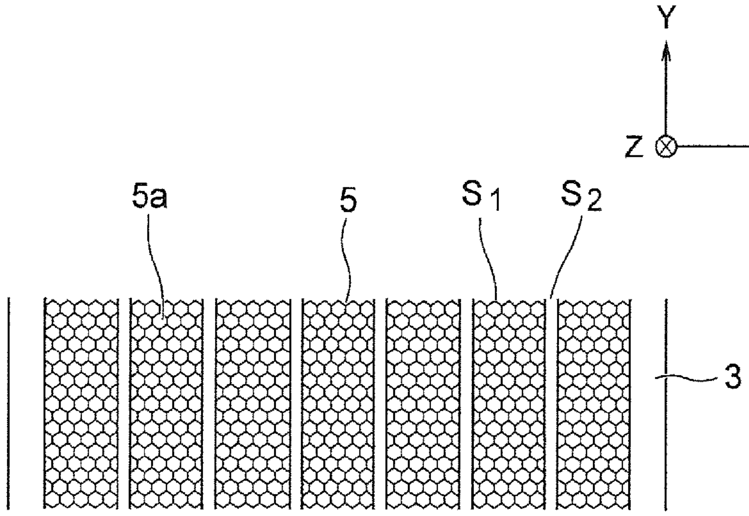



FIG.2C

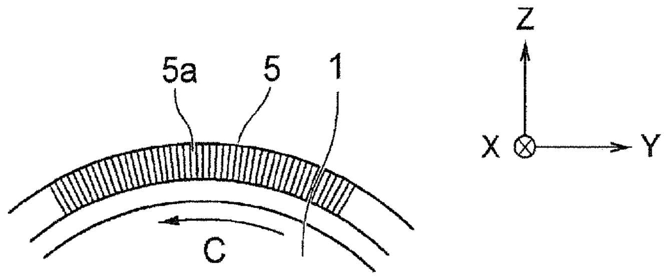


FIG.3A

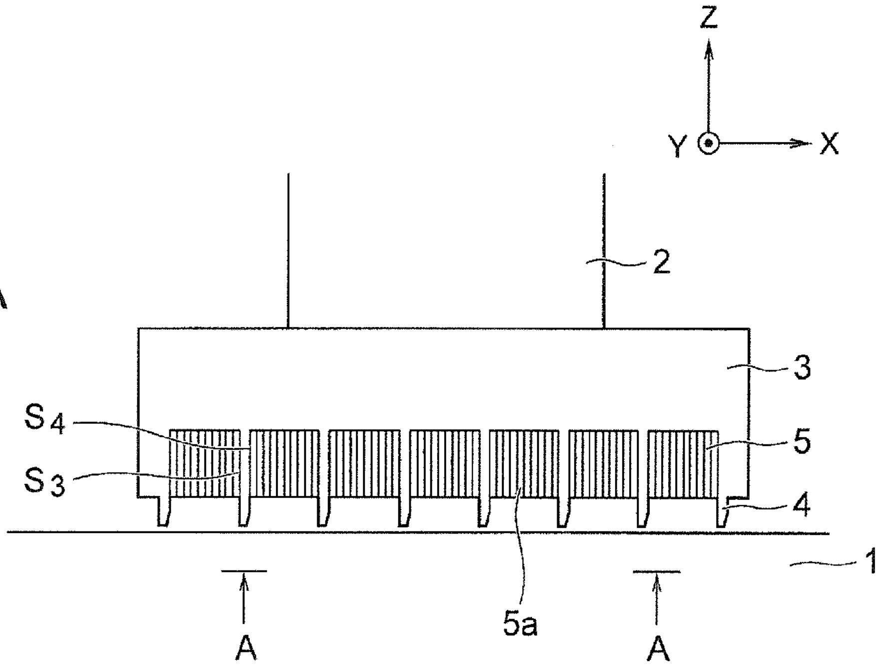



FIG.3B

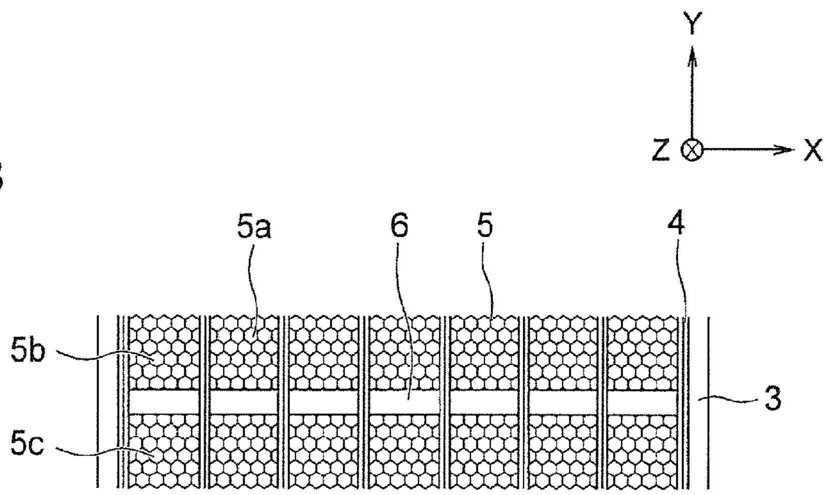


FIG.4A

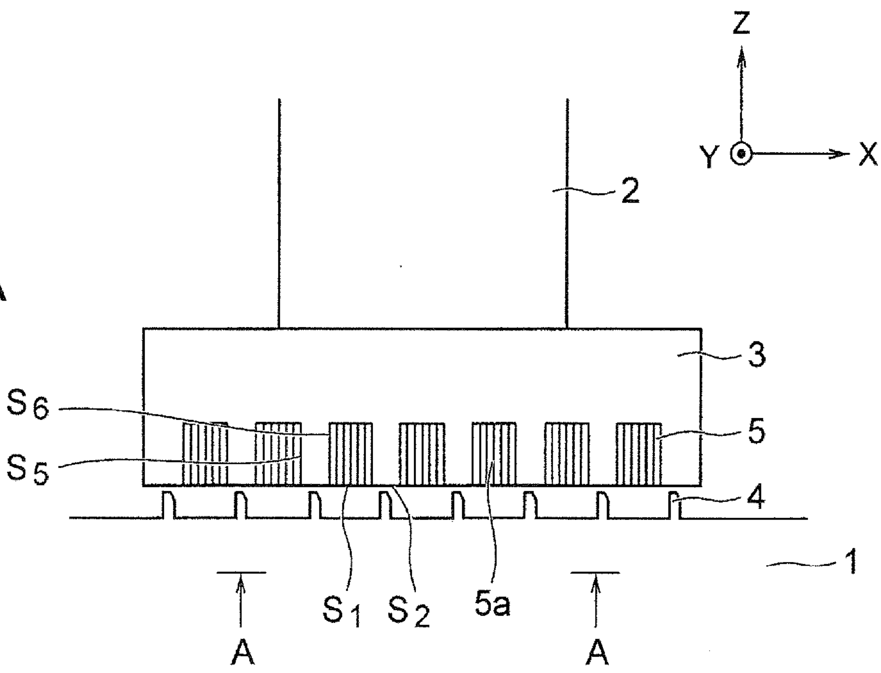



FIG.4B

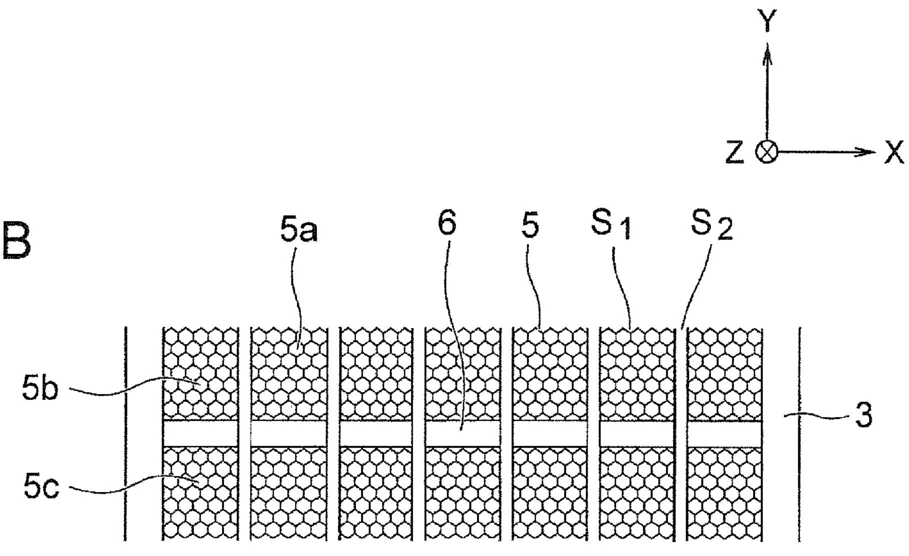


FIG.5A

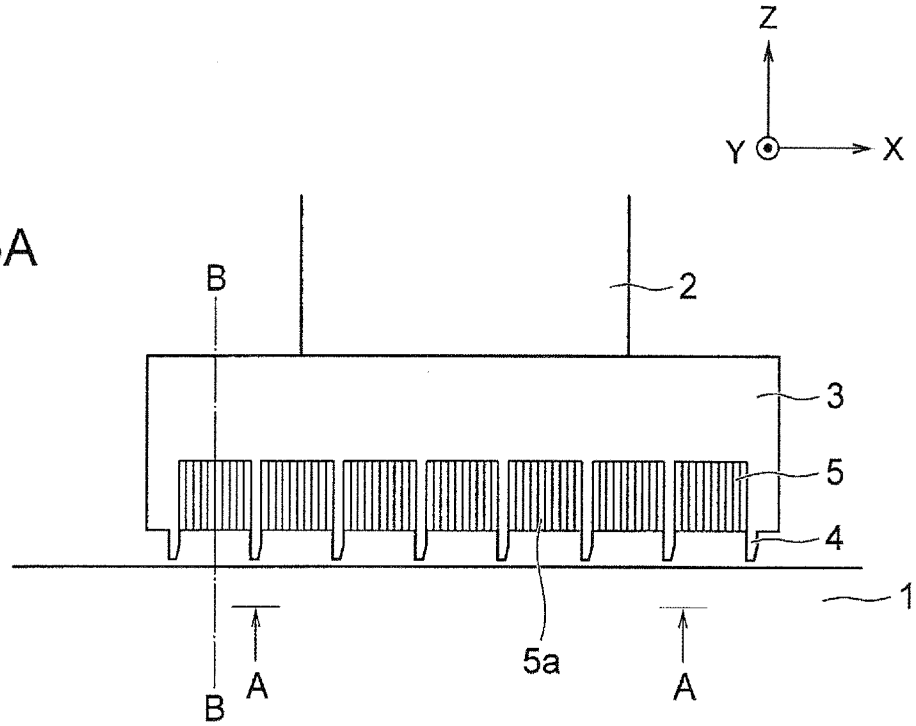



FIG.5B

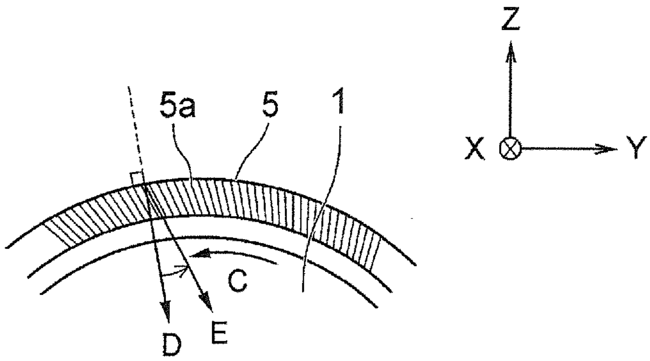


FIG.6A

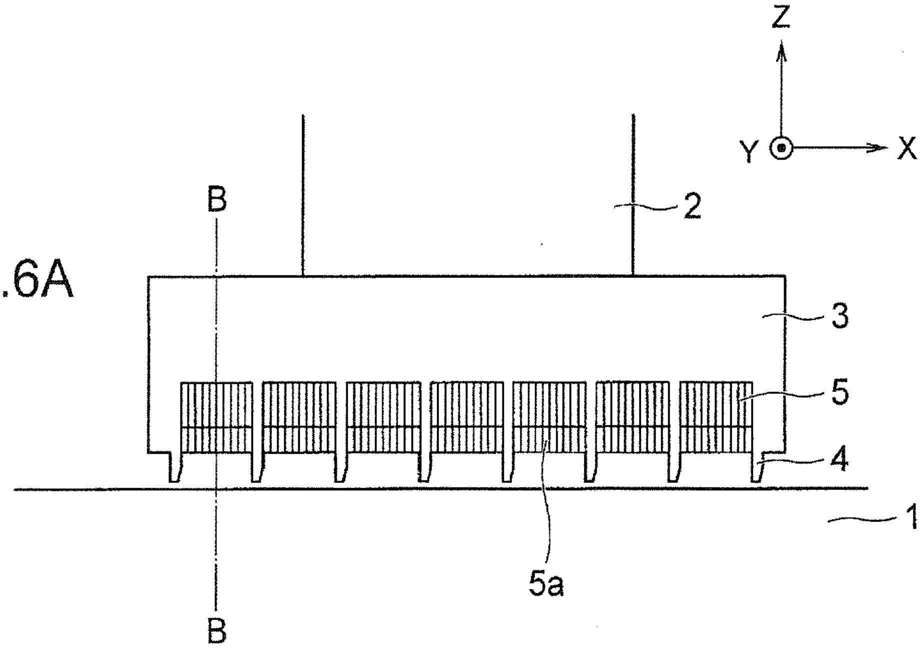



FIG.6B

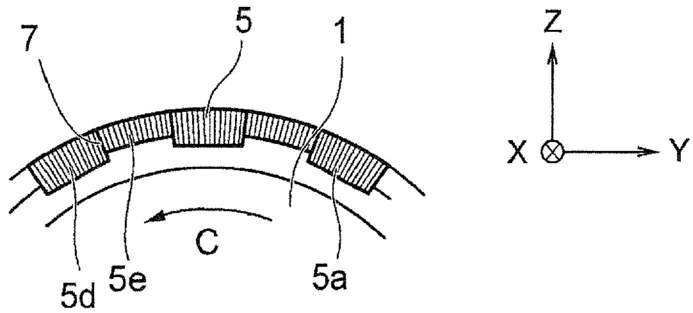


FIG.7

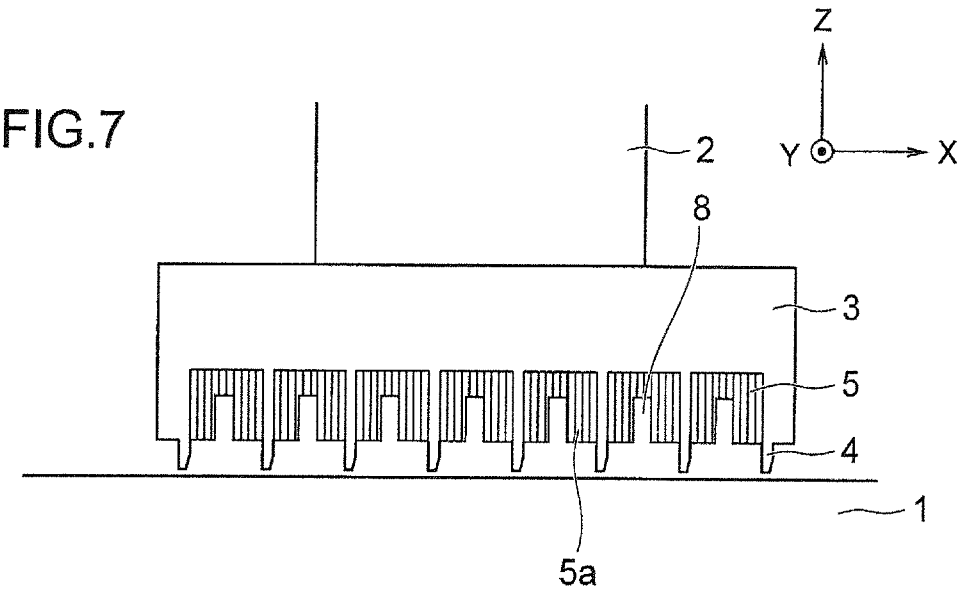



FIG.8

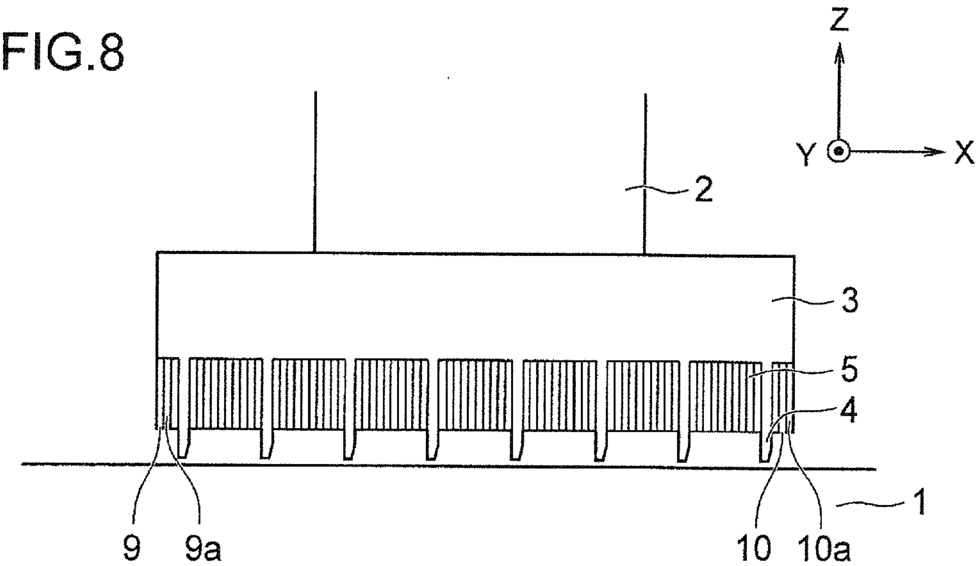


FIG.9A

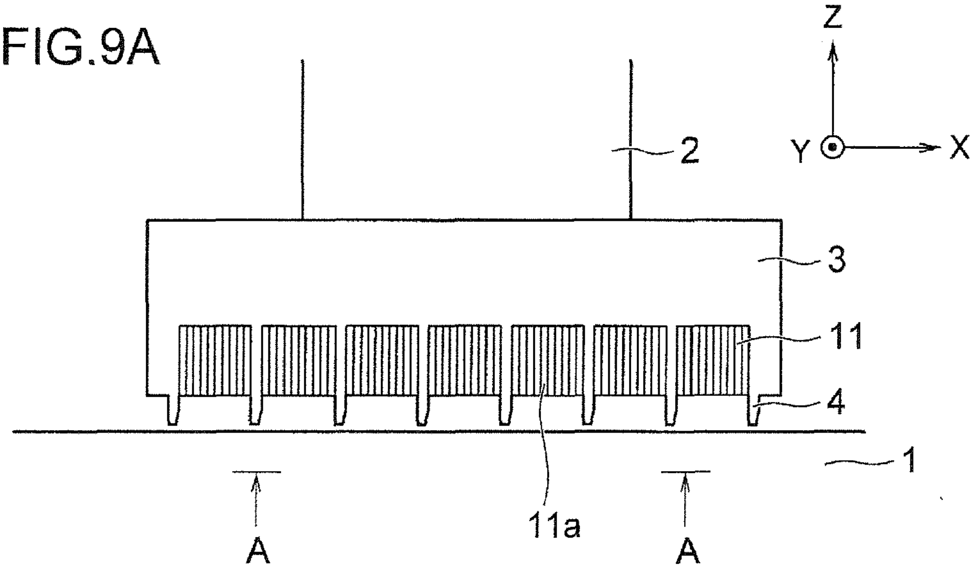



FIG.9B

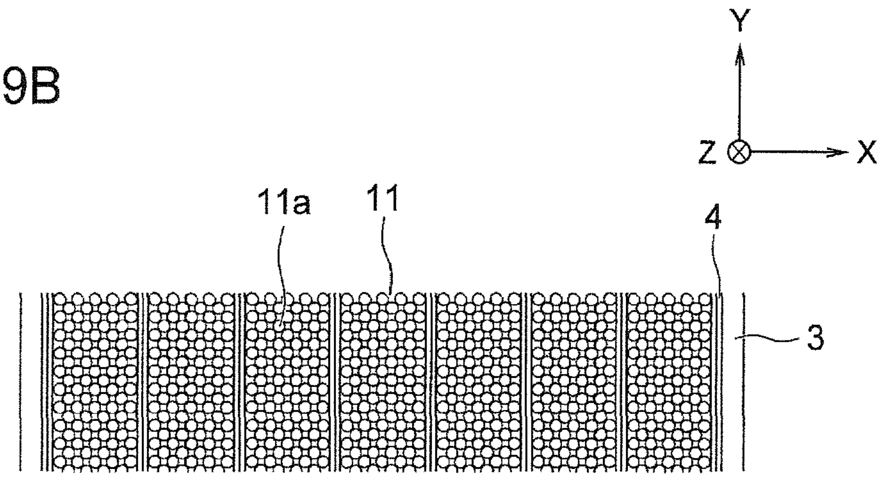


FIG.10

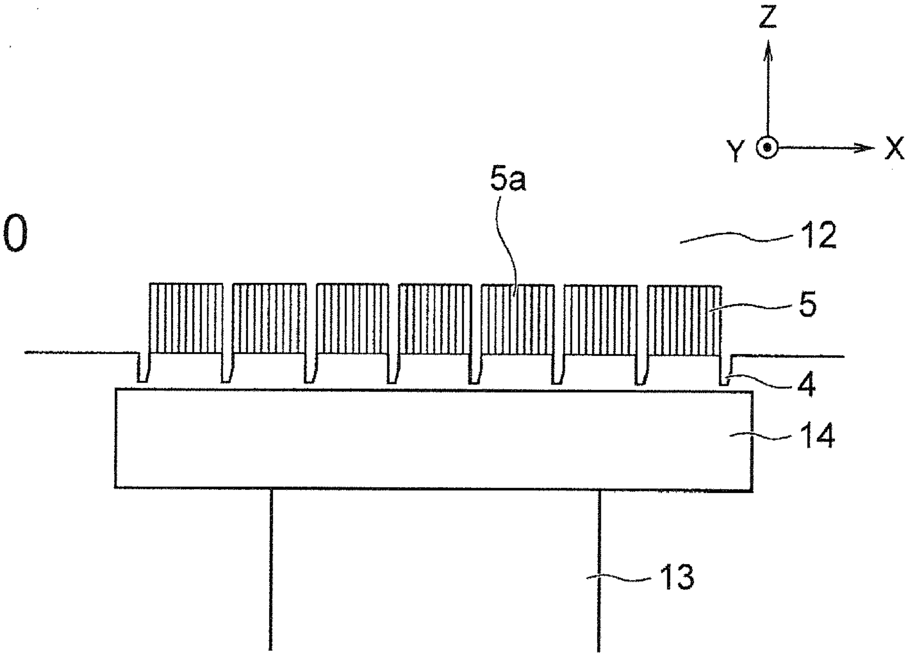
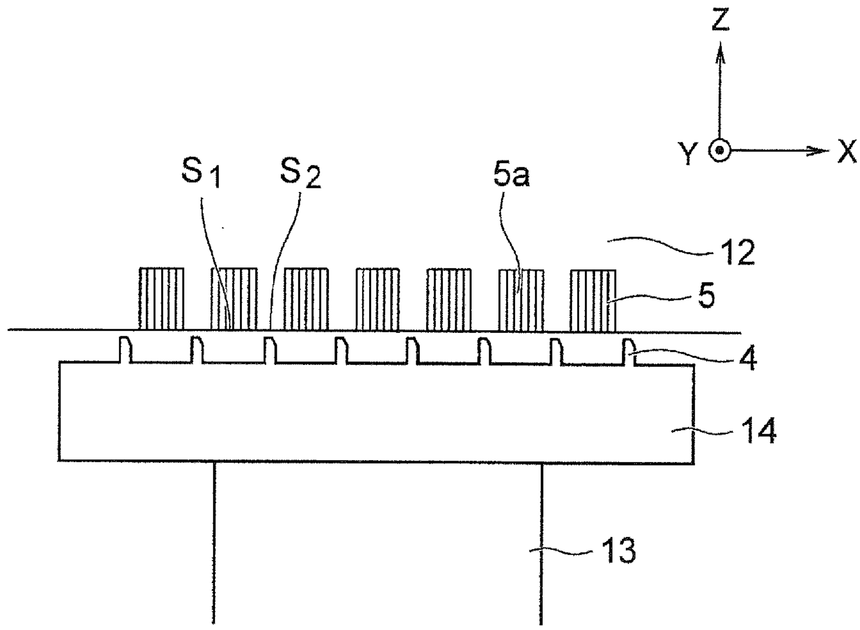



FIG.11



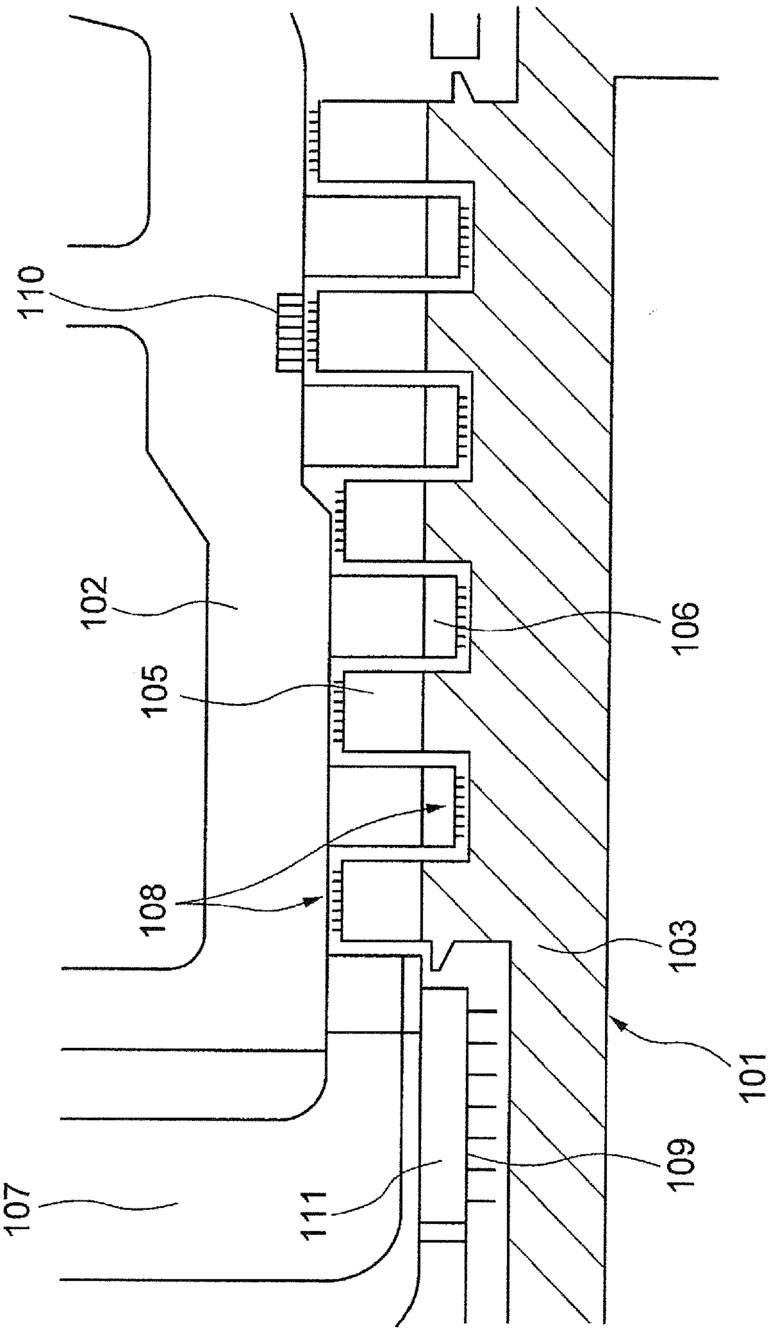
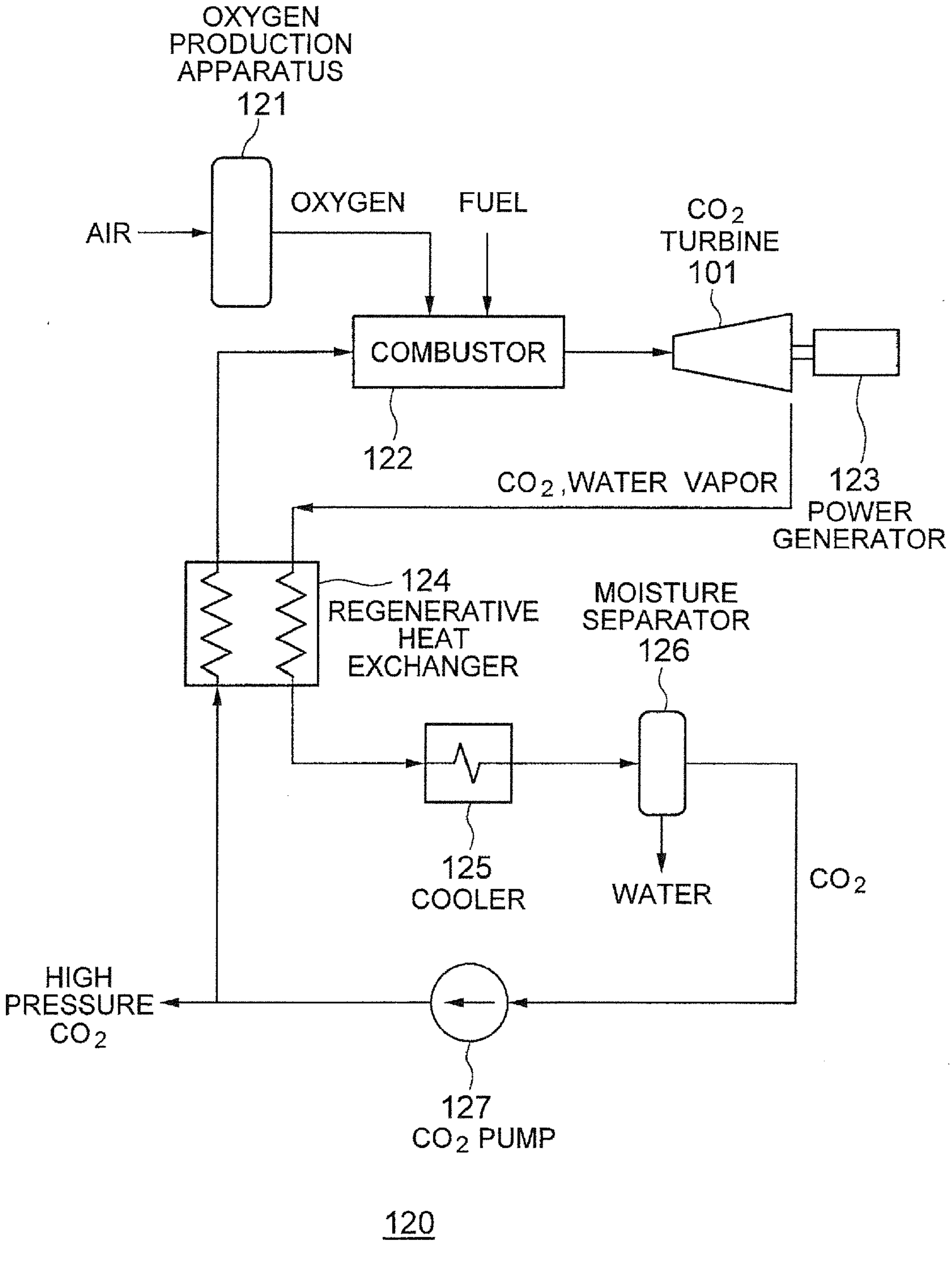



FIG.12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AIR
OXYGEN
FUEL
$CO_2$
TURBINE
101
COMBUSTOR
122
$CO_2$ ,WATER VAPOR
123
POWER
GENERATOR
124
REGENERATIVE
HEAT
EXCHANGER
MOISTURE
SEPARATOR
126
125
COOLER
WATER
$CO_2$
HIGH
PRESSURE
$CO_2$
127
$CO_2$ PUMP
120

FIG.13