(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 4 130 487 A1**

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

(43) Date of publication:
08.02.2023 Bulletin 2023/06

(21) Application number: **20927809.2**

(22) Date of filing: **24.03.2020**

(51) International Patent Classification (IPC):
F04D 29/38 *(1968.09)*

(52) Cooperative Patent Classification (CPC):
F04D 29/38

(86) International application number:
PCT/JP2020/013027

(87) International publication number:
WO 2021/192036 (30.09.2021 Gazette 2021/39)

(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
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

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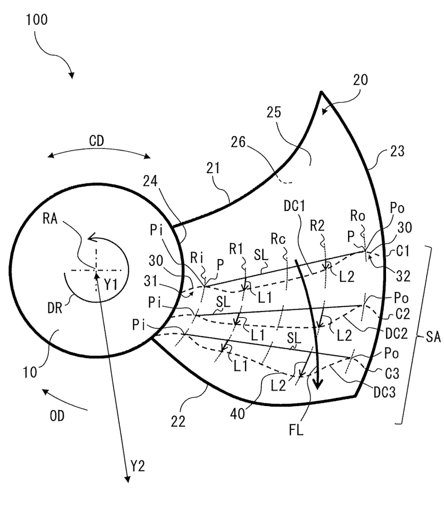
(54) **AXIAL FAN, BLOWING DEVICE, AND REFRIGERATION CYCLE DEVICE**

(57) An axial fan includes a hub, and a blade. The hub has a rotational axis, and is configured to be driven to rotate. The blade is connected to the hub, and has a front edge and a rear edge. In a shape of the blade as viewed in a cross section perpendicular to the rotational axis and in a part nearer to a pressure surface of the blade, the blade has a region in which a distance ratio L2/L1 increases in a direction from the front edge to the rear edge, where: a front end of a mountain-like portion formed to be convex in a rotation direction of the blade is defined as a vertex portion; a vertex portion positioned nearest to an inner circumference is defined as a vertex portion Pi; a vertex portion positioned nearest to an outer circumference is defined as a vertex portion Po; a position of a radius centering around the rotational axis and including the vertex portion Pi is defined as a radius position Ri; a position of a radius centering around the rotational axis and including the vertex portion Po is defined as a radius position Ro; a position of a radius in the middle between the radius position Ri and the radius position Ro is defined as a radius position Rc; a position of a radius in the middle between the radius position Ri and the radius position Rc is defined as a radius position R1; a position of a radius in the middle between the radius position Ro and the radius position Rc is defined as a radius position R2; a virtual straight line connecting the vertex portion Pi and the vertex portion Po is defined as a reference line SL; at the radius position R1, a distance between the reference line SL and the pressure surface is defined as a distance L1; at the radius position R2, a distance between the reference line SL and the pressure surface is defined as a distance L2; and a ratio between the distance L1 and the distance L2 is defined as the distance ratio L2/L1.

FIG. 3



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Description

Technical Field

[0001] The present disclosure relates to an axial fan including a plurality of blades, an air-sending device including the axial fan, and a refrigeration cycle apparatus including the air-sending device.

Background Art

[0002] Some proposed axial fans in the related art include a cylindrical hub provided with a plurality of thin blades (see, for example, Patent Literature 1). In the axial fan disclosed in Patent Literature 1, each blade has a greater chord length near the outer circumference than near the hub. The axial fan disclosed in Patent Literature 1 is designed such that in a cross section of the blade taken in the radial direction, with reference to a point of curvature defined at a distance from the hub equal to approximately 1/3 of the length of the blade connecting a hub portion and an outer circumferential portion, the blade has a straight shape near the outer circumference, and a convex shape near the hub that is convex upstream in the direction of airflow.

[0003] According to the configuration of the axial fan disclosed in Patent Literature 1, the radial inflow of fluid through the outer circumference of the blade is facilitated by the straight portion located near the outer circumference and the convex portion located near the hub. This optimizes the natural flow of fluid around the blade. The above-mentioned configuration allows the axial fan disclosed in Patent Literature 1 to sufficiently exhibit fan characteristics of low-pressure propeller fans, that is, improved fan efficiency and reduced noise. This leads to reduced seasonal power consumption of air-conditioning apparatuses.

Citation List

Patent Literature

[0004] Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2011-236860

Summary of Invention

Technical Problem

[0005] Typically, for outdoor units used for air-conditioning apparatuses, designing the heat exchanger to operate at high pressure drop results in a strong flow of a radial fluid component directed toward the outer circumference of the blade. As described above, as viewed in cross section taken in the radial direction, the axial fan disclosed in Patent Literature 1 has a straight shape near the outer circumference. Accordingly, the presence of a strong flow of a radial fluid component directed toward the outer circumference of the blade may cause the fluid to leak at the outer circumferential end of the blade from the blade pressure surface toward the blade suction surface. This may result in formation of a strong blade tip vortex.

[0006] The present disclosure has been made to address the above-mentioned problem. Accordingly, it is an object of the present disclosure to provide an axial fan that allows for reduced leakage of fluid from the blade pressure surface at the outer circumferential end of the blade to thereby reduce growth of a blade tip vortex, an air-sending device including the axial fan, and a refrigeration cycle apparatus including the air-sending device.

Solution to Problem

[0007] An axial fan according to an embodiment of the present disclosure includes a hub, and a blade. The hub has a rotational axis, and is configured to be driven to rotate. The blade is connected to the hub, and has a front edge and a rear edge. In a shape of the blade as viewed in a cross section perpendicular to the rotational axis and in a part nearer to a pressure surface of the blade, the blade has a region in which a distance ratio L2/L1 increases in a direction from the front edge to the rear edge, where: a front end of a mountain-like portion formed to be convex in a rotation direction of the blade is defined as a vertex portion; a vertex portion positioned nearest to an inner circumference is defined as a vertex portion Pi; a vertex portion positioned nearest to an outer circumference is defined as a vertex portion Po; a position of a radius centering around the rotational axis and including the vertex portion Pi is defined as a radius position Ri; a position of a radius centering around the rotational axis and including the vertex portion Po is defined as a radius position Ro; a position of a radius in the middle between the radius position Ri and the radius position Ro is defined as a radius position Rc; a position of a radius in the middle between the radius position Ri and the radius position Rc is defined as a radius position R1; a position of a radius in the middle between the radius position Ro and the radius position Rc is defined as a radius position R2; a virtual straight line connecting the vertex portion Pi and the vertex portion Po is defined as a reference line SL; at the radius position R1, a distance between the reference line SL and the pressure surface is defined as a distance L1; at the radius position R2, a distance between the reference line SL and the pressure surface is defined as a distance L2; and a ratio between the distance L1 and the distance L2 is defined as the distance ratio L2/L1.

[0008] An air-sending device according to an embodiment of the present disclosure includes the axial fan configured as described above, a drive source configured to provide a drive force to the axial fan, and a casing configured to accommodate the axial fan and the drive source.

[0009] A refrigeration cycle apparatus according to an embodiment of the present disclosure includes the air-sending device configured as described above, and a refrigerant circuit having a condenser and an evaporator. The air-sending device sends air to at least one of the condenser and the evaporator.

Advantageous Effects of Invention

[0010] According to an embodiment of the present disclosure, the axial fan has a region in which the distance ratio L2/L1 increases in the direction from the front edge to the rear edge. This allows the fluid flow to be guided toward an outer circumferential region of the blade where work is efficiently done. Further, over the pressure surface of the axial fan, the distance L2 increases relative to the distance L1 in a direction toward the downstream region in the airflow. This helps to avoid excessive guiding of the airflow toward the outer circumference. Further, the airflow is allowed to concentrate over a portion of the pressure surface that defines the distance L2. The above-mentioned configuration of the axial fan therefore helps to reduce leakage of the fluid from the blade pressure surface at the outer circumferential end of the blade, and consequently reduce growth of a blade tip vortex.

Brief Description of Drawings

[0011]

[Fig. 1] Fig. 1 is a schematic front view of an axial fan according to Embodiment 1.
[Fig. 2] Fig. 2 is a conceptual diagram representing a meridian plane of the axial fan according to Embodiment 1.
[Fig. 3] Fig. 3 is a schematic front view of a blade of the axial fan according to Embodiment 1.
[Fig. 4] Fig. 4 is a front view of a modification of a blade of the axial fan according to Embodiment 1.
[Fig. 5] Fig. 5 is a schematic front view of a blade of an axial fan according to a comparative example.
[Fig. 6] Fig. 6 is a schematic front view of a blade of an axial fan according to another comparative example.
[Fig. 7] Fig. 7 is a schematic front view of a blade of an axial fan according to Embodiment 2.
[Fig. 8] Fig. 8 is a schematic front view of a blade of an axial fan according to Embodiment 3.
[Fig. 9] Fig. 9 is a schematic front view of a blade of an axial fan according to Embodiment 4.
[Fig. 10] Fig. 10 is a schematic front view of a blade of an axial fan according to Embodiment 5.
[Fig. 11] Fig. 11 is a schematic front view of a blade of an axial fan according to Embodiment 6.
[Fig. 12] Fig. 12 is a schematic front view of a blade of an axial fan according to Embodiment 7.
[Fig. 13] Fig. 13 is a schematic front view of a blade of an axial fan according to Embodiment 8.
[Fig. 14] Fig. 14 is a schematic diagram of a refrigeration cycle apparatus according to Embodiment 9.
[Fig. 15] Fig. 15 is a perspective view, as viewed from near an air outlet, of an outdoor unit serving as an air-sending device.
[Fig. 16] Fig. 16 is a top view of the outdoor unit for explaining the configuration of the outdoor unit.
[Fig. 17] Fig. 17 illustrates the outdoor unit with a fan grille removed from the outdoor unit.
[Fig. 18] Fig. 18 illustrates the internal configuration of the outdoor unit with the fan grille, a front panel, and other components removed from the outdoor unit. Description of Embodiments

[0012] An axial fan, an air-sending device, and a refrigeration cycle apparatus according to embodiments will be described below with reference to the drawings. In the drawings below including Fig. 1, the relative dimensions, shapes, and other details of various components may differ from those of the actual components. In the drawings below, the same reference signs are used to indicate the same or corresponding components or features throughout the specification. Although terms representing directions (e.g., "upper", "lower", "right", "left", "front", and "rear") are used as appropriate to facilitate understanding of the present disclosure, such terms are for illustrative purposes only and not intended to limit the corresponding apparatus, device, or component to any particular placement or orientation.

Embodiment 1

[Axial Fan 100]

[0013] Fig. 1 is a schematic front view of an axial fan 100 according to Embodiment 1. A rotation direction DR shown by an arrow in Fig. 1 represents the direction of rotation of the axial fan 100. A reverse rotation direction OD shown by an arrow in Fig. 1 represents a direction opposite to the direction in which the axial fan 100 rotates. Further, a circumferential direction CD shown by a double headed arrow in Fig. 1 represents the circumferential direction of the axial fan 100. The circumferential direction CD includes the rotation direction DR and the reverse rotation direction OD.

[0014] The axial fan 100 according to Embodiment 1 is described below with reference to Fig. 1. The axial fan 100 is a device for forming a flow of fluid. The axial fan 100 is used for, for example, an air-conditioning apparatus or a ventilator. The axial fan 100 forms a flow of fluid as the axial fan 100 rotates in the rotation direction DR about a rotational axis RA. An example of fluid is a gas such as air.

[0015] The far side of Fig. 1 corresponds to an upstream region in the direction of fluid flow relative to the axial fan 100, and the near side of Fig. 1 corresponds to a downstream region in the direction of fluid flow relative to the axial fan 100. The upstream region relative to the axial fan 100 corresponds to a region where air is sucked into the axial fan 100, and the downstream region relative to the axial fan 100 corresponds to a region where air is blown out from the axial fan 100.

[0016] As illustrated in Fig. 1, the axial fan 100 includes a hub 10 disposed along the rotational axis RA, and a plurality of blades 20 connected to the hub 10. Examples of the axial fan 100 include so-called boss-less fans having a plurality of blades 20, with the front and rear edge portions of adjacent blades 20 being connected to define a continuous surface with no boss therebetween.

(Hub 10)

[0017] The hub 10 is connected to the rotary shaft of a drive source such as a motor (not illustrated). In one example, the hub 10 may have a cylindrical shape, or may have a plate-like shape. The hub 10 is not limited to any particular shape as long as the hub 10 is connected to the rotary shaft of the drive source as mentioned above.

[0018] The hub 10 is driven to rotate by the motor (not illustrated) or other drive sources, and defines the rotational axis RA. The hub 10 rotates about the rotational axis RA. The rotation direction DR of the axial fan 100 is the counterclockwise direction as represented by an arrow in Fig. 1. However, the rotation direction DR of the axial fan 100 may not necessarily be the counterclockwise direction. Alternatively, for example, the angle at which to mount the blades 20, or the orientation of the blades 20 may be changed so that the hub 10 rotates in the clockwise direction.

(Blades 20)

[0019] The blades 20 extend radially outward from the hub 10. The blades 20 are arranged in radial formation such that the blades 20 extend radially outward from the hub 10. The blades 20 are spaced apart from each other in the circumferential direction CD. Although Embodiment 1 is directed to an example of the axial fan 100 with three blades 20, the number of blades 20 is not limited to three.

[0020] The blade 20 has a front edge 21, a rear edge 22, an outer circumferential edge 23, and an inner circumferential edge 24. The front edge 21 is located near the leading portion of the blade 20 in the rotation direction DR. That is, the front edge 21 is located forward of the rear edge 22 in the rotation direction DR. The front edge 21 is located upstream of the rear edge 22 in the direction of the fluid flow to be generated.

[0021] The rear edge 22 is located near the trailing portion of the blade 20 in the rotation direction DR. That is, the rear edge 22 is located rearward of the front edge 21 in the rotation direction DR. The rear edge 22 is located downstream of the front edge 21 in the direction of the fluid flow to be generated. The axial fan 100 has the front edge 21 serving as a blade end oriented in the rotation direction DR of the axial fan 100, and the rear edge 22 serving as a blade end opposite to the front edge 21 in the rotation direction DR.

[0022] The outer circumferential edge 23 extends from the front to the rear of the blade 20 in the rotation direction DR such that the outer circumferential edge 23 connects the outermost circumferential portion of the front edge 21 with the outermost circumferential portion of the rear edge 22. The outer circumferential edge 23 defines an end near the outer circumference of the axial fan 100 (to be also referred to simply as "outer circumference" hereinafter) in the radial direction (Y-axis direction). The outer circumferential edge 23 has an arcuate shape as viewed parallel to the rotational axis RA. However, the outer circumferential edge 23 may not necessarily have an arcuate shape as viewed parallel to the rotational axis RA. As viewed parallel to the rotational axis RA, the outer circumferential edge 23 has a length in the circumferential direction CD that is greater than the length of the inner circumferential edge 24 in the circumferential direction CD. However, the length of the outer circumferential edge 23 in the circumferential direction CD, and the length of the inner circumferential edge 24 in the circumferential direction CD may not necessarily have the relationship mentioned above.

[0023] The inner circumferential edge 24 extends from the front to the rear of the blade 20 in the rotation direction DR such that the inner circumferential edge 24 connects the innermost circumferential portion of the front edge 21 with the innermost circumferential portion of the rear edge 22. The inner circumferential edge 24 defines an end near the inner circumference of the axial fan 100 (to be also referred to simply as "inner circumference" hereinafter) in the radial direction (Y-axis direction). The inner circumferential edge 24 has an arcuate shape as viewed parallel to the rotational axis RA. However, the inner circumferential edge 24 may not necessarily have an arcuate shape as viewed parallel to the rotational axis RA. The inner circumferential edge 24 of each blade 20 is connected with the hub 10, such as by being integrated with the hub 10. In one example, the inner circumferential edge 24 of each blade 20 is integrated with the outer circumferential wall of the hub 10 having a cylindrical shape.

[0024] The blades 20 are inclined relative to a plane perpendicular to the rotational axis RA. As the axial fan 100 rotates, the blade surface of each blade 20 pushes the fluid present between the blades 20 to thereby transport the fluid. In this case, a blade surface that pushes the fluid and undergoes an increase in pressure is defined as a pressure surface 25, and a blade surface that is on the reverse side from the pressure surface 25 and undergoes a decrease in pressure is defined as a suction surface 26. Relative to the direction of fluid flow, the upstream surface of the blade 20 corresponds to the suction surface 26, and the downstream surface of the blade 20 corresponds to the pressure surface 25. A surface of the blade 20 depicted on the near side of Fig. 1 corresponds to the pressure surface 25, and a surface on the reverse side of the blade 20 corresponds to the suction surface 26.

(Details of Blades 20)

[0025] Fig. 2 is a conceptual diagram representing a meridian plane of the axial fan 100 according to Embodiment 1. Fig. 2 illustrates the shape of the axial fan 100 when rotated and projected onto a meridian plane that covers the rotational axis RA and each blade 20. A direction of flow AF shown by a vertically hatched arrow in Fig. 2 represents the direction of fluid flow into the axial fan 100. An axial direction AD shown by an open arrow in Fig. 2 represents the direction of the rotational axis RA. The blade 20 has a blade length 27, which represents the distance between the inner circumferential edge 24 and the outer circumferential edge 23, and an intermediate portion 28, which represents the radially middle part of the blade length 27.

[0026] A viewpoint VP shown by a horizontally hatched arrow in Fig. 2 represents the direction of the line of sight taken parallel to the rotational axis RA. The Y-axis in Figs. 1 and 2 represents the radial direction relative to the rotational axis RA of the axial fan 100. Y1 represents a region of the axial fan 100 located nearer to the inner circumference than is a region represented by Y2, and Y2 represents a region of the axial fan 100 located nearer to the outer circumference than is the region represented by Y1.

[0027] Fig. 3 is a schematic front view of each blade 20 of the axial fan 100 according to Embodiment 1. To explain the configuration of each blade 20, Fig. 3 depicts only one of the blades 20, and does not depict other blades 20. An airflow FL shown by an arrow in Fig. 3 conceptually represents a portion of the flow of air along the pressure surface 25 of the blade 20.

[0028] Reference is now made to Figs. 2 and 3 to describe the structure of each blade 20 in detail. In Fig. 2, for the axial fan 100, the shape of the blade 20 when rotated and projected onto the meridian plane is represented by a blade projected portion 20p, and the shape of the hub 10 when rotated and projected onto the meridian plane is represented by a hub projected portion 10p.

[0029] A front-edge projection line 21p represents the shape of the front edge 21 when rotated about the rotational axis RA and projected onto the meridian plane that covers the rotational axis RA. A rear-edge projection line 22p represents the shape of the rear edge 22 when rotated about the rotational axis RA and projected onto the meridian plane that covers the rotational axis RA. An outer-edge projection line 23p represents the shape of the outer circumferential edge 23 when rotated about the rotational axis RA and projected onto the meridian plane that covers the rotational axis RA. An inner-edge projection line 24p represents the shape of the inner circumferential edge 24 when rotated about the rotational axis RA and projected onto the meridian plane that covers the rotational axis RA.

[0030] A position C1, a position C2, and a position C3 shown by dotted lines in Fig. 2 each represent the position of a cross section perpendicular to the rotational axis RA. Relative to the axial direction AD aligned with the rotational axis RA, the position C1, the position C2, and the position C3 are in this order from an upstream region toward a downstream region in the direction of fluid flow.

[0031] The position C1, the position C2, and the position C3 are representative of their relative locations between the front edge 21 and the rear edge 22. Although the foregoing description of Embodiment 1 is directed to the relationship between the three cross-sectional positions C1 to C3, such relationship between individual cross-sectional positions is applicable not only to the three cross-sectional positions C1 to C3 but also to two cross-sectional positions or to four or more cross-sectional positions.

[0032] Portions of the axial fan 100 located in the plane of the cross section shown at the position C1, which are illustrated in Fig. 2, are located at the same position in the axial direction AD aligned with the rotational axis RA. The cross-sectional shape of the blade 20 at the position C1 is shown by a dotted line as a cross-sectional shape DC1 in Figs. 2 and 3. The cross-sectional shape DC1 represents the shape of a cross section, taken at the position C1, of the blade 20 perpendicular to the rotational axis RA and in a part nearer to the pressure surface 25 of the blade 20.

[0033] Likewise, portions of the axial fan 100 located in the plane of the cross section shown at the position C2 are located at the same position in the axial direction AD aligned with the rotational axis RA. The cross-sectional shape of the blade 20 at the position C2 is shown by a dotted line as a cross-sectional shape DC2 in Figs. 2 and 3. The cross-sectional shape DC2 represents the shape of a cross section, taken at the position C2, of the blade 20 perpendicular to the rotational axis RA and in a part nearer to the pressure surface 25 of the blade 20.

[0034] Likewise, portions of the axial fan 100 located in the plane of the cross section shown at the position C3 are located at the same position in the axial direction AD aligned with the rotational axis RA. The cross-sectional shape of the blade 20 at the position C3 is shown by a dotted line as a cross-sectional shape DC3 in Figs. 2 and 3. The cross-sectional shape DC3 represents the shape of a cross section, taken at the position C3, of the blade 20 perpendicular to the rotational axis RA and in a part nearer to the pressure surface 25 of the blade 20.

[0035] As for the relationship between each portion of the axial fan 100 located in the plane of the cross section shown at the position C1, each portion of the axial fan 100 located in the plane of the cross section shown at the position C2, and each portion of the axial fan 100 located in the plane of the cross section shown at the position C3, these portions are located at different positions in the axial direction AD aligned with the rotational axis RA. Accordingly, as illustrated in Figs. 2 and 3, the blade 20 has different cross-sectional shapes DC at different positions in the axial direction AD, such as the cross-sectional shape DC1 at the position C1, the cross-sectional shape DC2 at the position C2, and the cross-sectional shape DC3 at the position C3. The term "cross-sectional shape DC" is the generic term for the cross-sectional shape DC1 at the position C1, the cross-sectional shape DC2 at the position C2, and the cross-sectional shape DC3 at the position C3, and is the generic term for the shape of the blade 20 as viewed in a cross section perpendicular to the rotational axis RA and in a part nearer to the pressure surface 25 of the blade 20.

[0036] As illustrated in Fig. 3, in the cross-sectional shape DC, which is the shape of the blade 20 as viewed in a cross section perpendicular to the rotational axis RA and in a part nearer to the pressure surface 25 of the blade 20, the blade 20 has a mountain-like portion 30 formed to be convex in the rotation direction DR of the blade 20. The mountain-like portion 30 is a region located forward in the rotation direction DR, relative to a region located nearer to the inner circumference than is the mountain-like portion 30, relative to a region located nearer to the outer circumference than is the mountain-like portion 30, or relative to a region located nearer to the inner circumference than is the mountain-like portion 30 and to a region located nearer to the outer circumference than is the mountain-like portion 30. In the radial direction centering around the rotational axis RA, the mountain-like portion 30 defines a slope on a portion of the pressure surface 25 near the inner circumference, on a portion of the pressure surface 25 near the outer circumference, or on both a portion of the pressure surface 25 near the inner circumference and a portion of the pressure surface 25 near the outer circumference.

[0037] With reference to the cross-sectional shape DC of the blade 20 in a part nearer to the pressure surface 25 of the blade 20, the following describes, for example, the positional relationship between individual portions forming the blade 20. First, in the shape of the blade 20 as viewed in a cross section in a part nearer to the pressure surface 25 of the blade 20, the front end of the mountain-like portion 30 formed to be convex in the rotation direction DR of the blade 20 is defined as a vertex portion P. The vertex portion P is the front end of the mountain-like portion 30 in the rotation direction DR.

[0038] In the cross-sectional shape DC, which is the shape of the blade 20 as viewed in a cross section in a part near the pressure surface 25, the vertex portion P positioned nearest to the outer circumference is defined as a vertex portion Pi, and the vertex portion P positioned nearest to the inner circumference is defined as a vertex portion Po. The vertex portion Pi represents the vertex portion P of an inner mountain-like portion 31 that is located nearest to the inner circumference (Y1). The vertex portion Po represents the vertex portion P of an outer mountain-like portion 32 that is located nearest to the outer circumference (Y2). In the shape of the blade 20 as viewed in a cross section in a part nearer to the pressure surface 25 of the blade 20, the inner mountain-like portion 31 represents the mountain-like portion 30 that is located nearest inner circumference (Y1). In the shape of the blade 20 as viewed in a cross section in a part near the pressure surface 25 of the blade 20, the outer mountain-like portion 32 represents the mountain-like portion 30 that is located nearest to the outer circumference (Y2).

[0039] Now, for the axial fan 100, the position of a radius centering around the rotational axis RA and including the vertex portion Pi is defined as a radius position Ri. Further, for the axial fan 100, the position of a radius centering around the rotational axis RA and including the vertex portion Po is defined as a radius position Ro.

[0040] Now, the position of a radius in the middle between the radius position Ri and the radius position Ro is defined as a radius position Rc. The position of a radius in the middle between the radius position Ri and the radius position Rc is defined as a radius position R1. The position of a radius in the middle between the radius position Ro and the radius position Rc is defined as a radius position R2.

[0041] Now, as viewed in the cross-sectional shape DC of the blade 20 in a part nearer to the pressure surface 25, a virtual straight line connecting the vertex portion Pi and the vertex portion Po is defined as a reference line SL.

[0042] Now, at the radius position R1, the distance between the reference line SL and the pressure surface 25 is defined as a distance L1. At the radius position R2, the distance between the reference line SL and the pressure surface 25 is defined as a distance L2. The ratio between the distance L1 and the distance L2 is defined as a distance ratio L2/L1.

[0043] With the positional relationship or other features of individual structural portions of the blade 20 being defined as described above, each blade 20 of the axial fan 100 has a region SA in which the distance ratio L2/L1 increases in the direction from the front edge 21 to the rear edge 22.

[0044] Each blade 20 has a valley-like portion 40 defined between the inner mountain-like portion 31 and the outer mountain-like portion 32. The valley-like portion 40 is recessed in a reverse rotation direction OD relative to the vertex portion Pi and the vertex portion Po. In other words, as viewed in the cross-sectional shape DC of the blade 20 in a part nearer to the pressure surface 25, the pressure surface 25 of the valley-like portion 40 is formed to be convex in the reverse rotation direction OD. The blade 20 may have, between the vertex portion Pi and the vertex portion Po of the cross-sectional shape DC, a single valley-like portion 40 or a plurality of valley-like portions 40.

[0045] Fig. 4 is a front view of a modification of the blade 20 of the axial fan 100 according to Embodiment 1. As illustrated in Fig. 4, the vertex portion Pi of the inner mountain-like portion 31 may be located at the inner circumferential edge 24 of the blade 20. That is, the vertex portion Pi of the inner mountain-like portion 31 may be located at the inner circumferential end of the blade 20, or may be located at the position of connection with the hub 10. The vertex portion Po of the outer mountain-like portion 32 may be located at the outer circumferential edge 23 of the blade 20. That is, the vertex portion Po of the outer mountain-like portion 32 may be located at the outer circumferential end of the blade 20.

[Operation of Axial Fan 100]

[0046] As the axial fan 100 rotates in the rotation direction DR illustrated in Fig. 1, the pressure surface 25 of each blade 20 pushes out ambient air. As a result, the fluid flows in a direction orthogonal to the plane of Fig. 1. More specifically, rotation of the axial fan 100 in the rotation direction DR illustrated in Fig. 1 produces a fluid flow directed from the far side to the near side of Fig. 1. As the axial fan 100 rotates, the pressure on the suction surface 26 becomes lower than the pressure on the pressure surface 25. This causes a pressure difference to develop around each blade 20 between the pressure surface 25 and the suction surface 26.

[Advantageous Effects of Axial Fan 100]

[0047] The axial fan 100 has the region SA in which the distance ratio L2/L1 increases in the direction from the front edge 21 to the rear edge 22. This allows the fluid flow to be guided toward an outer circumferential region (Y2) of the blade 20 where work is efficiently done. Further, the axial fan 100 is designed such that over the pressure surface 25, the distance L2 increases relative to the distance L1 in the direction toward the downstream region in the airflow FL. This helps to avoid excessive guiding of the airflow FL toward the outer circumference (Y2). Further, the airflow FL is allowed to concentrate over a portion of the pressure surface 25 that defines the distance L2. The above-mentioned configuration of the axial fan 100 helps to reduce leakage of the fluid from the pressure surface 25 at the outer circumferential end of the blade 20, and consequently reduce growth of a blade tip vortex.

[0048] A blade tip vortex refers to a vortex of air that is generated at the tip of the blade 20 due to a difference in pressure between the pressure surface 25 and the suction surface 26 of the blade 20. Generation of a blade tip vortex leads to unnecessary energy consumption. Accordingly, reducing generation of a blade tip vortex results in improved efficiency of the axial fan 100 and consequently reduced power consumption of the axial fan 100. Further, a blade tip vortex causes noise. Accordingly, reducing generation of a blade tip vortex helps to reduce noise associated with rotation of the blade 20.

[0049] With typical axial fans, the blade has a straight cross-sectional shape near the outer circumference of the blade. Such axial fans are not able to draw, toward the inner circumference of the blade, an airflow heading toward the outer circumference of the blade. This may result in leakage of the airflow at the outer circumferential end of the blade. As the airflow along the pressure surface of the blade travels gradually downstream, the airflow moves in the radial direction of the blade with its radial component increasing due to the centrifugal force. Accordingly, defining a blade shape based on the shape of the blade as viewed in a cross section perpendicular to the rotational axis of the axial fan can be effective in reducing leakage of the airflow at the outer circumferential end of the blade.

[0050] Fig. 5 is a schematic front view of a blade 20L of an axial fan 100L according to a comparative example. Generally, as illustrated in Fig. 5, to reduce blade tip vortex, the axial fan 100L may in some cases have the blade 20L with a cross-sectional shape DCL. The cross-sectional shape DCL represents the shape of the blade 20L as viewed in a cross section perpendicular to the rotational axis RA of the axial fan 100L according to the comparative example and in a part nearer to the pressure surface 25 of the blade 20L.

[0051] The cross-sectional shape DCL of the axial fan 100L is recessed in the reverse rotation direction OD, which results in an orientation of the pressure surface 25 such that the airflow FL is drawn toward the inner circumference. The pressure surface 25 is thus designed to have a uniform concavo-convex profile with no changes in concavity and convexity from the front edge 21 to the rear edge 22.

[0052] The above-mentioned configuration may allow the axial fan 100L to draw the airflow FL toward the inner circumference to thereby reduce the leakage of the airflow at the outer circumferential end of the blade 20L. The above-mentioned configuration, however, fails to increase the load on an outer circumferential region of the blade 20L where work is efficiently done, and consequently fails to sufficiently reduce required power consumption. As described above, the axial fan 100L is designed to draw the airflow FL toward the inner circumference. Consequently, a maximum air velocity point MP, where the airflow FL is at its maximum, occurs in a portion of the blade 20L from an inner circumferential region to the vicinity of the middle of the blade 20L. With the axial fan 100L, the airflow FL at high velocity leaving the maximum air velocity point MP collides with a structure such as a grille located downstream of the maximum air velocity point MP. This results in increased energy loss. The collision of the airflow FL at high velocity with a structure may cause the axial fan 100L to generate noise. Further, the collision of the airflow FL at high velocity with a structure may lead to an increase in the required power consumption of the axial fan 100L.

[0053] Fig. 6 is a schematic front view of a blade 20R of an axial fan 100R according to another comparative example. As illustrated in Fig. 6, the axial fan 100R according to this comparative example has a cross-sectional shape DCR with the pressure surface 25 designed to have a uniform concavo-convex profile from the front edge 21 to the rear edge 22. The cross-sectional shape

DCR represents the shape of the blade 20R as viewed in a cross section perpendicular to the rotational axis RA of the axial fan 100R according to this comparative example and in a part nearer to the pressure surface 25 of the blade 20R.

[0054] In comparison to the cross-sectional shape DCL of the axial fan 100L, the cross-sectional shape DCR of the axial fan 100R has a deepest part in the vicinity of the outer circumference. It is to be noted, however, that for both the cross-sectional shape DCR of the axial fan 100R and the cross-sectional shape DCL of the axial fan 100L, the pressure surface 25 is designed to have a uniform concavo-convex profile with no changes in concavity and convexity from the front edge 21 to the rear edge 22.

[0055] The concavo-convex profile of the cross-sectional shape DCR of the pressure surface 25 may make it possible for the axial fan 100R to increase the load on an outer circumferential region where work is efficiently done. However, due to the uniform concavo-convex profile of the axial fan 100R with no changes in concavity and convexity from the front edge 21 to the rear edge 22, the airflow FL is guided excessively toward the outer circumference of the blade 20R. This may cause leakage of the airflow FL at the outermost circumference of the blade 20R of the axial fan 100R, which may lead to generation of a blade tip vortex. The blade tip vortex may cause the axial fan 100R to generate noise, leading to a potential increase in required power consumption.

[0056] As opposed to the comparative examples mentioned above, the axial fan 100 has the region SA in which the distance ratio L2/L1 increases in the direction from the front edge 21 to the rear edge 22. The axial fan 100 has, near the outer circumference (Y2) of the blade 20, a cross-sectional portion that is convex in the reverse rotation direction OD. As a result, a flow can be guided from a region (Y1) located nearer to the inner circumference than is the cross-sectional portion, toward the cross-sectional portion located in an outer circumferential region (Y2) of the blade 20 where work is efficiently done. This helps to reduce the required power consumption of the axial fan 100. The cross-sectional shape DC of the axial fan 100 is such that the distance L2 gradually increases relative to the distance L1 in the direction toward the downstream region in the airflow FL. This helps to avoid excessive guiding of the airflow FL toward the outer circumference. Further, due to the above-mentioned cross-sectional shape DC of the axial fan 100 in which the distance L2 gradually increases relative to the distance L1 in the direction toward the downstream region in the airflow FL, the airflow FL is allowed to concentrate at the location corresponding to the distance L2. This helps to reduce leakage of the airflow FL at the outer circumferential end of the blade 20.

Embodiment 2.

[Axial Fan 100A]

[0057] Fig. 7 is a schematic front view of a blade 20A of an axial fan 100A according to Embodiment 2. Reference is now made to Fig. 7 to describe the configuration of the blade 20A in detail. Portions or parts of the axial fan 100A identical in configuration to those of the axial fan 100 illustrated in Figs. 1 to 4 are denoted by the same reference signs and not described below in further detail. For the axial fan 100A according to Embodiment 2, the position of the vertex portion Po is further specified.

[0058] The blade 20A of the axial fan 100A is formed such that in the direction from the front edge 21 to the rear edge 22, the vertex portion Po shifts in position toward the outer circumference (Y2) from a position near the inner circumference (Y1). As viewed parallel to the axial direction AD aligned with the rotational axis RA, the blade 20A of the axial fan 100A is formed such that in the direction from the front edge 21 to the rear edge 22, the distance between the rotational axis RA and the vertex portion Po increases.

[0059] As viewed parallel to the axial direction AD aligned with the rotational axis RA, the blade 20A of the axial fan 100A is formed such that in the direction from the front edge 21 to the rear edge 22, the vertex portion Po shifts in position away from the vertex portion Pi. Accordingly, as viewed parallel to the axial direction AD aligned with the rotational axis RA, the blade 20A of the axial fan 100A is formed such that in the direction from the front edge 21 to the rear edge 22, the distance between the vertex portion Po and the vertex portion Pi increases. As viewed parallel to the axial direction AD aligned with the rotational axis RA, the blade 20A of the axial fan 100A is formed such that in the direction from the front edge 21 to the rear edge 22, the valley-like portion 40 increases in width in the radial direction.

[Advantageous Effects of Axial Fan 100A]

[0060] The axial fan 100A has the region SA in which the distance ratio L2/L1 increases in the direction from the front edge 21 to the rear edge 22. The axial fan 100A thus provides the same effect as that of the axial fan 100.

[0061] Further, the blade 20A of the axial fan 100A is formed such that in the direction from the front edge 21 to the rear edge 22, the vertex portion Po shifts in position toward the outer circumference (Y2) from a position near the inner circumference (Y1). That is, the axial fan 100A is designed such that in the direction toward the downstream region in the airflow FL, a portion of the axial fan 100A that defines the distance L2 shifts gradually in position toward the outer circumference (Y2) in the radial direction. This helps to avoid excessive guiding of the airflow FL toward the outer circumference. As a result, in comparison to the blade 20 of the axial fan 100, the blade 20A of the axial fan 100A makes it possible to further reduce leakage of the airflow FL at the outer circumferential end of the blade 20A. That is, the axial fan 100A allows the airflow FL to be guided toward the outer circumference (Y2) with gradually increasing intensity. This makes it possible to increase the airflow FL directed toward an outer circumferential region (Y2) where work is efficiently done, while reducing leakage of the airflow FL at the outer circumferential end of the blade 20A.

Embodiment 3.

[Axial Fan 100B]

[0062] Fig. 8 is a schematic front view of a blade 20B of an axial fan 100B according to Embodiment 3. Reference is now made to Fig. 8 to describe the configuration of the blade 20B in detail. Portions or parts of the axial fan 100B identical in configuration to those of the axial fan 100 or other axial fans illustrated in Figs. 1 to 7 are denoted by the same reference signs and not described below in further detail. For the axial fan 100B according to Embodiment 3, the position of the vertex portion Po is further specified.

[0063] For the blade 20B, the blade length 27 represents the distance between the inner circumferential edge 24 and the outer circumferential edge 23, and the intermediate portion 28 represents the radially middle part of the blade length 27. The intermediate portion 28 represents a position in the middle of the distance between the inner circumferential edge 24 and the outer circumferential edge 23. The blade length 27 is the same at any position in the circumferential direction CD of the axial fan 100B. That is, the blade length 27 of the blade 20B is constant in the region between the front edge 21 and the rear edge 22, and the outer circumferential edge 23 of the blade 20B has the shape of a circular arc as viewed parallel to the axial direction AD aligned with the rotational axis RA. However, the blade length 27 of the blade 20B may not necessarily be constant in the region between the front edge 21 and the rear edge 22. The blade length 27 of the blade 20B may vary with the position in the circumferential direction CD of the axial fan 100B. That is, the outer circumferential edge 23 of the blade 20B may not necessarily have the shape of a circular arc as viewed parallel to the axial direction AD aligned with the rotational axis RA.

[0064] In the radial direction centering around the rotational axis RA, with the middle position of the blade 20B being defined as the intermediate portion 28, a region of the blade 20B located nearer to the inner circumference (Y1) than is the intermediate portion 28 is defined as an inner-circumference-side region Ai, and a region of the blade 20B located nearer to the outer circumference (Y2) than is the intermediate portion 28 is defined as an outer-circumference-side region Ao.

[0065] The vertex portion Po of the blade 20B is located in the outer-circumference-side region Ao of the blade 20B. That is, the vertex portion Po of the blade 20B is located nearer to the outer circumference (Y2) than is the intermediate portion 28.

[Advantageous Effects of Axial Fan 100B]

[0066] The axial fan 100B has the region SA in which the distance ratio L2/L1 increases in the direction from the front edge 21 to the rear edge 22. The axial fan 100B thus provides the same effect as that of the axial fan 100.

[0067] The blade 20B of the axial fan 100B is formed such that the vertex portion Po is located nearer to the outer circumference (Y2) than is the intermediate portion 28. Since a portion of the blade 20B that defines the distance L2 is located in an outer circumferential region (Y2) of the blade 20B where work is efficiently done, the airflow FL is allowed to concentrate in the outer circumferential region (Y2) of the blade 20B. This helps to reduce required power consumption. That is, the axial fan 100B allows the airflow FL to be guided toward the outer circumference (Y2) with gradually increasing intensity. This makes it possible to increase the airflow FL directed toward an outer circumferential region (Y2) where work is efficiently done, while reducing leakage of the airflow FL at the outer circumferential end of the blade 20B.

Embodiment 4.

[Axial Fan 100C]

[0068] Fig. 9 is a schematic front view of a blade 20C of an axial fan 100C according to Embodiment 4. Reference is now made to Fig. 9 to describe the configuration of the blade 20C in detail. Portions or parts of the axial fan 100C identical in configuration to those of the axial fan 100 or other axial fans illustrated in Figs. 1 to 8 are denoted by the same reference signs and not described below in further detail. For the axial fan 100C according to Embodiment 4, the position of the vertex portion Po is further specified.

[0069] In the radial direction centering around the rotational axis RA, with the middle position of the blade 20C being defined as the intermediate portion 28, a region of the blade 20C located nearer to the inner circumference (Y1) than is the intermediate portion 28 is defined as the inner-circumference-side region Ai, and a region of the blade 20C located nearer to the outer circumference (Y2) than is the intermediate portion 28 is defined as the outer-circumference-side region Ao.

[0070] The vertex portion Po of the blade 20C is located in the inner-circumference-side region Ai of the blade 20C. That is, the vertex portion Po of the blade 20C is located nearer to the inner circumference (Y1) than is the intermediate portion 28.

[Advantageous Effects of Axial Fan 100C]

[0071] The axial fan 100C has the region SA in which the distance ratio L2/L1 increases in the direction from the front edge 21 to the rear edge 22. The axial fan 100C thus provides the same effect as that of the axial fan 100.

[0072] In some cases, generally, designing the heat exchanger to operate at high pressure drop may result in increased amount of work done in an outer circumferential region (Y2) of an axial fan. In other cases, generally, the presence of a structure such as a fan-motor support disposed upstream of an axial fan may impede the inflow of air toward the inner circumference (Y1) of the axial fan. In such cases, the decreased inflow of air toward the inner circumference (Y1) of the axial fan may result in increased load on the axial fan, which may lead to an increase in required power consumption. In this case, guiding the airflow from an outer circumferential region (Y2) of the axial fan toward the inner circumference (Y1) makes it possible to increase the efficiency of the axial fan.

[0073] The blade 20C of the axial fan 100C is formed such that the vertex portion Po is located nearer to the inner circumference (Y1) than is the intermediate portion 28. Due to this configuration of the axial fan 100C, a region that is convex in the reverse rotation direction OD can be positioned near the inner circumference (Y1) of the axial fan 100C. As a result, for the blade 20C as a whole, the airflow FL can be guided from an outer circumferential region (Y2) toward the inner circumference (Y1). Further, within the above-mentioned area, an airflow FL1 is guided toward a portion of the axial fan 100C defining the distance L2 and located nearer to the outer circumference than is a portion of the axial fan 100C that defines the distance L1. This helps to reduce required power consumption. That is, the axial fan 100B is designed such that in the inner-circumference-side region Ai of the blade 20C, the airflow FL1 can be guided toward the outer circumference (Y2) with gradually increasing intensity, which makes it possible to increase an airflow FL2 directed toward an outer circumferential region (Y2) where work is efficiently done.

Embodiment 5.

[Axial Fan 100D]

[0074] Fig. 10 is a schematic front view of a blade 20D of an axial fan 100D according to Embodiment 5. Reference is now made to Fig. 10 to describe the configuration of the blade 20D in detail. Portions or parts of the axial fan 100D identical in configuration to those of the axial fan 100 or other axial fans illustrated in Figs. 1 to 9 are denoted by the same reference signs and not described below in further detail. For the axial fan 100D according to Embodiment 5, the shape of its portion between the vertex portion Pi and the vertex portion Po is further specified.

[0075] As illustrated in Fig. 10 and Fig. 2, in the cross-sectional shape DC, which is the shape of the blade 20D as viewed in a cross section perpendicular to the rotational axis RA and in a part nearer to the pressure surface 25 of the blade 20D, the blade 20D has the mountain-like portion 30 formed to be convex in the rotation direction DR of the blade 20D.

[0076] The blade 20D has, in the radial direction centering around the rotational axis RA, an intermediate mountain-like portion 33 between the inner mountain-like portion 31 and the outer mountain-like portion 32. That is, the mountain-like portion 30 of the blade 20D has the inner mountain-like portion 31, the outer mountain-like portion 32, and the intermediate mountain-like portion 33.

[0077] The intermediate mountain-like portion 33 is a region located forward in the rotation direction DR, relative to a region located nearer to the inner circumference than is the intermediate mountain-like portion 33, relative to a region located nearer to the outer circumference than is the intermediate mountain-like portion 33, or relative to a region located nearer to the inner circumference than is the intermediate mountain-like portion 33 and to a region located nearer to the outer circumference than is the intermediate mountain-like portion 33. The intermediate mountain-like portion 33 defines a slope on the pressure surface 25 near the inner circumference, on the pressure surface 25 near the outer circumference, or on the pressure surface 25 near both the inner circumference and the outer circumference.

[0078] As viewed in the cross-sectional shape DC of the blade 20D in a part nearer to the pressure surface 25, the vertex portion P of the intermediate mountain-like portion 33 is defined as a vertex portion Pc. As viewed in its cross-sectional shape DC, the blade 20D has, in the region between the radius position R1 and the radius position R2, the vertex portion Pc defining the vertex portion P. The vertex portion Pc is a portion of the blade 20D located in the region between the radius position R1 and the radius position R2 and where the separation between the reference line SL and the pressure surface 25 is smallest. As viewed in the cross-sectional shape DC of the blade 20D in a part nearer to the pressure surface 25, the intermediate mountain-like portion 33 with the vertex portion Pc has a cross-sectional shape oriented forward in the rotation direction DR.

[0079] The blade 20D has an inner valley-like portion 41 defined between the inner mountain-like portion 31 and the intermediate mountain-like portion 33. The inner valley-like portion 41 is recessed in the reverse rotation direction OD relative to the vertex portion Pi and the vertex portion Pc. In other words, as viewed in the cross-sectional shape DC of the blade 20D in a part nearer to the pressure surface 25, the pressure surface 25 in the inner valley-like portion 41 is formed to be convex in the reverse rotation direction OD. The blade 20D may have, between the vertex portion Pi and the vertex portion Pc, a single inner valley-like portion 41 or a plurality of inner valley-like portions 41.

[0080] The blade 20D has an outer valley-like portion 42 defined between the outer mountain-like portion 32 and the intermediate mountain-like portion 33. The outer valley-like portion 42 is recessed in the reverse rotation direction OD relative to the vertex portion Po and the vertex portion Pc. In other words, as viewed in the cross-sectional shape DC of the blade 20D in a part nearer to the pressure surface 25, the pressure surface 25 in the outer valley-like portion 42 is formed to be convex in the reverse rotation direction OD. The blade 20D may have, between the vertex portion Po and the vertex portion Pc, a single outer valley-like portion 42 or a plurality of outer valley-like portions 42.

[Advantageous Effects of Axial Fan 100D]

[0081] The axial fan 100D has the region SA in which the distance ratio L2/L1 increases in the direction from the front edge 21 to the rear edge 22. The axial fan 100D thus provides the same effect as that of the axial fan 100.

[0082] As viewed in the cross-sectional shape DC, the blade 20D of the axial fan 100D has, in the region between the radius position R1 and the radius position R2, the vertex portion Pc defining the vertex portion P. The presence of the vertex portion Pc, which is the vertex portion of the intermediate mountain-like portion 33 having a cross-sectional shape oriented forward in the rotation direction DR, makes it possible for the blade 20D to reduce radial inflow of the airflow FL toward a region located midway between the following regions: a region of the outer valley-like portion 42 that defines the distance L2; and a region of the inner valley-like portion 41 that defines the distance L1. The above-mentioned configuration of the axial fan 100D allows the airflow FL to concentrate toward an outer circumferential region (Y2) of the blade 20D where work is efficiently done. This helps to reduce required power consumption.

Embodiment 6.

[Axial Fan 100E]

[0083] Fig. 11 is a schematic front view of a blade 20E of an axial fan 100E according to Embodiment 6. Reference is now made to Fig. 11 to describe the configuration of the blade 20E in detail. Portions or parts of the axial fan 100E identical in configuration to those of the axial fan 100 or other axial fans illustrated in Figs. 1 to 10 are denoted by the same reference signs and not described below in further detail. For the axial fan 100E according to Embodiment 6, the configuration of the vertex portion Pc is further specified.

[0084] As illustrated in Fig. 11, for the axial fan 100E, the position of a radius centering around the rotational axis RA and including the vertex portion Pc is defined as a radius position R3. As described above, a virtual straight line connecting the vertex portion Pi and the vertex portion Po is defined as the reference line SL. At the radius position R3, the distance between the reference line SL and the pressure surface 25 is defined as a distance L3.

[0085] The blade 20E is formed such that the distance L3 decreases in the direction from the front edge 21 to the rear edge 22. That is, the blade 20E is formed such that in the direction from the front edge 21 to the rear edge 22, the vertex portion Pc shifts in position toward the reference line SL. Further, the blade 20E is formed such that in the direction from the front edge 21 to the rear edge 22, the amount of projection of the intermediate mountain-like portion 33 in the rotation direction DR increases.

[Advantageous Effects of Axial Fan 100E]

[0086] The axial fan 100E has the region SA in which the distance ratio L2/L1 increases in the direction from the front edge 21 to the rear edge 22. The axial fan 100E thus provides the same effect as that of the axial fan 100.

[0087] The blade 20E is formed such that the distance L3 decreases in the direction from the front edge 21 to the rear edge 22. This configuration of the blade 20E ensures that in a region near the front edge 21 of the blade 20E, inflow of the airflow FL2 from the inner valley-like portion 41, which is a portion of the blade 20E defining the distance L1, to the outer valley-like portion 42, which is a portion of the blade 20E defining the distance L2, is not impeded. The above-mentioned configuration of the axial fan 100E makes it possible to increase the airflow FL directed toward an outer circumferential region (Y2) of the blade 20E where work is efficiently done. This helps to reduce required power consumption.

[0088] Further, the blade 20E is designed such that in a region near the rear edge 22 of the blade 20E, inflow of the airflow FL1 toward the outer circumference in the radial direction is reduced. This helps to reduce generation of a radial component of the airflow FL at the time when the airflow FL leaves the rear edge 22. The above-mentioned configuration of the axial fan 100E helps to ensure that the airflow FL leaving the rear edge 22 does not collide obliquely with a structure such as a grille located downstream of the blade 20E. This makes it possible to reduce noise generated when the airflow FL collides with the structure.

Embodiment 7.

[Axial Fan 100F]

[0089] Fig. 12 is a schematic front view of a blade 20F of an axial fan 100F according to Embodiment 7. Reference is now made to Fig. 12 to describe the configuration of the blade 20F in detail. Portions or parts of the axial fan 100F identical in configuration to those of the axial fan 100 or other axial fans illustrated in Figs. 1 to 11 are denoted by the same reference signs and not described below in further detail. For the axial fan 100F according to Embodiment 7, the position of the vertex portion Pc is further specified.

[0090] As illustrated in Fig. 12, for the axial fan 100F, the position of a radius centering around the rotational axis RA and including the vertex portion Pc is defined as the radius position R3. At the radius position R3, the distance between the reference line SL and the pressure surface 25 is defined as the distance L3.

[0091] The blade 20F of the axial fan 100F is formed such that in the direction from the front edge 21 to the rear edge 22, the vertex portion Pc shifts in position toward the outer circumference (Y2) from a position near the inner circumference (Y1).

[Advantageous Effects of Axial Fan 100F]

[0092] The axial fan 100F has the region SA in which the distance ratio L2/L1 increases in the direction from the front edge 21 to the rear edge 22. The axial fan 100F thus provides the same effect as that of the axial fan 100.

[0093] Further, the blade 20F of the axial fan 100F is formed such that in the direction from the front edge 21 to the rear edge 22, the vertex portion Pc shifts in position toward the outer circumference (Y2) from a position near the inner circumference (Y1). The axial fan 100F is thus designed such that in the direction toward the downstream region in the airflow FL, the vertex portion Pc gradually shifts in position toward the outer circumference (Y2) in the radial direction. As a result, the airflow FL shifts in position toward the outer circumference (Y2) of the blade 20F along the vertex portion Pc. The above-mentioned configuration of the axial fan 100F allows the airflow FL to further concentrate toward the outer circumference (Y2) of the blade 20F. This helps to reduce required power consumption.

Embodiment 8.

[Axial Fan 100G]

[0094] Fig. 13 is a schematic front view of a blade 20G of an axial fan 100G according to Embodiment 8. Reference is now made to Fig. 13 to describe the configuration of the blade 20G in detail. Portions or parts of the axial fan 100G identical in configuration to those of the axial fan 100 or other axial fans illustrated in Figs. 1 to 12 are denoted by the same reference signs and not described below in further detail. For the axial fan 100G according to Embodiment 8, the position of the vertex portion Pc is further specified.

[0095] As illustrated in Fig. 13, for the axial fan 100G, the position of a radius centering around the rotational axis RA and including the vertex portion Pc is defined as the radius position R3. At the radius position R3, the distance between the reference line SL and the pressure surface 25 is defined as the distance L3.

[0096] The blade 20G of the axial fan 100G is formed such that in the direction from the front edge 21 to the rear edge 22, the vertex portion Pc shifts in position toward the inner circumference (Y1) from a position near the outer circumference (Y2).

[Advantageous Effects of Axial Fan 100G]

[0097] The axial fan 100G has the region SA in which the distance ratio L2/L1 increases in the direction from the front edge 21 to the rear edge 22. The axial fan 100G thus provides the same effect as that of the axial fan 100.

[0098] The blade 20G of the axial fan 100G is formed such that in the direction from the front edge 21 to the rear edge 22, the vertex portion Pc shifts in position toward the inner circumference (Y1) from a position near the outer circumference (Y2). As a result, the outer valley-like portion 42 that defines the distance L2 has a radial width that gradually increases in the direction from the front edge 21 to the rear edge 22. The above-mentioned configuration of the axial fan 100G ensures that the airflow FL is dispersed in the radial direction. This allows for improved radial uniformity of air velocity distribution, which makes the axial fan 100G less susceptible to formation of the maximum air velocity point MP mentioned above. The above-mentioned configuration of the axial fan 100G allows the airflow FL leaving the rear edge 22 to collide, in a dispersed manner, with a structure such as a grille located downstream of the blade 20G. This makes it possible to reduce noise generated when the airflow FL collides with the structure.

Embodiment 9.

[Refrigeration Cycle Apparatus 70]

[0099] Embodiment 9 is directed to using the axial fan 100 or other axial fans according to Embodiments 1 to 8 for an outdoor unit 50, which serves as an air-sending device of a refrigeration cycle apparatus 70.

[0100] Fig. 14 is a schematic diagram of the refrigeration cycle apparatus 70 according to Embodiment 9. Although the following description is directed to the refrigeration cycle apparatus 70 used for air-conditioning purposes, this is not intended to limit the use of the refrigeration cycle apparatus 70 to air conditioning. For example, the refrigeration cycle apparatus 70 is used for refrigeration or air-conditioning purposes, such as for refrigerators or freezers, vending machines, air-conditioning apparatuses, refrigeration apparatuses, or water heaters.

[0101] As illustrated in Fig. 14, the refrigeration cycle apparatus 70 includes a refrigerant circuit 71 formed by sequentially connecting a compressor 64, a condenser 72, an expansion valve 74, and an evaporator 73 by a refrigerant pipe. For the condenser 72, a condenser fan 72a is disposed to send air used for heat exchange to the condenser 72. For the evaporator 73, an evaporator fan 73a is disposed to send sends air used for heat exchange to the evaporator 73. At least one of the condenser fan 72a and the evaporator fan 73a is the axial fan 100 or other axial fans according to any one of Embodiments 1 to 8 mentioned above. In the refrigeration cycle apparatus 70, the refrigerant circuit 71 may be provided with a flow switching device such as a four-way valve that switches the flows of refrigerant to allow switching between heating operation and cooling operation.

[0102] Fig. 15 is a perspective view, as seen from near an air outlet, of the outdoor unit 50 serving as an air-sending device. Fig. 16 is a top view of the outdoor unit 50 for explaining the configuration of the outdoor unit 50. Fig. 17 illustrates the outdoor unit 50 with a fan grille removed from the outdoor unit 50. Fig. 18 illustrates the internal configuration of the outdoor unit 50 with the fan grille, a front panel, and other components removed from the outdoor unit 50.

[0103] As illustrated in Figs. 15 to 18, an outdoor unit body 51 serving as a casing is formed as an enclosure having the following surfaces: a lateral surface 51a and a lateral surface 51c, which define a pair of left and right lateral surfaces; a front surface 51b; a back surface 51d; a top surface 51e; and a bottom surface 51f. The lateral surface 51a and the back surface 51d each have an opening (not illustrated) for sucking in air from the outside. The front surface 51b has an air outlet 53 formed in a front panel 52 to blow air to the outside. Further, the air outlet 53 is covered with a fan grille 54. This ensures safety by preventing contact between the axial fan 100 and, for example, an object located outside the outdoor unit body 51. Arrows AR in Fig. 16 each represent the flow of air.

[0104] The axial fan 100 and a fan motor 61 are accommodated in the outdoor unit body 51. The axial fan 100 is connected via a rotary shaft 62 to the fan motor 61, which is a drive source located near the back surface 51d. The axial fan 100 is driven to rotate by the fan motor 61. The fan motor 61 provides a drive force to the axial fan 100. The fan motor 61 is mounted to a motor support 69. The motor support 69 is disposed between the fan motor 61 and a heat exchanger 68.

[0105] The interior of the outdoor unit body 51 is divided by a partition plate 51g, which is a wall element, into an air-sending chamber 56 in which the axial fan 100 is installed, and a machine chamber 57 in which the compressor 64 and other components are installed. The heat exchanger 68, which extends in a substantially L-shape in plan view, is disposed at a location within the air-sending chamber 56 near the lateral surface 51a and the back surface 51d. The heat exchanger 68 may not necessarily have the shape mentioned above. The heat exchanger 68 acts as the evaporator 73 during heating operation, and acts as the condenser 72 during cooling operation.

[0106] A bell mouth 63 is disposed radially outward of the axial fan 100 disposed in the air-sending chamber 56. The bell mouth 63 surrounds an outer circumferential region of the axial fan 100, and serves to adjust the flow of gas created by the axial fan 100 or other components. The bell mouth 63 is located further outside than is the outer circumferential end of the blade 20, and defines an annular shape in the direction of rotation of the axial fan 100. The partition plate 51g is located beside one side of the bell mouth 63, and a portion of the heat exchanger 68 is located beside the other side of the bell mouth 63.

[0107] The front end of the bell mouth 63 is connected to the front panel 52 of the outdoor unit 50 so as to surround the periphery of the air outlet 53. The bell mouth 63 may be integral with the front panel 52, or may be provided as a separate component that can be connected to the front panel 52. Due to the presence of the bell mouth 63, the flow passage between the inlet side and the outlet side of the bell mouth 63 is defined as an air passageway near the air outlet 53. That is, the air passageway near the air outlet 53 is partitioned off by the bell mouth 63 from other spaces within the air-sending chamber 56.

[0108] The heat exchanger 68 disposed near the air inlet of the axial fan 100 includes a plurality of fins with plate-like surfaces arranged side by side in parallel to each other, and heat transfer tubes penetrating the fins in a direction in which the fins are arranged side by side. Refrigerant that circulates in the refrigerant circuit flows in the heat transfer tubes. In the heat exchanger 68 according to Embodiment 9, a plurality of rows of heat transfer tubes extend in an L-shape over an area of the outdoor unit body 51 including the lateral surface 51a and the back surface 51d, and follow a meandering path while penetrating the fins. The heat exchanger 68 is connected to the compressor 64 via a pipe 65 or other components, and is further connected to an indoor-side heat exchanger (not illustrated), the expansion valve, and other components to form the refrigerant circuit 71 of the air-conditioning apparatus. A board case 66 is disposed in the machine chamber 57. A control board 67 disposed in the board case 66 is configured to control devices mounted in the outdoor unit.

[Operational Effects of Refrigeration Cycle Apparatus 70 and Air-Sending Device]

[0109] Embodiment 9 provides advantages similar to Embodiments 1 to 8 corresponding to Embodiment 9. For example, the axial fan 100 makes it possible to reduce leakage of the fluid from the pressure surface 25 at the outer circumferential end of the blade 20, and consequently reduce growth of a blade tip vortex. Further, the required power consumption of the axial fan 100 can be reduced. This consequently makes it possible to reduce the required power consumption of the refrigeration cycle apparatus 70, and the required power consumption of the outdoor unit 50, which is an air-sending device. The axial fan 100 thus allows for improved radial uniformity of the velocity distribution of the fluid blown by the axial fan 100. This consequently makes it possible to reduce noise generated by the refrigeration cycle apparatus 70, and noise generated by the outdoor unit 50, which is an air-sending device.

[0110] The configurations described in the foregoing description of the embodiments are intended to be illustrative only. These configurations can be combined with other known techniques, or can be partially omitted or changed without departing from the scope of the present disclosure.

Reference Signs List

[0111] 10: hub, 10p: hub projected portion, 20: blade, 20A: blade, 20B: blade, 20C: blade, 20D: blade, 20E: blade, 20F: blade, 20G: blade, 20L: blade, 20R: blade, 20p: blade projected portion, 21: front edge, 21p: front-edge projection line, 22: rear edge, 22p: rear-edge projection line, 23: outer circumferential edge, 23p: outer-edge projection line, 24: inner circumferential edge, 24p: inner-edge projection line, 25: pressure surface, 26: suction surface, 27: blade length, 28: intermediate portion, 30: mountain-like portion, 31: inner mountain-like portion, 32: outer mountain-like portion, 33: intermediate mountain-like portion, 40: valley-like portion, 41: inner valley-like portion, 42: outer valley-like portion, 50: outdoor unit, 51: outdoor unit body, 51a: lateral surface, 51b: front surface, 51c: lateral surface, 51d: back surface, 51e: top surface, 51f: bottom surface, 51g: partition plate, 52: front panel, 53: air outlet, 54: fan grille, 56: air-sending chamber, 57: machine room, 61: fan motor, 62: rotary shaft, 63: bell mouth, 64: compressor, 65: pipe, 66: board case, 67: control board, 68: heat exchanger, 69: motor support, 70: refrigeration cycle apparatus, 71: refrigerant circuit, 72: condenser, 72a: condenser fan, 73: evaporator, 73a: evaporator fan, 74: expansion valve, 100: axial fan, 100A: axial fan, 100B: axial fan, 100C: axial fan, 100D: axial fan, 100E: axial fan, 100F: axial fan, 100G: axial fan, 100L: axial fan, 100R: axial fan, AD: axial direction, AF: direction, AR: arrow, Ai: inner-circumference-side region, Ao: outer-circumference-side region, CD: circumferential direction, DC: cross-sectional shape, DC1: cross-sectional shape, DC2: cross-sectional shape, DC3: cross-sectional shape, DCL: cross-sectional shape, DCR: cross-sectional shape, DR: rotation direction, FL: airflow, FL1: airflow, FL2: airflow, L1: distance, L2: distance, L3: distance, MP: maximum air velocity point, OD: reverse rotation direction, P: vertex portion, Pc: vertex portion, Pi: vertex portion, Po: vertex portion, R1: radius position, R2: radius position, R3: radius position, RA: rotational axis, Rc: radius position, Ri: radius position, Ro: radius position, SA: region, SL: reference line, VP: viewpoint.

Claims

1. An axial fan, comprising:

   a hub having a rotational axis and configured to be driven to rotate; and
   a blade connected to the hub and having a front edge and a rear edge, wherein
   in a shape of the blade as viewed in a cross section perpendicular to the rotational axis and in a part nearer to a pressure surface of the blade, the blade having a region in which a distance ratio L2/L1 increases in a direction from the front edge to the rear edge, where
   a front end of a mountain-like portion formed to be convex in a rotation direction of the blade being defined as a vertex portion,
   a vertex portion positioned nearest to an inner circumference being defined as a vertex portion Pi,
   a vertex portion positioned nearest to an outer circumference being defined as a vertex portion Po,
   a position of a radius centering around the rotational axis and including the vertex portion Pi being defined as a radius position Ri,
   a position of a radius centering around the rotational axis and including the vertex portion Po being defined as a radius position Ro,
   a position of a radius in the middle between the radius position Ri and the radius position Ro being defined as a radius position Rc,
   a position of a radius in the middle between the radius position Ri and the radius position Rc being defined as a radius position R1,
   a position of a radius in the middle between the radius position Ro and the radius position Rc being defined as a radius position R2,
   a virtual straight line connecting the vertex portion Pi and the vertex portion Po being defined as a reference line SL,
   at the radius position R1, a distance between the reference line SL and the pressure surface being defined as a distance L1,
   at the radius position R2, a distance between the reference line SL and the pressure surface being defined as a distance L2, and
   a ratio between the distance L1 and the distance L2 being defined as the distance ratio L2/L1.

2. The axial fan of claim 1, wherein
   the blade is formed such that in the direction from the front edge to the rear edge, the vertex portion Po shifts in position toward the outer circumference from a position near the inner circumference.

3. The axial fan of claim 1 or 2, wherein

   the blade is formed such that the vertex portion Po is located nearer to the outer circumference than is the intermediate portion, where
   an intermediate position of the blade in a radial direction centering around the rotational axis being defined as the intermediate portion.

4. The axial fan of claim 1 or 2, wherein

   the blade is formed such that the vertex portion Po is located nearer to the inner circumference than is an intermediate portion, where
   an intermediate position of the blade in a radial

direction centering around the rotational axis being defined as the intermediate portion.

5. The axial fan of any one of claims 1 to 4, wherein

in the shape of the blade as viewed in the cross section, the blade has, in a region between the radius position R1 and the radius position R2, a vertex portion Pc defining the vertex portion, and the vertex portion Pc is a portion of the blade located in the region between the radius position R1 and the radius position R2 and where a separation between the reference line SL and the pressure surface is smallest.

6. The axial fan of claim 5, wherein

the blade is formed such that a distance L3 decreases in the direction from the front edge to the rear edge, where
a position of a radius centering around the rotational axis and including the vertex portion Pc being defined as a radius position R3, and
at the radius position R3, a distance between the reference line SL and the pressure surface being defined as the distance L3.

7. The axial fan of claim 5 or 6, wherein
the blade is formed such that in the direction from the front edge to the rear edge, the vertex portion Pc shifts in position toward the outer circumference from a position near the inner circumference.

8. The axial fan of claim 5 or 6, wherein
the blade is formed such that in the direction from the front edge to the rear edge, the vertex portion Pc shifts in position toward the inner circumference from a position near the outer circumference.

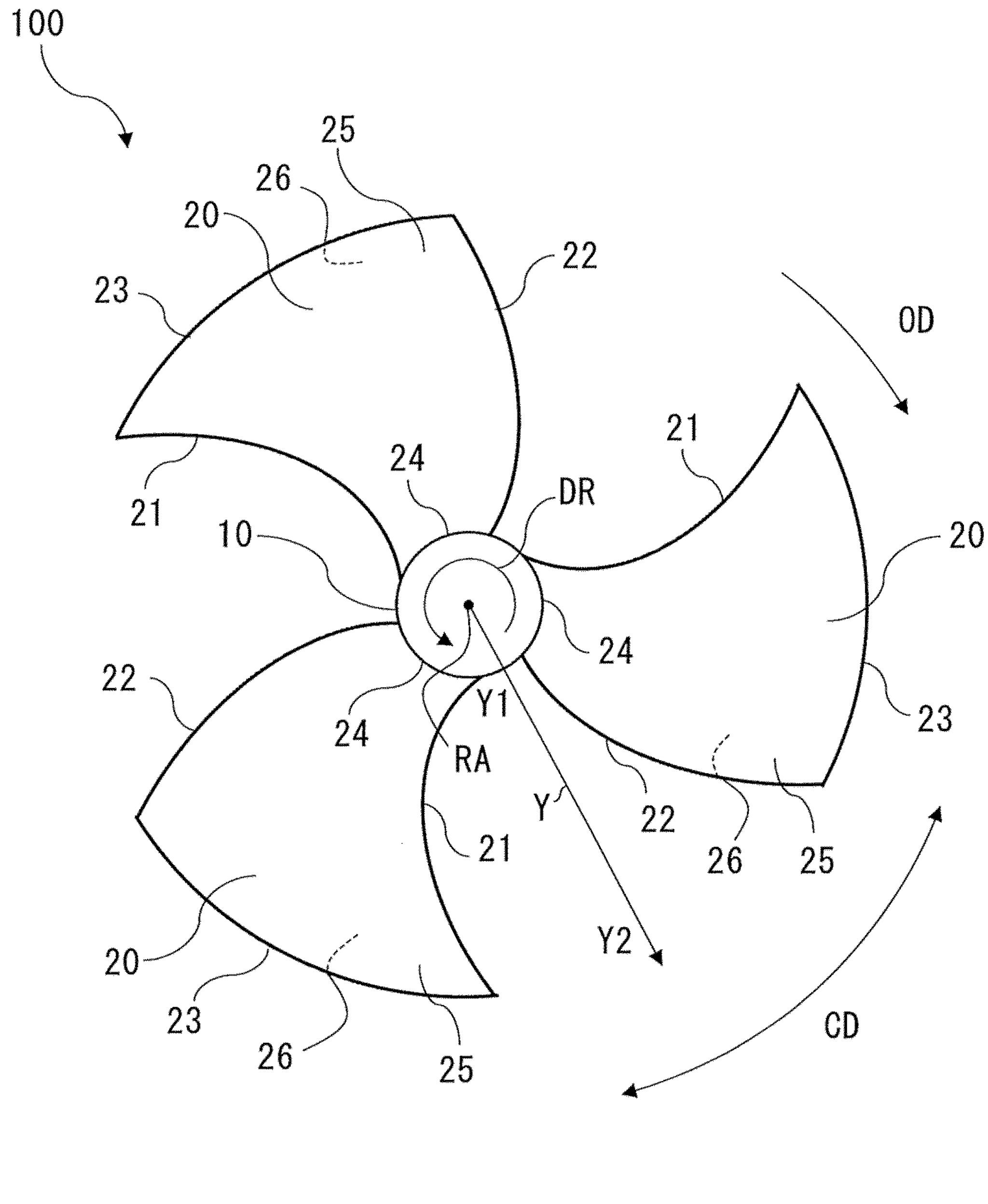
9. An air-sending device, comprising:

the axial fan of any one of claims 1 to 8;
a drive source configured to provide a drive force to the axial fan; and
a casing configured to accommodate the axial fan and the drive source.

10. A refrigeration cycle apparatus, comprising:

the air-sending device of claim 9; and
a refrigerant circuit including a condenser and an evaporator,
the air-sending device being configured to send air to at least one of the condenser and the evaporator.

FIG. 1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Y2
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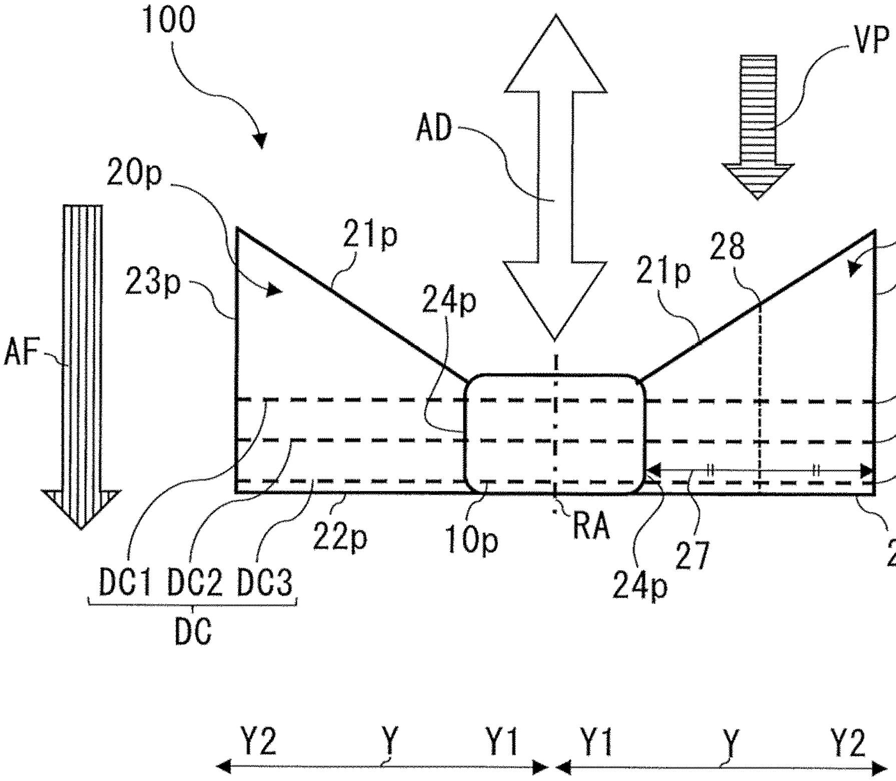
25
CD

FIG. 2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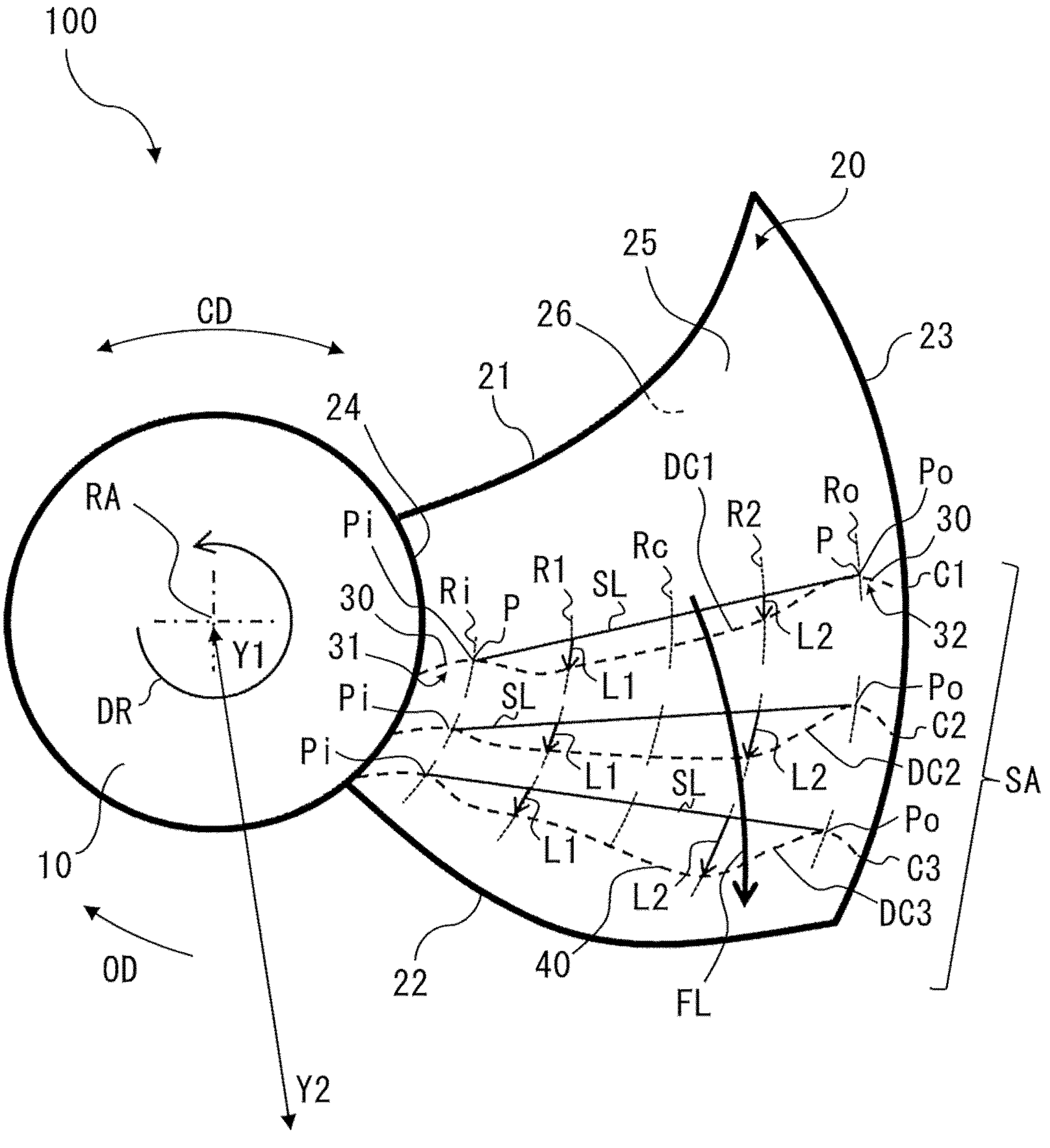
DC1 DC2 DC3
DC
Y2
Y
Y1
Y1
Y
Y2

FIG. 3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C2
DR
L1
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FL
Y2

FIG. 4

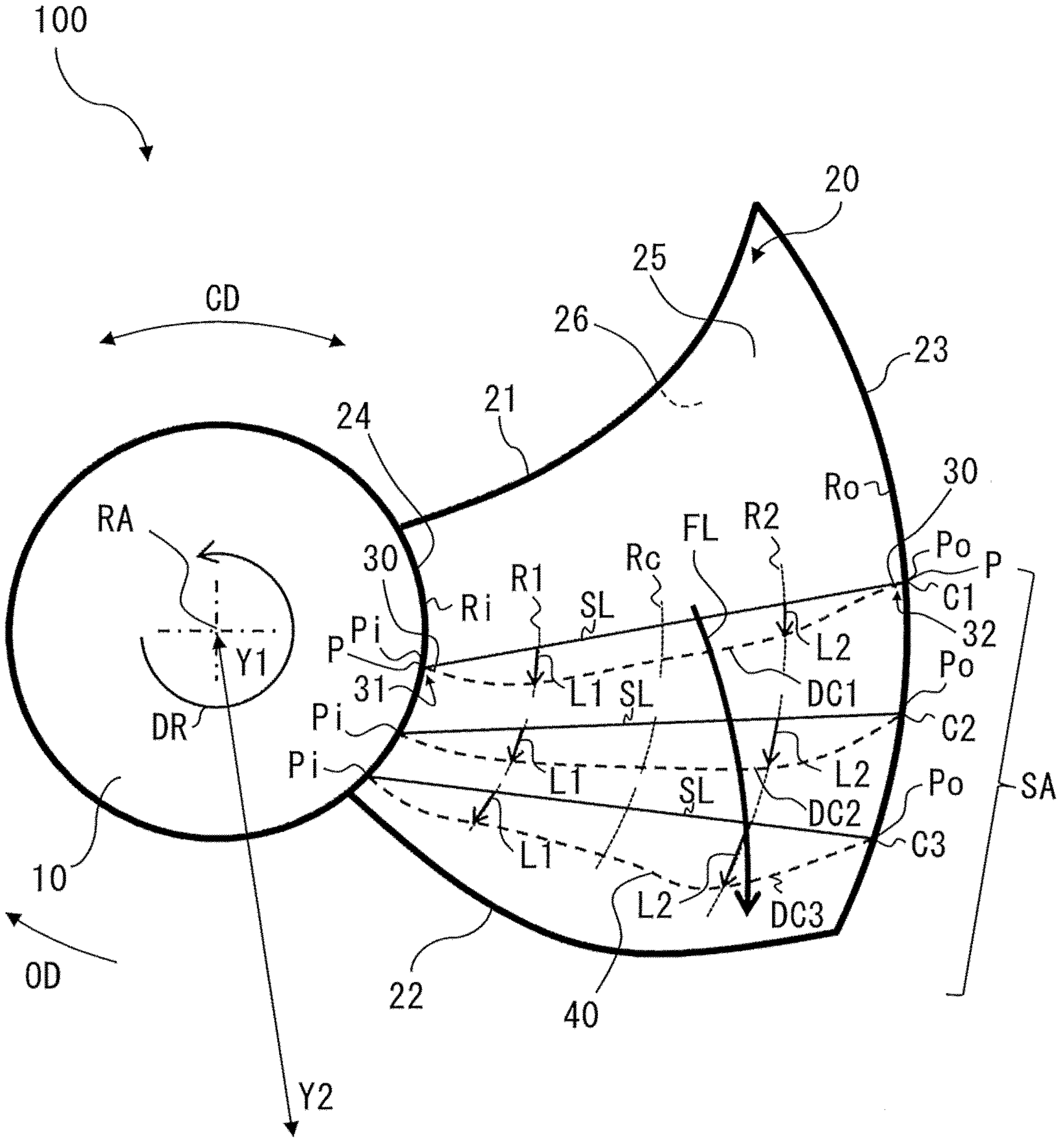
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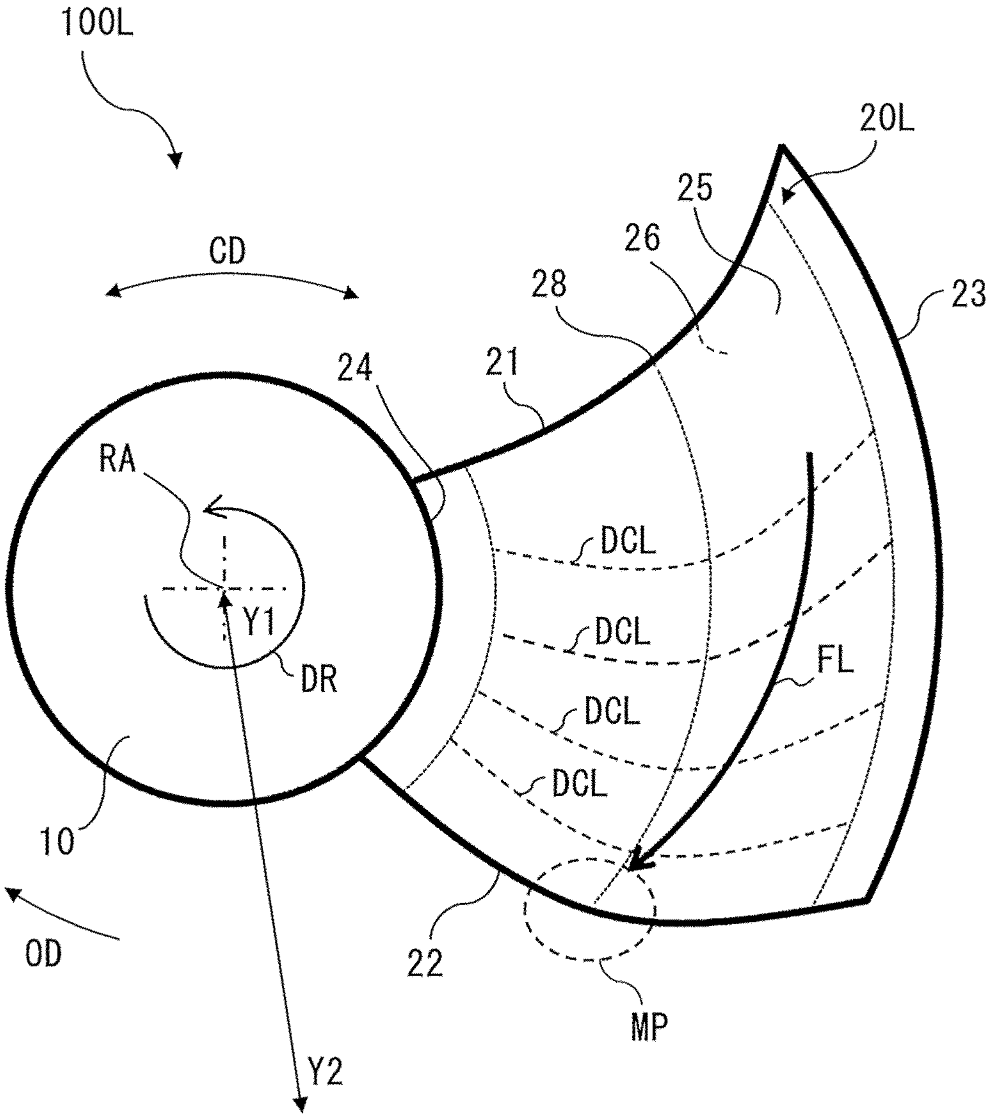
FIG. 5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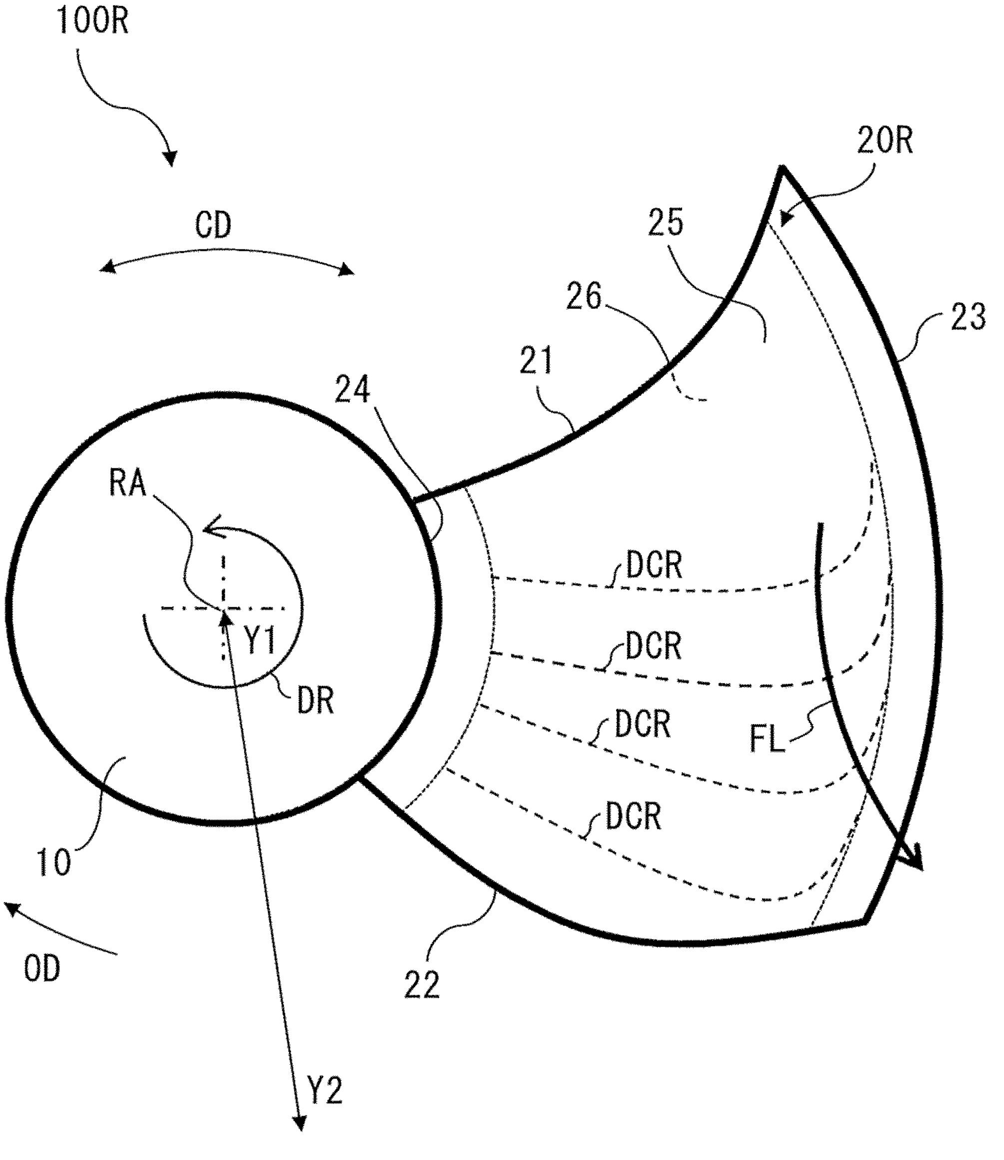
Y2

FIG. 6



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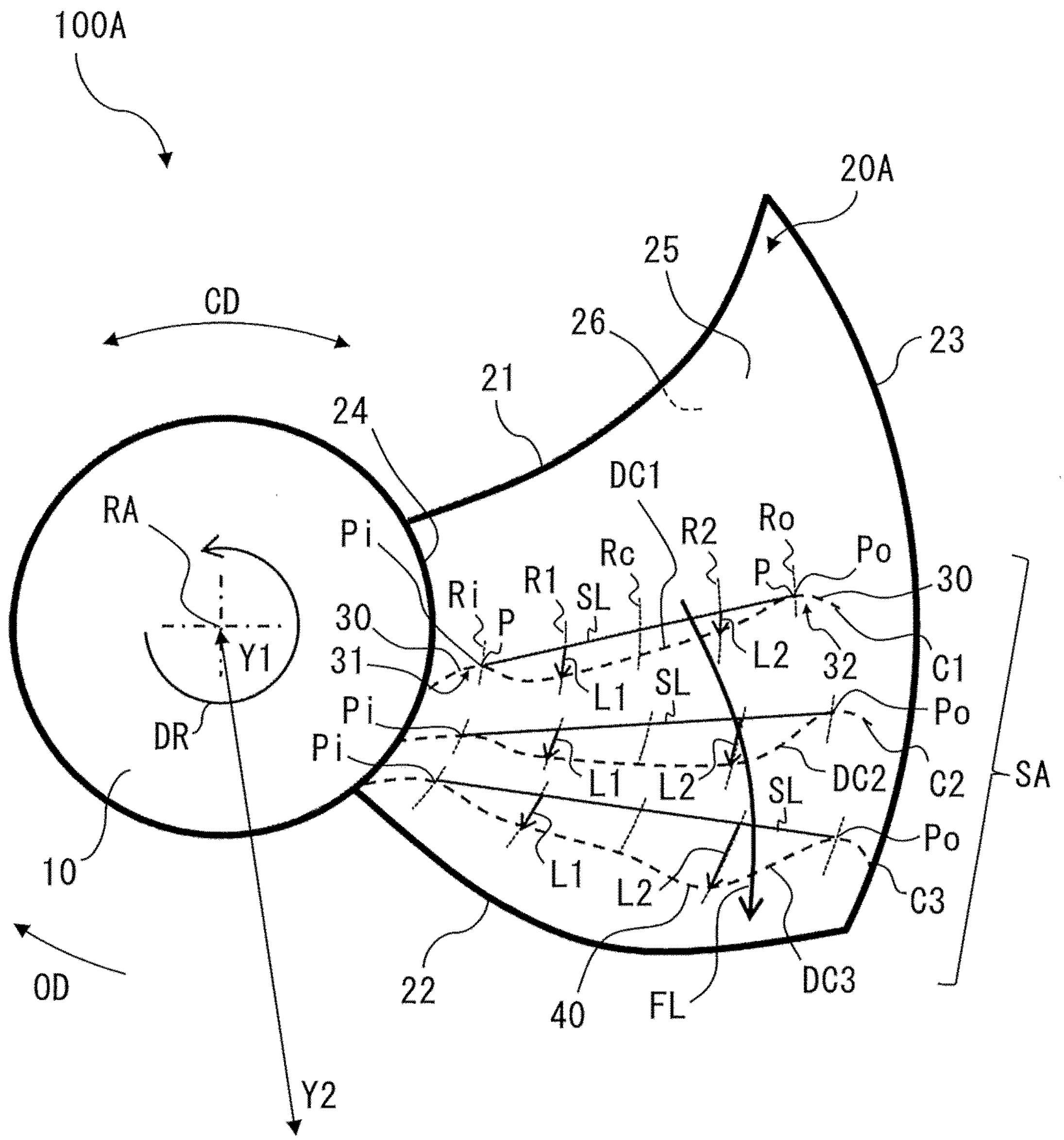
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FIG. 8

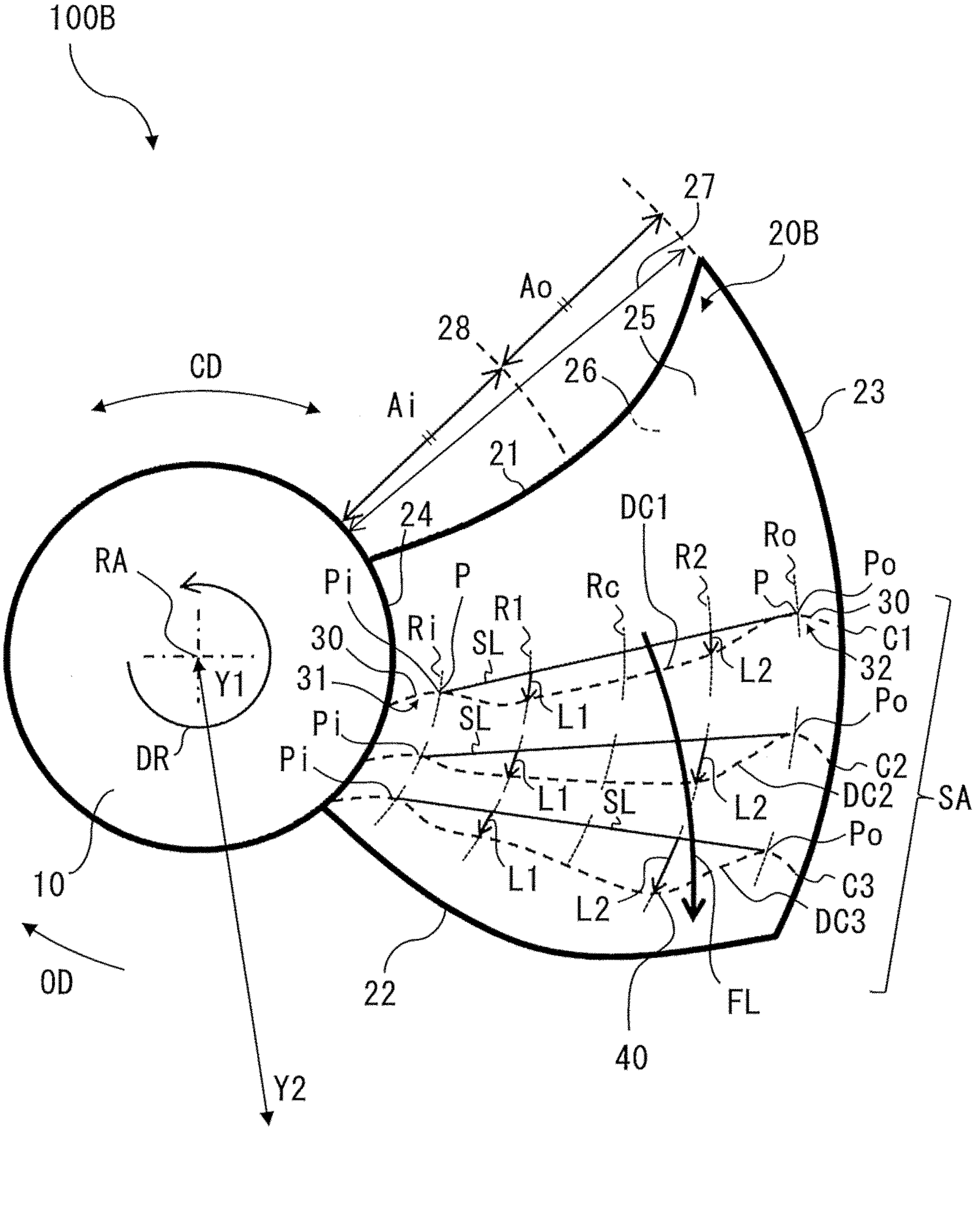
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FIG. 9

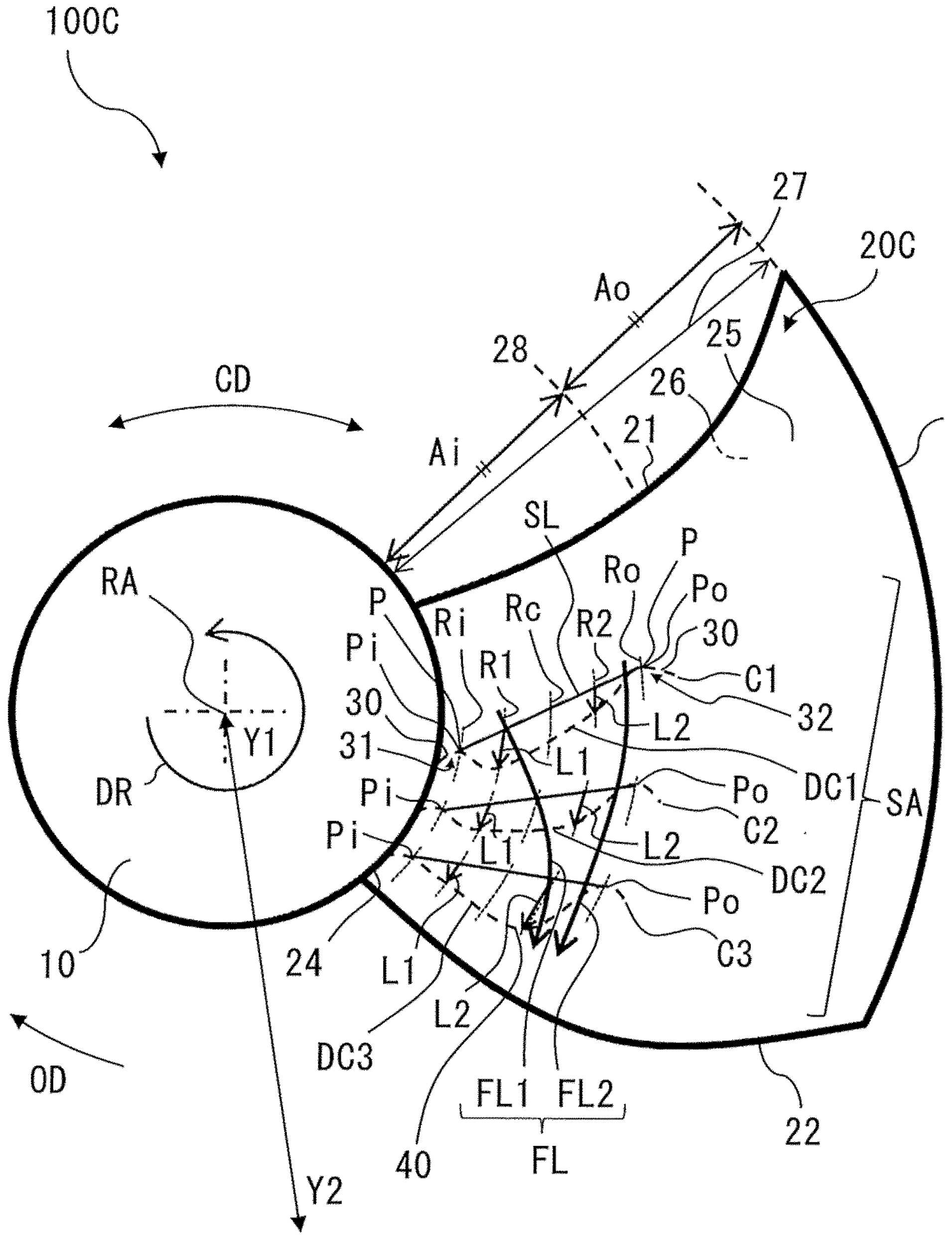
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FIG. 10

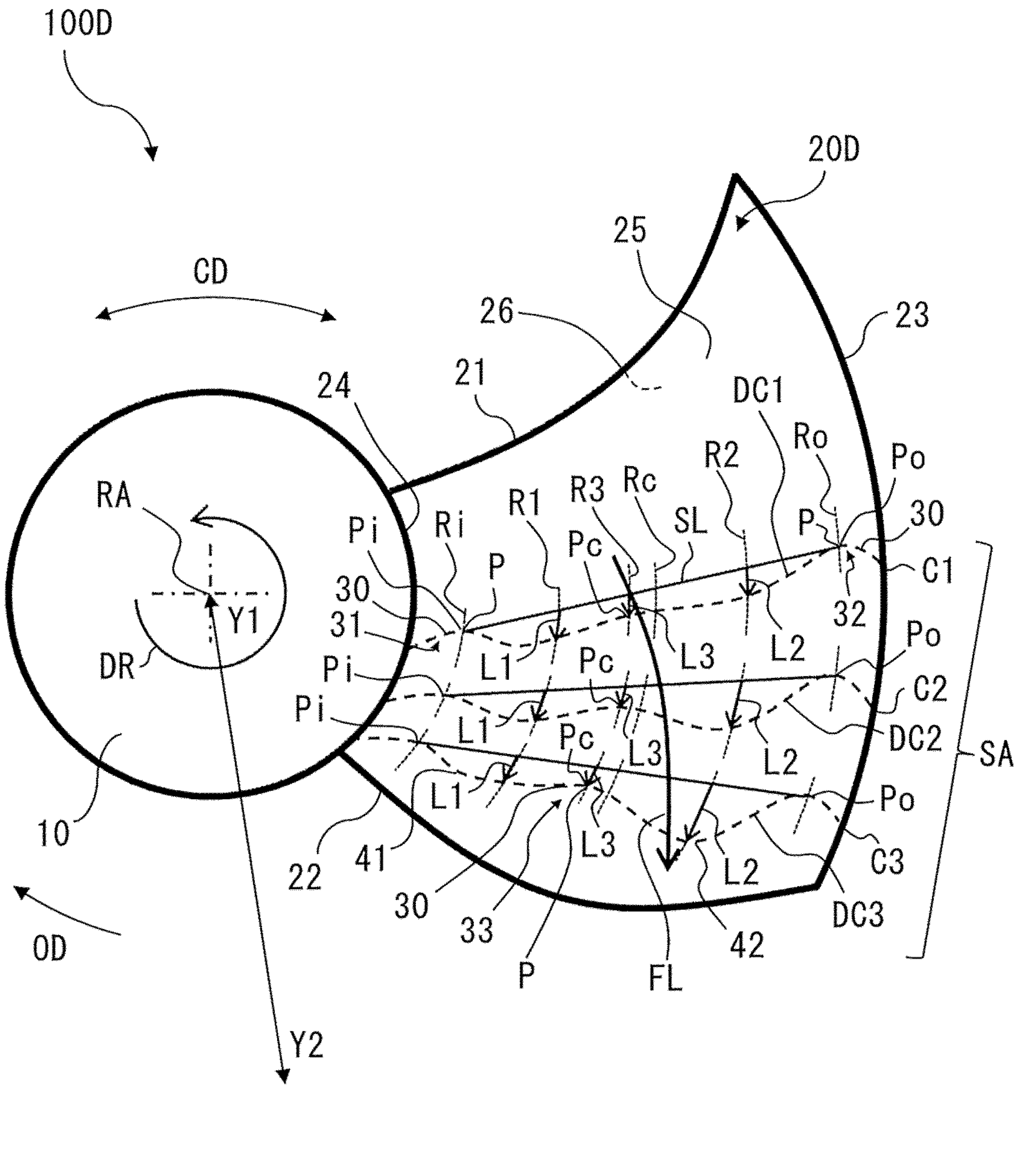
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FIG. 11

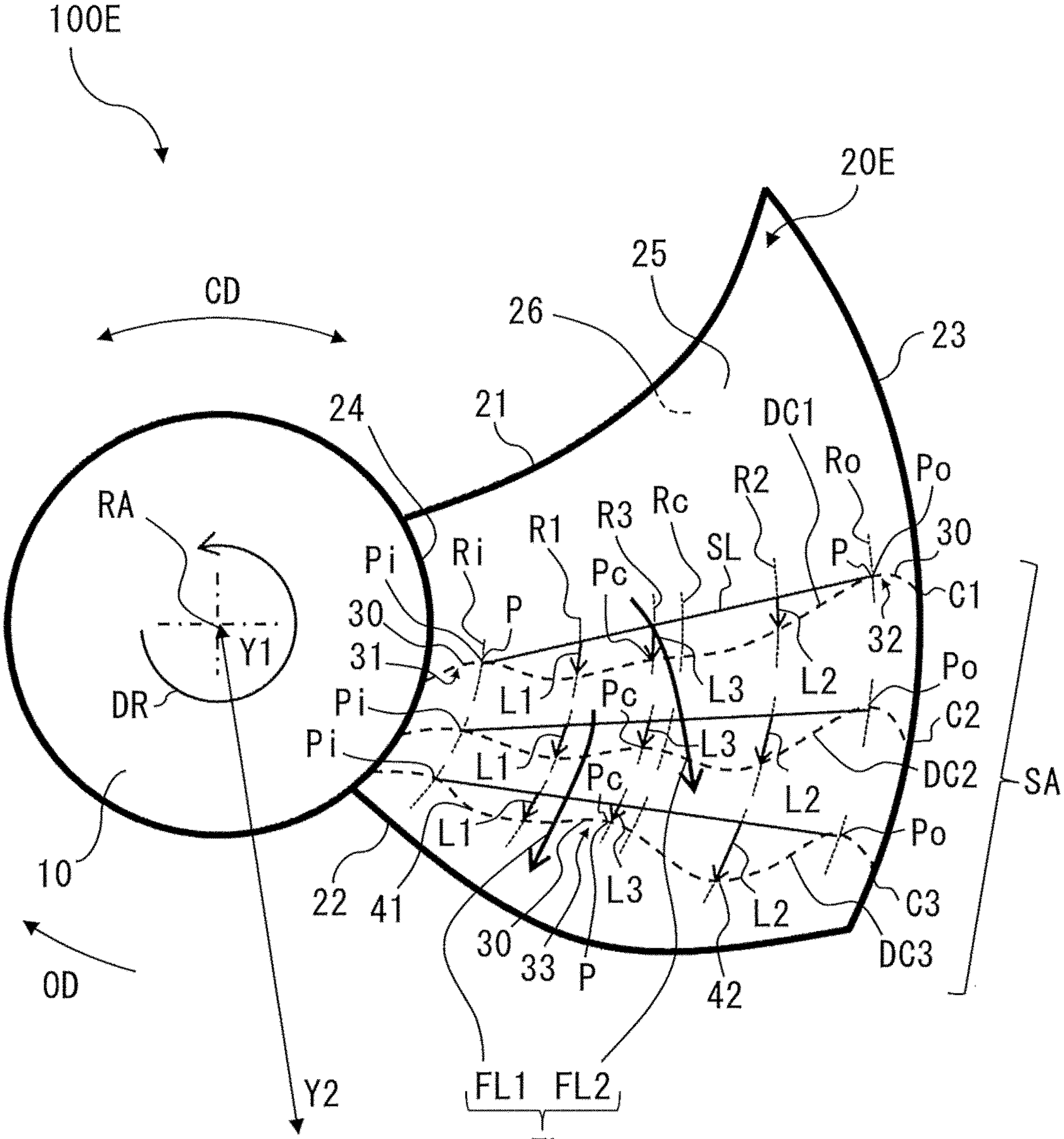
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FIG. 12

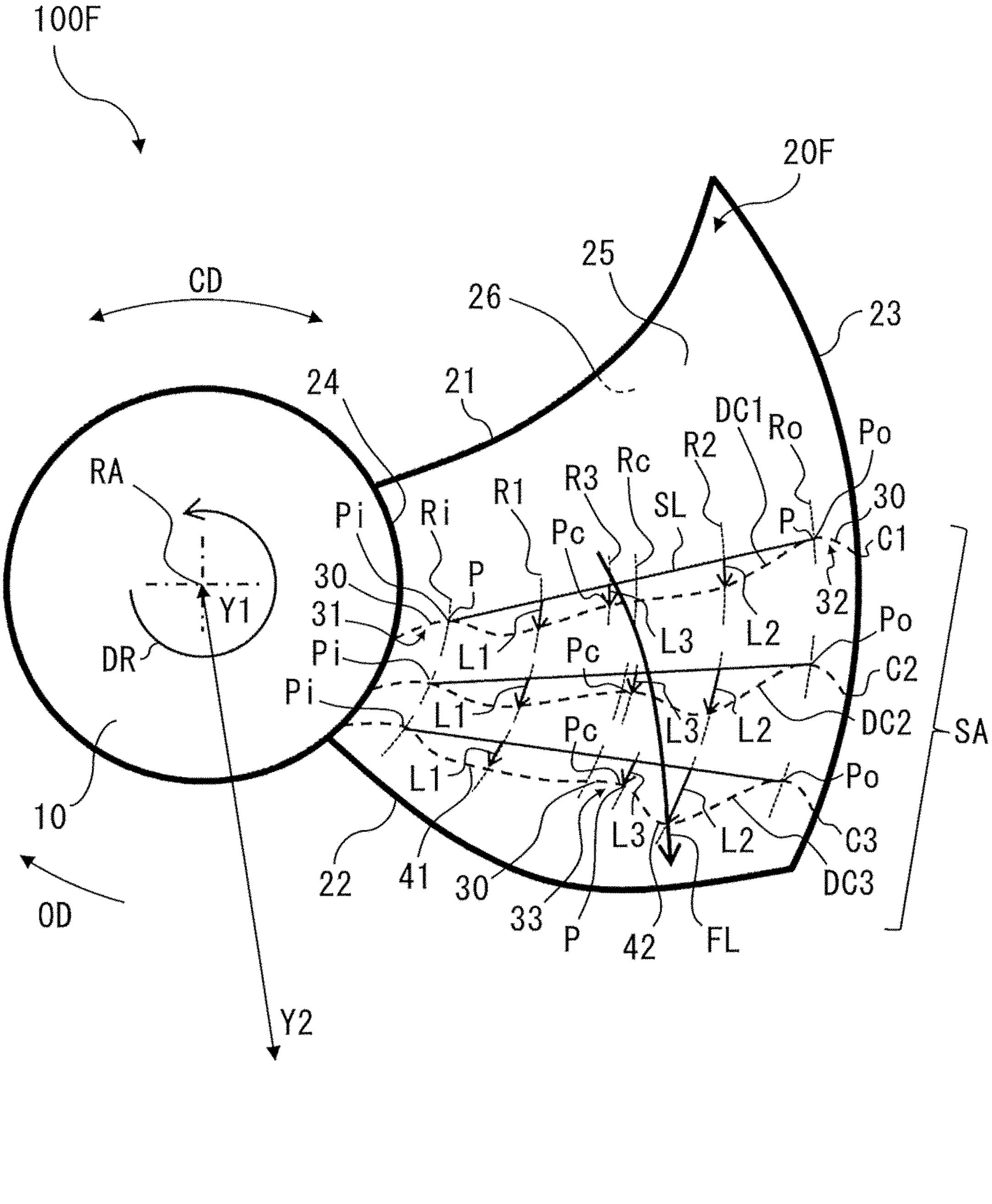
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FIG. 13

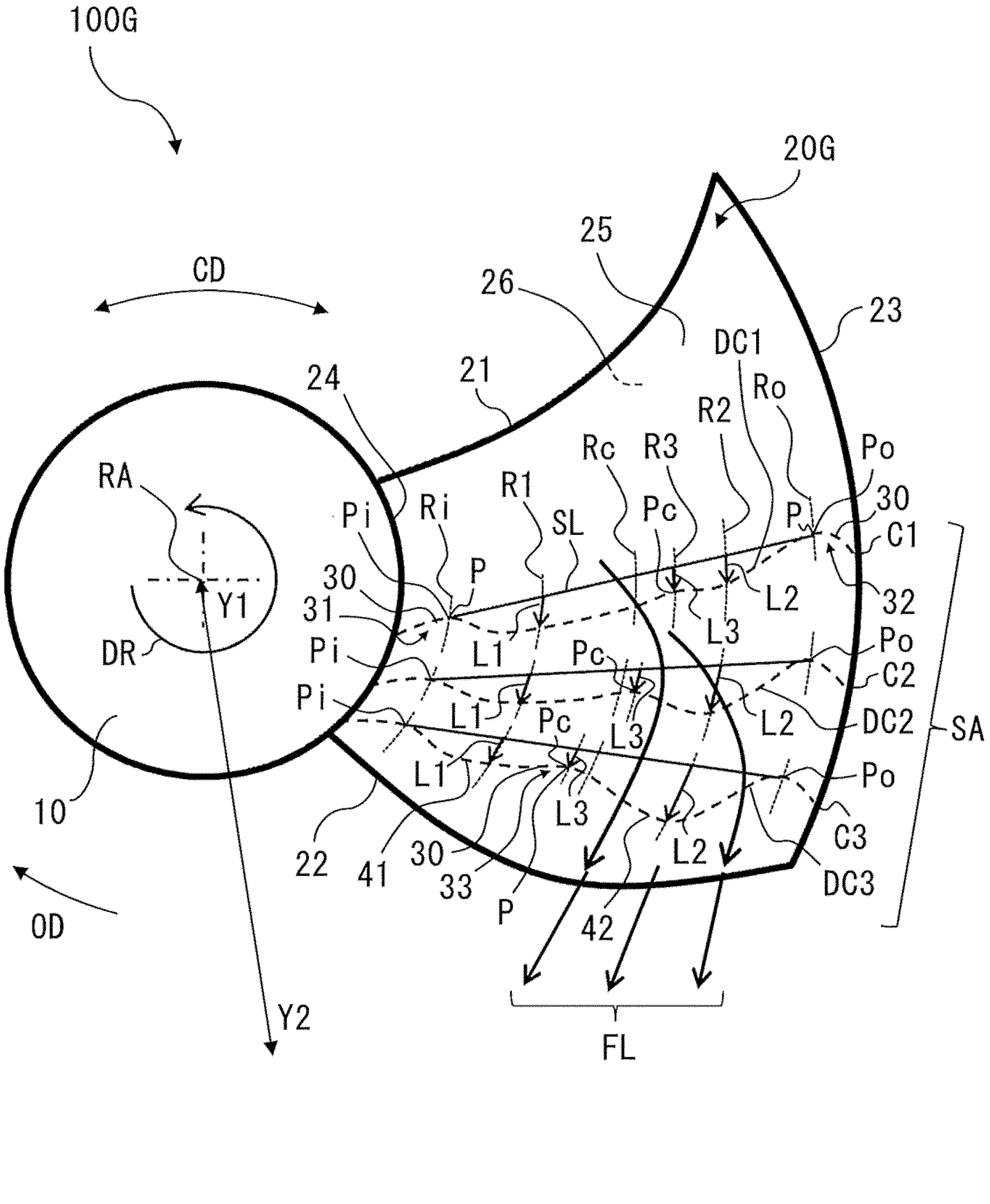
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FIG. 14

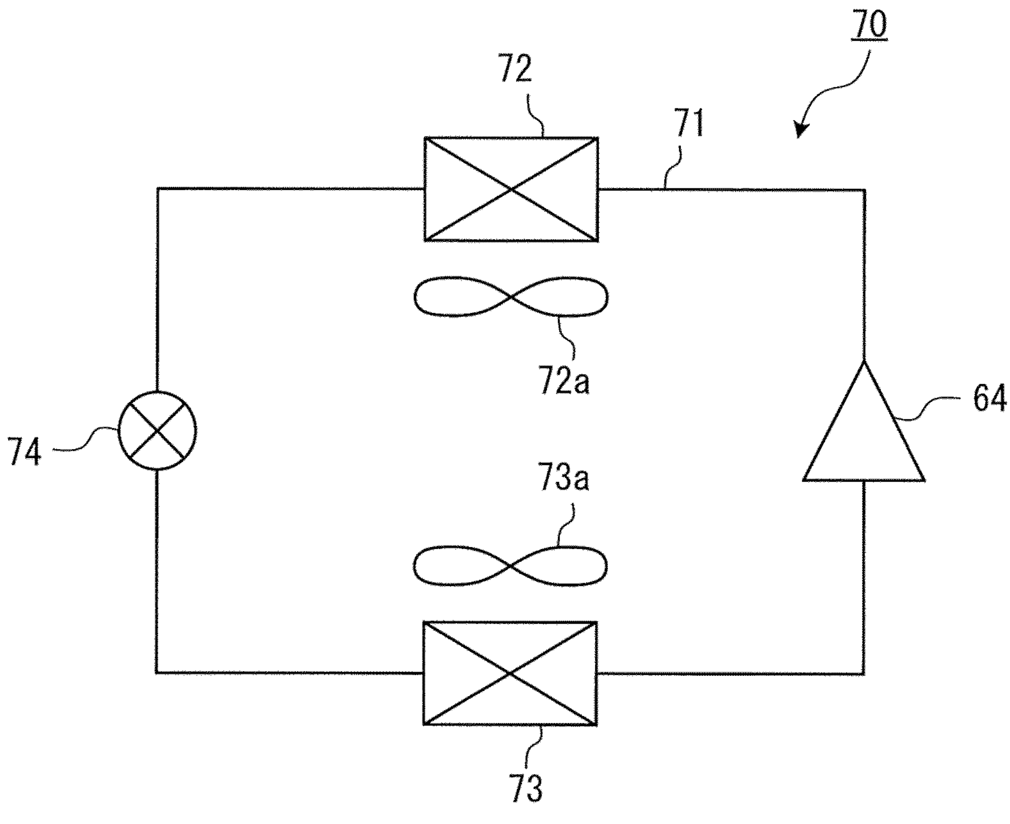

FIG. 15

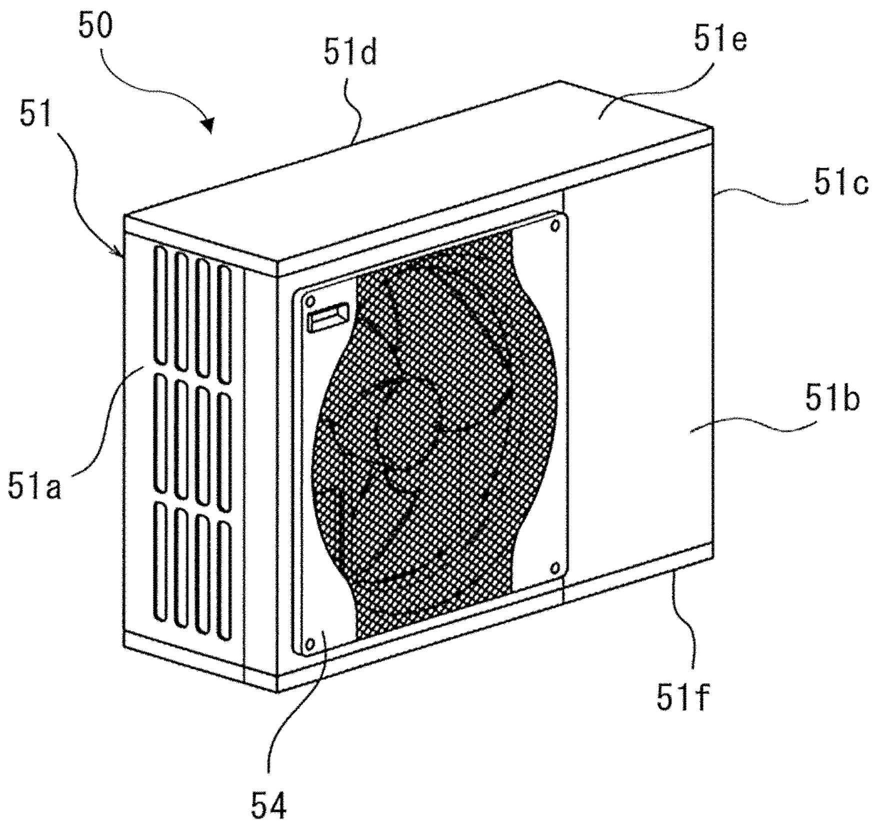
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FIG. 16

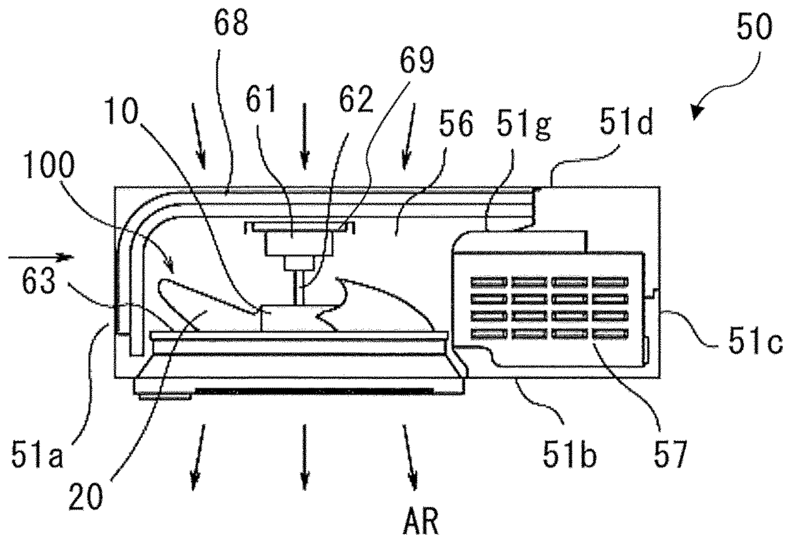
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FIG. 17

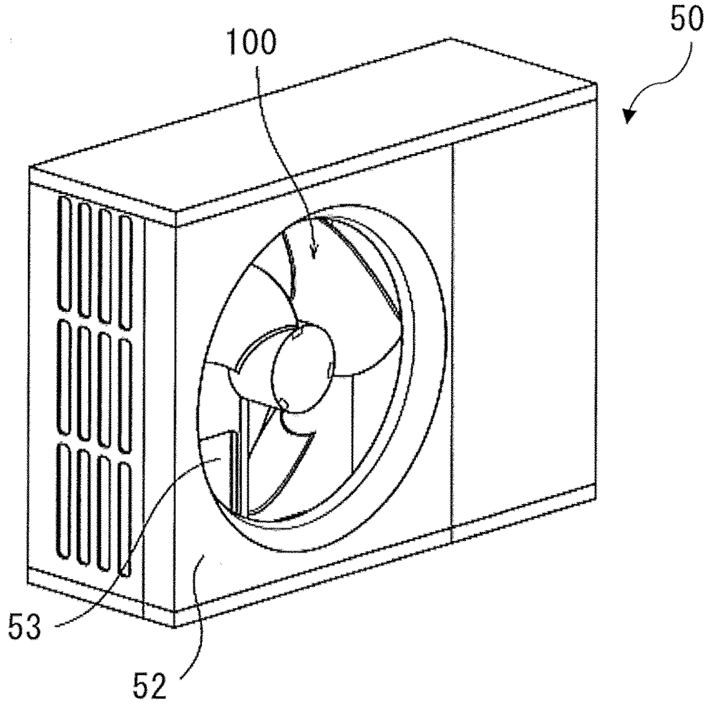
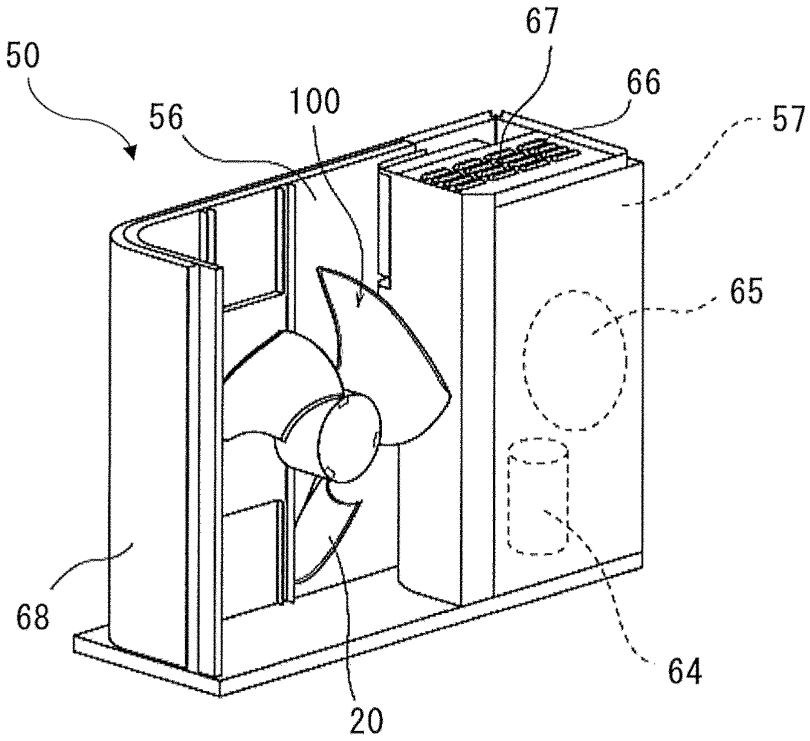


FIG. 18



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2020/013027

A. CLASSIFICATION OF SUBJECT MATTER
F04D 29/38(2006.01)i
FI: F04D29/38 D; F04D29/38 A

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04D29/38

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2020
Registered utility model specifications of Japan	1996-2020
Published registered utility model applications of Japan	1994-2020

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2015/092924 A1 (MITSUBISHI ELECTRIC CORP.) 25 June 2015 (2015-06-25) all drawings	1-10
A	WO 2018/158859 A1 (MITSUBISHI ELECTRIC CORP.) 07 September 2018 (2018-09-07) all drawings	1-10
A	CN 102465917 A (XIE, Qihao) 23 May 2012 (2012-05-23) fig. 2-3	1-10
A	CN 102011739 A (HONG, Yinshu) 13 April 2011 (2011-04-13) fig. 9	1-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
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"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	Date of mailing of the international search report
02 June 2020 (02.06.2020)	16 June 2020 (16.06.2020)

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2020/013027

Patent Documents referred in the Report	Publication Date	Patent Family	Publication Date
WO 2015/092924 A1	25 Jun. 2015	EP 3085966 A1 all drawings	
WO 2018/158859 A1	07 Sep. 2018	EP 3591236 A1 all drawings CN 110325745 A	
CN 102465917 A	23 May 2012	CN 105221480 A	
CN 102011739 A	13 Apr. 2011	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

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Patent documents cited in the description

- JP 2011236860 A **[0004]**