DESCRIPTION

Title of Invention

AXIAL FLOW FAN AND AIR-CONDITIONING APPARATUS HAVING AXIAL FLOW FAN

Technical Field

[0001]

The present invention relates to an axial flow fan equipped with a plurality of blades, and to an air-conditioning apparatus having such an axial flow fan.

Background Art

[0002]

Figs. 20 to 23 schematically illustrate an axial flow fan in the related art.

Fig. 20 is a perspective view of a boss-equipped axial flow fan in the related art.

Fig. 21 is a front view of the boss-equipped axial flow fan in the related art, as viewed from upstream in a fluid flowing direction.

Fig. 22 is a front view of the boss-equipped axial flow fan in the related art, as viewed from downstream in the fluid flowing direction.

Fig. 23 is a side view of the boss-equipped axial flow fan in the related art, as viewed from a lateral side relative to a rotation axis.

[0003]

As shown in Figs. 20 to 23, the axial flow fan in the related art includes a plurality of blades 1 along the peripheral surface of a cylindrical boss. When a rotational force is applied to the boss, the blades 1 rotate in a rotational direction 11 to convey a fluid in a fluid flowing direction 10. Such a configuration is also disclosed in, for example, Patent Literature 1. In the axial flow fan, the blades 1 rotate to cause the fluid existing between the blades to collide against the blade surfaces. The surfaces against which the fluid collides increase in pressure and

press and move the fluid in the direction of a rotation axis serving as a central axis when the blades 1 rotate.

[0004]

In terms of the shape of an axial flow fan, a so-called boss-less fan not having a cylindrical boss is also known (see Patent Literature 2). In a boss-less fan, leading edges and trailing edges of neighboring blades among a plurality of blades 1 are connected by a continuous surface without the intervention of a boss, and the boss-less fan is provided with a small-diameter cylindrical portion at the center thereof for securing a drive shaft of a motor thereto. Thus, the minimum radius of the continuous surface between the blades centered on a rotation axis is larger than the radius of the cylindrical portion for securing the drive shaft thereto.

Citation List

Patent Literature

[0005]

Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2005-105865

Patent Literature 2: Japanese Unexamined Patent Application Publication No. 2010-101223

Summary of Invention

Technical Problem

[0006]

In the boss-equipped axial flow fan in the related art, it is difficult to achieve weight reduction due to the increased weight of the boss, thus making it difficult to save resources (i.e., to reduce the load on the environment). In addition, since the boss does not have an air-blowing function, there is a problem in that it is difficult to improve the air-blowing efficiency of the fan.

In contrast, in the so-called boss-less fan, the aforementioned problem is minimized due to the absence of a boss. However, due to insufficient strength, the blades deform by a large amount when a centrifugal force generated by rotation is applied to the blades. This is problematic in that the air-blowing performance deteriorates due to an inability to maintain the shape of the blades or in that the blades may break due to the centrifugal force when the propeller rotates at high speed in response to strong wind during, for example, a typhoon. If the strength is ensured by increasing the thickness near the rotation axis, the advantage of weight reduction, which is the advantage of the boss-less type, is lost.

[0007]

The present invention has been made to solve the problems of the axial flow fan described above, and an object thereof is to reduce the weight of an axial flow fan by eliminating a boss while maintaining the strength of the blades, and also to improve the air-blowing efficiency.

Solution to Problem

[0008]

An axial flow fan according an embodiment of the present invention, includes a plurality of blades and being configured to rotate about a rotation axis of the blades to convey a fluid, the plurality of blades each having a leading edge at a leading side in a rotational direction, a trailing edge at a trailing side in the rotational direction, and an outer peripheral edge connecting the leading edge and the trailing edge, the leading edge of one of the plurality of blades and the trailing edge of another blade adjacent to the leading edge of the blade in the rotational direction being connected by a plate-shaped connection portion, the plurality of blades each having a pressure surface located at a downstream side in a flow direction of the fluid and a suction surface located at a reverse side of

the pressure surface, the connection portion continuously connecting the pressure surfaces of two adjacent blades of the plurality of blades, and continuously connecting the suction surfaces of the two adjacent blades of the plurality of blades, the plurality of blades each having at least one plate-shaped reinforcement rib extending from a periphery of the rotation axis toward the outer peripheral edge of the blade, the rotation axis being surrounded by a minimum radius portion having a radius defined by a shortest distance between the rotation axis and a peripheral edge of the connection portion, at least a part of the reinforcement ribs is located in the minimum radius portion.

Advantageous Advantages of Invention

[0009]

With the axial flow fan according the embodiment of the present invention, the weight of the axial flow fan is reduced by eliminating a boss and the strength of the blades is maintained. In addition, the air-blowing function by the reinforcement ribs is added so that the air-blowing efficiency can be improved.

A "propeller fan" in the following description is described as an example of an "axial flow fan".

Brief Description of Drawings

[0010]

[Fig. 1] Fig. 1 is a front view of a propeller fan according to Embodiment 1, as viewed from upstream in a fluid flowing direction.

[Fig. 2] Fig. 2 is a front view of the propeller fan according to Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 3] Fig. 3 is a perspective view of the propeller fan according to Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 4] Fig. 4 is a perspective view of the propeller fan according to Embodiment 1, as viewed from a lateral side relative to the fluid flowing direction.

[Fig. 5] Fig. 5 is a side view of the propeller fan according to Embodiment 1, as viewed from a lateral side relative to the fluid flowing direction.

[Fig. 6] Fig. 6 is a cross-sectional view of a reinforcement rib of the propeller fan according to Embodiment 1.

[Fig. 7] Fig. 7 is a comparative cross-sectional view of the reinforcement rib of the propeller fan according to Embodiment 1.

[Fig. 8] Fig. 8 is a wind-direction diagram in a direction of a rotation axis, illustrating an air current formed by the propeller fan according to Embodiment 1.

[Fig. 9] Fig. 9 is a front view of a propeller fan according Modification 1 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 10] Fig. 10 is a front view of a propeller fan according to Embodiment 2, as viewed from downstream in the fluid flowing direction.

[Fig. 11] Fig. 11 is a P-Q diagram illustrating air-blowing performance of a propeller fan.

[Fig. 12] Fig. 12 illustrates the position of a blade chord center line in a front view of a propeller fan according to Embodiment 3.

[Fig. 13] Fig. 13 illustrates the position of the blade chord center line in a side view comparing the rearward-inclined-type propeller fan according to Embodiment 3 with a forward-inclined-type propeller fan.

[Fig. 14] Fig. 14 is a diagram comparing velocity distribution (rearward-inclined type) of the rearward-inclined-type propeller fan according to Embodiment 3 with velocity distribution (forward-inclined type) of the forward-inclined-type propeller fan.

[Fig. 15] Fig. 15 is an external perspective view in a case where the propeller fan according to any one of Embodiment 1 to Embodiment 3 is attached to an outdoor unit according to Embodiment 4.

[Fig. 16] Fig. 16 is an internal perspective view in a case where the propeller fan according to any one of Embodiment 1 to Embodiment 3 is attached to the outdoor unit according to Embodiment 4.

[Fig. 17] Fig. 17 illustrates the effects of reinforcement ribs when outdoor air strikes against the propeller fan in the outdoor unit according to Embodiment 4.

[Fig. 18] Fig. 18 schematically illustrates a packaged state of the propeller fan according to any one of Embodiment 1 to Embodiment 3.

[Fig. 19] Fig. 19 schematically illustrates a packaged state of a boss-equipped propeller fan in the related art.

[Fig. 20] Fig. 20 is a perspective view of the boss-equipped axial flow fan in the related art.

[Fig. 21] Fig. 21 is a front view of the boss-equipped axial flow fan in the related art, as viewed from upstream in the fluid flowing direction.

[Fig. 22] Fig. 22 is a front view of the boss-equipped axial flow fan in the related art, as viewed from downstream in the fluid flowing direction.

[Fig. 23] Fig. 23 is a side view of the boss-equipped axial flow fan in the related art, as viewed from a lateral side relative to a rotation axis.

[Fig. 24] Fig. 24 is a front view illustrating velocity components when an air current formed by the boss-equipped propeller fan in the related art is viewed from downstream.

[Fig. 25] Fig. 25 illustrates velocity components, in the direction of the rotation axis, of the air current formed by the boss-equipped propeller fan in the related art.

[Fig. 26] Fig. 26 is a wind-direction diagram in the direction of the rotation axis, illustrating the air current formed by the boss-equipped propeller fan in the related art.

[Fig. 27] Fig. 27 is a perspective view of a propeller fan according to Modification 2 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 28] Fig. 28 is a perspective view of a propeller fan according to Modification 3 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 29] Fig. 29 is a perspective view of a propeller fan according to Modification 4 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 30] Fig. 30 is a perspective view of a propeller fan according to Modification 5 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 31] Fig. 31 is a perspective view of a propeller fan according to Modification 6 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 32] Fig. 32 is a perspective view of a propeller fan according to Modification 7 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 33] Fig. 33 is a perspective view of a propeller fan according to Modification 8 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 34] Fig. 34 is a perspective view of a propeller fan according to Modification 9 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 35] Fig. 35 is a perspective view of a propeller fan according to Modification 10 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 36] Fig. 36 is a perspective view of a propeller fan according to Modification 11 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

[Fig. 37] Fig. 37 is a perspective view of a propeller fan according to Modification 1 of Embodiment 2, as viewed from downstream in the fluid flowing direction.

[Fig. 38] Fig. 38 is a perspective view of a propeller fan according to Modification 2 of Embodiment 2, as viewed from downstream in the fluid flowing direction.

[Fig. 39] Fig. 39 is a perspective view of a propeller fan according to Modification 3 of Embodiment 2, as viewed from downstream in the fluid flowing direction.

[Fig. 40] Fig. 40 is a perspective view of a propeller fan according to Modification 4 of Embodiment 2, as viewed from downstream in the fluid flowing direction.

[Fig. 41] Fig. 41 is a perspective view of a propeller fan according to Modification 5 of Embodiment 2, as viewed from downstream in the fluid flowing direction.

[Fig. 42] Fig. 42 is a front view of a propeller fan according to Embodiment 5, as viewed from downstream in the fluid flowing direction.

[Fig. 43] Fig. 43 is a front view of a propeller fan according to Modification 1 of Embodiment 5, as viewed from downstream in the fluid flowing direction.

[Fig. 44] Fig. 44 is a front view of a propeller fan according to Modification 2 of Embodiment 5, as viewed from downstream in the fluid flowing direction.

[Fig. 45] Fig. 45 is a front view of a propeller fan according to Embodiment 6, as viewed from downstream in the fluid flowing direction.

[Fig. 46] Fig. 46 is a front view of a propeller fan according to Modification 1 of Embodiment 6, as viewed from downstream in the fluid flowing direction.

[Fig. 47] Fig. 47 is a front view of a propeller fan according to Modification 2 of Embodiment 6, as viewed from downstream in the fluid flowing direction.

[Fig. 48] Fig. 48 is a front view of a propeller fan according to Embodiment 7, as viewed from downstream in the fluid flowing direction.

[Fig. 49] Fig. 49 is a front view of a propeller fan according to Modification 1 of Embodiment 7, as viewed from downstream in the fluid flowing direction.

[Fig. 50] Fig. 50 is a front view of a propeller fan according to Modification 2 of Embodiment 7, as viewed from downstream in the fluid flowing direction.

[Fig. 51] Fig. 51 is a partial perspective view of a propeller fan according to Embodiment 8, as viewed from downstream in the fluid flowing direction.

[Fig. 52] Fig. 52 is a partial perspective view of a propeller fan according to Modification 1 of Embodiment 8, as viewed from downstream in the fluid flowing direction.

[Fig. 53] Fig. 53 is a partial perspective view of a propeller fan according to Modification 2 of Embodiment 8, as viewed from downstream in the fluid flowing direction.

[Fig. 54] Fig. 54 is a front view of a propeller fan according to Embodiment 9, as viewed from downstream in the fluid flowing direction.

Description of Embodiments

[0011]

Embodiment 1

The structure of a propeller fan according to Embodiment 1 will be described with reference to Figs. 1 to 5.

Fig. 1 is a front view of the propeller fan according to Embodiment 1, as viewed from upstream in a fluid flowing direction.

Fig. 2 is a front view of the propeller fan according to Embodiment 1, as viewed from downstream in the fluid flowing direction.

Fig. 3 is a perspective view of the propeller fan according to Embodiment 1, as viewed from downstream in the fluid flowing direction.

Fig. 4 is a perspective view of the propeller fan according to Embodiment 1, as viewed from a lateral side relative to the fluid flowing direction.

Fig. 5 is a side view of the propeller fan according to Embodiment 1, as viewed from a lateral side relative to the fluid flowing direction.

Fig. 6 is a cross-sectional view of a reinforcement rib of the propeller fan according to Embodiment 1.

Fig. 7 is a comparative cross-sectional view of the reinforcement rib of the propeller fan according to Embodiment 1.

[0012]

<Overall Configuration of Propeller Fan>

The propeller fan according to Embodiment 1 rotates about a rotation axis 2a serving as a central axis. In the propeller fan, a cylindrical shaft hole 2 that engages with a drive shaft of a motor and a cylindrical portion 3 that supports the shaft hole 2 are provided around the rotation axis 2a, and a plurality of blades 1 are fixed to the outer wall surface of the cylindrical portion 3. A plurality of connection ribs 4 are provided between the shaft hole 2 and the cylindrical portion 3.

The propeller fan is composed of, for example, resin and is formed by, for example, injection molding. The resin used for the propeller fan is, for example, a material given increased strength by mixing glass-reinforced fibers and mica in polypropylene. Thus, since it is not easy to separate polypropylene resin alone from a material mixed with microscopic glass or rocks and such a material is

difficult to recycle, it is desirable to reduce the amount of material used as much as possible to save resources.

The blades 1 are inclined at a predetermined angle relative to the rotation axis 2a serving as the central axis when the propeller fan rotates, and conveys a fluid existing between the blades in a fluid flowing direction 10 by pressing against the fluid with the blade surfaces as the propeller fan rotates. Each blade surface includes a pressure surface 1a, at which the pressure increases as a result of pressing against the fluid, and a suction surface 1b that is located at the reverse side of the pressure surface 1a and at which the pressure decreases.

[0013]

Each blade 1 has a shape defined by a leading edge 6 at the leading side in a rotational direction 11 of the blade 1, a trailing edge 7 at the trailing side in the rotational direction 11 of the blade 1, and an outer peripheral edge 8 at the outer periphery of the blade 1.

As shown in Figs. 1 and 2, the plurality of blades 1 surrounding the cylindrical portion 3 are smoothly connected by a connection portion 1c that connects the leading edges 6 and the trailing edges 7 of the blades 1. A circular minimum radius portion 1d indicated by a dashed line and having a radius defined by the shortest distance between the rotation axis 2a and the peripheral edge of the connection portion 1c is provided. Specifically, the minimum radius portion 1d having a radius defined by the shortest distance between the rotation axis 2a and the peripheral edge of the connection portion 1c is provided around the rotation axis 2a, and the cylindrical portion 3 defined with the rotation axis 2a as the central axis and having an outer radius smaller than the radius of the minimum radius portion 1d is provided in the minimum radius portion 1d.

Thus, the radius of the minimum radius portion 1d centered on the rotation axis 2a is larger than the outer radius of the cylindrical portion 3. A propeller fan having this shape is a so-called boss-less fan.

As shown in Fig. 5 in particular, the connection portion 1c is inclined from the leading edge 6 of the neighboring blade 1 toward the trailing edge 7 of the blade 1 in the fluid flowing direction 10 that is parallel to the rotation axis 2a.

[0014]

As shown in Fig. 5, in the cylindrical portion 3, a length h1 at the pressure surface 1a of each blade 1, which is on the downstream side in the fluid flowing direction 10, is larger than a length h2 at the suction surface 1b. Moreover, reinforcement ribs 9 are provided between the outer wall surface of the cylindrical portion 3 and the pressure surfaces 1a of the blades 1.

[0015]

<Configuration of Reinforcement Ribs 9>

The reinforcement ribs 9 are, for example, plate-like members standing parallel to the rotation axis 2a on the pressure surfaces 1a of the blades 1. The reinforcement ribs 9 connect the outer peripheral surface of the cylindrical portion 3 to the plurality of blades 1. When viewed from the front in the direction of the rotation axis 2a, each reinforcement rib 9 has a curved shape (i.e., turbo blade shape) convex toward the leading edge 6 of the propeller fan, as shown in Fig. 2.

For example, two reinforcement ribs 9 (i.e., an upstream rib 9a and a downstream rib 9b) are disposed for each blade 1. The upstream rib 9a is disposed at the leading side in the rotational direction 11 of the propeller fan, whereas the downstream rib 9b is disposed at the trailing side in the rotational direction 11 of the propeller fan.

[0016]

The upstream rib 9a and the downstream rib 9b respectively have upper edges 9ah and 9bh at their ends facing the connection areas with the blade 1. As shown in Fig. 5, the upstream rib 9a and the downstream rib 9b are shaped such that the upper edge 9ah of the upstream rib 9a is inclined relative to the direction of the rotation axis 2a and the upper edge 9bh of the downstream rib 9b is substantially orthogonal to the direction of the rotation axis 2a of the shaft hole 2. The upper edge 9ah of the upstream rib 9a is inclined to extend upstream in the fluid flowing direction 10 as it extends toward the outer periphery of the propeller fan.

[0017]

An upstream-rib contact point 9as serving as a contact point between the upper edge 9ah of the upstream rib 9a and the pressure surface 1a of the blade 1 and a downstream-rib contact point 9bs serving as a contact point between the upper edge 9bh of the downstream rib 9b and the pressure surface 1a of the blade 1 are substantially concentrically disposed with respect to the rotation axis 2a.

Furthermore, the upstream-rib contact point 9as and the downstream-rib contact point 9bs are disposed near the leading edge 6 of the blade 1 and near the trailing edge 7 of the blade 1, respectively, to support the blade 1.

Moreover, the upstream-rib contact point 9as is located upstream of the downstream-rib contact point 9bs in the fluid flowing direction 10.

Furthermore, an intersection point between the outer peripheral surface of the cylindrical portion 3 and the upper edge 9ah of the upstream rib 9a is located at the same position, in the direction of the rotation axis 2a, as an intersection point between the outer peripheral surface of the cylindrical portion 3 and the upper edge 9bh of the downstream rib 9b.

[0018]

<Cross-Sectional Shape of Reinforcement Ribs 9>

As shown in Fig. 6, the upper edge 9ah of the upstream rib 9a and the upper edge 9bh of the downstream rib 9b each have a cross-sectional shape defined by two circular arcs, that is, a first circular arc 9c1 and a second circular arc 9c2, at the leading-edge side and the trailing-edge side, respectively, of the propeller fan in the rotational direction 11.

A cross-sectional radius r1 of the first circular arc 9c1 at the leading-edge side is set to be larger than a cross-sectional radius r2 of the second circular arc 9c2 at the trailing-edge side.

As a comparison with Fig. 6, Fig. 7 illustrates the flow of an air current in a case where the first circular arc 9c1 and the second circular arc 9c2 have the same cross-sectional radius r.

[0019]

A drive shaft having a D-shaped cross section is to be fitted and secured to the shaft hole 2, and an indicator 3a indicating the position of a horizontal portion of the D-cut drive shaft and having a protruding shape or a recessed shape is provided between the blades 1 at the outer wall surface of the cylindrical portion 3.

<Dimensions of Components of Propeller Fan>

[0020]

Assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the outer diameter of the shaft hole 2 is defined as ϕA in Fig. 1, it is preferable that ϕA be set such that the value of $\phi A/\phi D$ is between 0.02 and 0.05 inclusive.

Furthermore, assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the outer diameter of the cylindrical

portion 3 is defined as ϕB in Fig. 1, it is preferable that ϕB be set such that the value of ϕB/ϕD is between 0.05 and 0.15 inclusive.

Moreover, assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the length of each connection rib 4 (i.e., the length between the outer peripheral surface of the shaft hole 2 and the inner peripheral surface of the cylindrical portion 3) is defined as L1 in Fig. 1, it is preferable that L1 be set such that the value of L1/ϕD is between 0.01 and 0.05 inclusive.

By setting the length L1 of each connection rib 4 to this dimension, the resin material constituting the connection rib 4 can exhibit a vibration attenuation effect for reducing electromagnetic vibration of the drive shaft of the motor.

[0021]

Assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the outer diameter of the cylindrical portion 3 is defined as ϕC in Fig. 2, it is preferable that ϕC be set such that the value of ϕC/ϕD is between 0.05 and 0.15 inclusive.

Moreover, assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the length of the upstream rib 9a in the radial direction (i.e., the length between the rotation axis 2a and the upstream-rib contact point 9as) is defined as L2 in Fig. 2, it is preferable that L2 be set such that the value of L2/ϕD is between 0.1 and 0.2 inclusive.

Furthermore, assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the length of the downstream rib 9b in the radial direction (i.e., the length between the rotation axis 2a and the downstream-rib contact point 9bs) is defined as L3 in Fig. 2, it is preferable that L3 be set such that the value of L3/ϕD is between 0.1 and 0.2 inclusive.

Moreover, assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the length of each connection rib 4 (i.e., the length between the outer peripheral surface of the shaft hole 2 and the inner peripheral surface of the cylindrical portion 3) is defined as L4 in Fig. 2, it is preferable that L4 be set such that the value of L4/ϕD is between 0.01 and 0.05 inclusive.

By setting the length L4 of each connection rib 4 to this dimension, the resin material constituting the connection rib 4 can exhibit a vibration attenuation effect for reducing electromagnetic vibration of the drive shaft of the motor.

[0022]

Assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the length of the upstream rib 9a in the direction of the rotation axis 2a is defined as L5 in Fig. 3, it is preferable that L5 be set such that the value of L5/ϕD is between 0.05 and 0.15 inclusive.

Furthermore, assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the length of the downstream rib 9b in the direction of the rotation axis 2a is defined as L6 in Fig. 3, it is preferable that L5 be set such that the value of L6/ϕD is between 0.05 and 0.15 inclusive.

[0023]

Assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the length of the cylindrical portion 3 at the pressure surface 1a side is defined as h1 in Fig. 5, it is preferable that h1 be set such that the value of h1/ϕD is between 0.05 and 0.2 inclusive.

Furthermore, assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the length of the cylindrical portion 3 at the suction surface 1b side is defined as h2 in Fig. 5, it is preferable that h2 be set such that the value of h2/ϕD is 0.1 or smaller.

[0024]

Assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the thickness of each of the upstream rib 9a and the downstream rib 9b is defined as L7 in Fig. 6, it is preferable that L7 be set such that the value of $L7/\phi D$ is between 0.0025 and 0.025 inclusive.

[0025]

<Flow of Air Current>

Next, the flow of an air current when the propeller fan according to Embodiment 1 rotates will be described with reference to Fig. 8 and Figs. 24 to 26.

Fig. 8 is a wind-direction diagram in the direction of the rotation axis, illustrating an air current formed by the propeller fan according to Embodiment 1.

Fig. 24 is a front view illustrating velocity components when an air current formed by a boss-equipped propeller fan in the related art is viewed from downstream.

Fig. 25 illustrates velocity components, in the direction of the rotation axis, of the air current formed by the boss-equipped propeller fan in the related art.

Fig. 26 is a wind-direction diagram in the direction of the rotation axis, illustrating the air current formed by the boss-equipped propeller fan in the related art.

[0026]

Since a strong centrifugal force acts toward the outer periphery of an outflow air current in a propeller fan, an outflow air current 20 has an outflow angle α of a positive value and expands in an inverted V shape, as shown in Fig. 8.

The air-current components of the boss-equipped propeller fan in the related art are as shown in Figs. 24 and 25. Assuming that an outflow wind

velocity is decomposed into rotation system coordinates (r, θ, z), a wind velocity component in the radial direction can be defined as Vr, a wind velocity component in the rotational direction 11 can be defined as Vθ, and a wind velocity component in the direction of the rotation axis 2a of the propeller fan can be defined as Vz.

[0027]

Since the purpose of the propeller fan is to blow air in the direction of the rotation axis 2a, only the wind velocity component Vz corresponds to the amount of air to be blown. In other words, since the Vr component expanding in the outer peripheral direction of the rotation and the rotating Vθ component are not involved in the air-blowing process, these components after being blown out are ultimately converted into heat in the air and lose their energy. Thus, relatively increasing the wind velocity component Vz enhances the air-blowing efficiency, thereby contributing to reduced power consumption of the electric motor.

Furthermore, as shown in Fig. 26, it is clear from actual measurement that the air blown out in the direction of the rotation axis 2a flows reversely toward the propeller fan around the rotation axis 2a.

[0028]

The flow of the air current when the propeller fan according to Embodiment 1 rotates is as shown in Fig. 8.

The outflow air current 20 conveyed from the pressure surface 1a is blown out as wind V including a combination of a velocity component Vr in the radial direction, a velocity component Vθ in the rotational direction 11, and a velocity component Vz in the direction of the rotation axis 2a of the propeller fan.

[0029]

In an area of the rotation axis 2a of the propeller fan, a reverse air current 21 occurs relative to the outflow air current 20 and flows reversely toward the

center of the propeller fan. The reverse air current 21 becomes a swirling flow due to negative pressure generated as a result of the rotation of the reinforcement ribs 9, and is forcedly suctioned in the direction of the rotation axis 2a of the propeller fan. Because each reinforcement rib 9 has a convex shape toward the leading edge 6 of the propeller fan (i.e., turbo blade shape), this suction effect is same as an effect of a suction-side air current exhibited by a turbo fan.

[0030]

The air forcedly suctioned in the direction of the rotation axis 2a of the propeller fan is pressed like an inverted air current 23 toward the outer periphery of the blades 1 by the pressure surfaces of the reinforcement ribs 9 and inflows onto the pressure surfaces 1a of the blades 1. Then, a negative pressure region is formed near the rotation axis 2a of the propeller fan, thereby exhibiting an effect of intensifying the flow of the reverse air current 21.

Because the heights of the reinforcement ribs 9 are configured such that the downstream ribs 9b are higher than the upstream ribs 9a, as described above, the air not colliding against the upstream ribs 9a collides against the downstream ribs 9b, moves toward the outer periphery of the blades 1, becomes the inverted air current 23, and inflows onto the pressure surfaces 1a.

Then, the air travels between the blades, merges with an inflow air current 22 normally inflowing to the pressure surfaces 1a, and is blown out in the direction of the outflow air current 20.

[0031]

To clarify the suction effect of the reinforcement ribs 9, a comparison will be made with the air current in the boss-equipped propeller fan in the related art having no suction effect at all.

As shown in Fig. 26, in the case of the boss-equipped propeller fan in the related art, a stagnant flow near the boss circulates by being attracted toward the outflow air current 20. In contrast, as shown in Fig. 8, in the case of the propeller fan according to Embodiment 1, negative pressure is generated near the rotation axis 2a due to the reinforcement ribs 9 so that the reverse air current 21 is suctioned. Thus, the outflow air current 20 is convolved in the direction of the rotation axis 2a in a manner similar to a tornado, so that the outflow angle α of the outflow air current 20 is reduced. Specifically, an outflow angle $\alpha 2$ of the propeller fan according to Embodiment 1 is smaller than an outflow angle $\alpha 1$ of the boss-equipped propeller fan in the related art.

Since the wind velocity component Vz in the direction of the rotation axis 2a is equal to $\cos\alpha \cdot V$, the wind direction of the outflow air current 20 narrows with decreasing outflow angle α, so that the wind velocity component Vz in the direction of the rotation axis 2a is increased, whereby the air-blowing efficiency can be enhanced. When the wind velocity component Vz is relatively increased, the rotation speed for causing the propeller fan to generate the same amount of air can be lowered, thereby allowing for reduced power consumption.

[0032]

<Modification 1>

Fig. 9 is a front view of a propeller fan according Modification 1 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

In the description of the propeller fan according to Embodiment 1, each reinforcement rib 9 has a turbo blade shape convex toward the leading edge 6 of the blade 1, when viewed from the front in the direction of the rotation axis 2a. Alternatively, as shown in Fig. 9, reinforcement ribs 9 according to Modification 1 have a shape of linear flat plates extending radially from the rotation axis 2a of the propeller fan.

Even with such radial flat-plate-shaped reinforcement ribs 9, the air current is forcedly suctioned in the direction of the rotation axis 2a of the propeller fan due to negative pressure generated as a result of the rotation of the reinforcement ribs 9, although the negative pressure is slightly weaker than that generated with the turbo blade shape. Thus, the outflow angle α is reduced so that the wind velocity component Vz in the direction of the rotation axis 2a is increased, whereby the air-blowing efficiency can be enhanced.

[0033]

<Advantages>

In the propeller fan according to Embodiment 1 and Modification 1 thereof having the above-described configuration, that is, in a so-called boss-less propeller fan, a plurality of reinforcement ribs 9 extend toward the leading edges 6 and the trailing edges 7 of the blades 1 from the outer peripheral surface of the cylindrical portion 3 having a radius smaller than that of the minimum radius portion 1d of the connection portion 1c. This is advantageous in that the reverse air current 21 near the rotation axis 2a is suctioned by the reinforcement ribs 9. This causes the reverse air current 21 with the increased wind velocity to convolve the outflow air current 20 in the direction of the rotation axis 2a, so that the outflow angle α of the outflow air current 20 can be reduced. Thus, the wind velocity component Vz, in the direction of the rotation axis 2a, of the outflow air current 20 is relatively increased, whereby the air-blowing efficiency of the fan can be enhanced.

[0034]

Furthermore, since the blades 1 are smoothly connected by the connection portion 1c, stress concentration caused by the centrifugal force acting on the blades 1 is distributed. Moreover, since the reinforcement ribs 9 support the blades 1, strength equivalent to that of a boss-equipped propeller fan is ensured,

so that deformation of the blades 1 is suppressed and the air-blowing efficiency can be enhanced. With the blades 1 having increased strength, deterioration in the air-blowing performance caused by deformation of the blades due to the centrifugal force can be suppressed when the propeller fan rotates. Furthermore, the large amount of resin used for a boss is reduced, and the strength equivalent to that of a boss-equipped fan can be ensured with the reinforcement ribs 9 alone, thereby achieving weight reduction (i.e., saving resources).

[0035]

Furthermore, as shown in Fig. 5, with regard to the shapes of each upstream rib 9a and each downstream rib 9b, the upper edge 9ah of the upstream rib 9a is inclined relative to the direction of the central axis of the shaft hole 2, and the upper edge 9bh of the downstream rib 9b is substantially orthogonal to the direction of the central axis of the shaft hole 2. Therefore, the air current not hitting against the upstream rib 9a is pressed against the pressure surface 1a of the blade 1 by the downstream rib 9b. Thus, the plurality of reinforcement ribs 9 suction the air current six times (i.e., approximately 60° each time) in one cycle (360°) to distribute the air current along the entire perimeter, so that fluctuations in the suctioning negative pressure can be reduced, thereby achieving a stable suction effect with the negative pressure.

[0036]

Furthermore, as shown in Fig. 6, the cross-sectional radius r1 of the first circular arc 9c1 at the leading-edge side of each reinforcement rib 9 is larger than the cross-sectional radius r2 of the second circular arc 9c2 at the trailing-edge side. Thus, as compared with the cross-sectional shape with the uniform cross-sectional radius shown in Fig. 7, the fluid flows smoothly along the first circular arc 9c1 having the large cross-sectional radius r1, so that a separation vortex of

the air current on the second circular arc 9c2 at the trailing-edge side is suppressed. Consequently, an energy loss of the fluid is reduced so that the driving force for rotating the propeller fan is reduced, thereby achieving reduced power consumption of the motor.

[0037]

Furthermore, as shown in Fig. 4 in particular, the connection portion 1c is inclined from the leading edge 6 of the neighboring blade 1 toward the trailing edge 7 of the blade 1 in the fluid flowing direction 10. Therefore, the air current inflowing to the pressure surface 1a of the connection portion 1c is made to smoothly collide against the reinforcement ribs 9, so that the air current can be pressed out toward the outer periphery of the blade 1.

[0038]

Moreover, the indicator 3a indicating the position of the horizontal portion of the D-cut drive shaft is provided between the blades 1 at the outer wall surface of the cylindrical portion 3. Therefore, when fitting the shaft hole 2 of the propeller fan to the drive shaft of the motor, the attaching direction of the propeller fan can be readily identified, thereby shortening the assembly time and improving the working efficiency.

[0039]

Next, modifications in which the reinforcement ribs 9 of the propeller fan according to Embodiment 1 each have a turbo blade shape will be described.

<Modification 2>

Fig. 27 is a perspective view of a propeller fan according to Modification 2 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 27, reinforcement ribs 9 according to Modification 2 include a third intermediate rib 9c disposed between the upstream rib 9a and the downstream rib 9b according to Embodiment 1 (see Figs. 2 and 3).

Specifically, each reinforcement rib 9 has a turbo blade shape convex toward the leading edge 6 of the propeller fan, and the upstream rib 9a, the intermediate rib 9c, and the downstream rib 9b are disposed for each blade 1.

Other configurations are the same as those of the propeller fan according to Embodiment 1.

[0040]

<Advantages>

In Modification 2, three reinforcement ribs 9 are disposed for each blade 1 so that the strength of the blade 1 can be increased, as compared with the propeller fan according to Embodiment 1 in which two reinforcement ribs 9 are disposed for each blade 1. Moreover, since a total number of reinforcement ribs is changed to six to nine, the effect of the reinforcement ribs 9 for suctioning the reverse air current 21 near the rotation axis 2a increases. Thus, the wind velocity component Vz, in the direction of the rotation axis 2a, of the outflow air current 20 is relatively increased, whereby the air-blowing efficiency of the fan can be enhanced.

[0041]

<Modification 3>

Fig. 28 is a perspective view of a propeller fan according to Modification 3 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 28, reinforcement ribs 9 according to Modification 3 are not provided with the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 1, and six turbo-blade-shaped reinforcement ribs 9 (i.e., upstream ribs 9a and downstream ribs 9b) are joined to one another by extending to and intersecting at the rotation axis 2a. Specifically, the six reinforcement ribs 9 intersect one another at the rotation axis 2a to form an axial portion 2b, and connect the axial portion 2b and the plurality of blades 1.

Other configurations are the same as those of the propeller fan according to Embodiment 1.

[0042]

<Advantages>

Although Modification 3 has a simple configuration in which the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 1 are not provided, the reinforcement ribs 9 extend to the rotation axis 2a so that the strength of the blades 1 of the propeller fan can be ensured.

<Modification 4>

Fig. 29 is a perspective view of a propeller fan according to Modification 4 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 29, reinforcement ribs 9 according to Modification 4 include a third intermediate rib 9c disposed between the upstream rib 9a and the downstream rib 9b according to Modification 3.

Each reinforcement rib 9 has a turbo blade shape convex toward the leading edge 6 of the propeller fan, and the upstream rib 9a, the intermediate rib 9c, and the downstream rib 9b are disposed for each blade 1. The nine reinforcement ribs 9 intersect one another at the rotation axis 2a to form an axial portion 2b, and connect the axial portion 2b and the plurality of blades 1.

Other configurations are the same as those of the propeller fan according to Embodiment 1.

[0043]

<Advantages>

In Modification 4, three reinforcement ribs 9 are disposed for each blade 1 so that the strength of the blade 1 can be increased, as compared with the propeller fan according to Modification 3 in which two reinforcement ribs 9 are disposed for each blade 1. Moreover, since a total number of reinforcement ribs

is changed to six to nine, the effect of the reinforcement ribs 9 for suctioning the reverse air current 21 near the rotation axis 2a increases. Thus, the wind velocity component Vz, in the direction of the rotation axis 2a, of the outflow air current 20 is relatively increased, whereby the air-blowing efficiency of the fan can be enhanced.

[0044]

<Modification 5>

Fig. 30 is a perspective view of a propeller fan according to Modification 5 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 30, reinforcement ribs 9 according to Modification 5 are not provided with the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 1, and a circular opening 1e for attaching the drive shaft of the motor thereto is provided around the rotation axis 2a. Six turbo-blade-shaped reinforcement ribs 9 (i.e., upstream ribs 9a and downstream ribs 9b) extend to the opening edge of the circular opening 1e.

Specifically, a minimum radius portion 1d having a radius defined by the shortest distance between the rotation axis 2a and the connection portion 1c is provided around the rotation axis 2a, and the circular opening 1e with the rotation axis 2a as the central axis and having a radius smaller than the radius of the minimum radius portion 1d is provided in the minimum radius portion 1d. The reinforcement ribs 9 connect the opening edge of the circular opening 1e and the plurality of blades 1.

Other configurations are the same as those of the propeller fan according to Embodiment 1.

[0045]

<Advantages>

Although Modification 5 has a simple configuration in which the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 1 are not provided, the reinforcement ribs 9 extend to the opening edge of the circular opening 1e so that the strength of the blades 1 of the propeller fan can be ensured.

<Modification 6>

Fig. 31 is a perspective view of a propeller fan according to Modification 6 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 31, reinforcement ribs 9 according to Modification 6 include a third intermediate rib 9c disposed between the upstream rib 9a and the downstream rib 9b according to Modification 5.

Specifically, each reinforcement rib 9 has a turbo blade shape convex toward the leading edge 6 of the propeller fan, and the upstream rib 9a, the intermediate rib 9c, and the downstream rib 9b are disposed for each blade 1.

Other configurations are the same as those of the propeller fan according to Embodiment 1.

[0046]

<Advantages>

In Modification 6, three reinforcement ribs 9 are disposed for each blade 1 so that the strength of the blade 1 can be increased, as compared with the propeller fan according to Modification 5 in which two reinforcement ribs 9 are disposed for each blade 1. Moreover, since a total number of reinforcement ribs is changed to six to nine, the effect of the reinforcement ribs 9 for suctioning the reverse air current 21 near the rotation axis 2a increases. Thus, the wind velocity component Vz, in the direction of the rotation axis 2a, of the outflow air current 20 is relatively increased, whereby the air-blowing efficiency of the fan can be enhanced.

[0047]

Next, modifications in which the reinforcement ribs 9 of the propeller fan have a shape of linear flat plates extending radially from the rotation axis 2a will be described.

<Modification 7>

Fig. 32 is a perspective view of a propeller fan according to Modification 7 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 32, reinforcement ribs 9 according to Modification 7 include a third intermediate rib 9c disposed between the upstream rib 9a and the downstream rib 9b according to Modification 1 (see Fig. 9) of Embodiment 1.

Specifically, the reinforcement ribs 9 have the shape of linear flat plates extending radially from the rotation axis 2a of the propeller fan, and the upstream rib 9a, the intermediate rib 9c, and the downstream rib 9b are disposed for each blade 1.

Other configurations are the same as those of the propeller fan according to Embodiment 1.

[0048]

<Advantages>

In Modification 7, three reinforcement ribs 9 are disposed for each blade 1 so that the strength of the blade 1 can be increased, as compared with the propeller fan according to Modification 1 of Embodiment 1 in which two reinforcement ribs 9 are disposed for each blade 1. Moreover, since a total number of reinforcement ribs is changed to six to nine, the effect of the reinforcement ribs 9 for suctioning the reverse air current 21 near the rotation axis 2a increases. Thus, the wind velocity component Vz, in the direction of the rotation axis 2a, of the outflow air current 20 is relatively increased, whereby the air-blowing efficiency of the fan can be enhanced.

[0049]

<Modification 8>

Fig. 33 is a perspective view of a propeller fan according to Modification 8 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 33, reinforcement ribs 9 according to Modification 8 are not provided with the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 1, and six linear-flat-plate-shaped reinforcement ribs 9 (i.e., upstream ribs 9a and downstream ribs 9b) extending radially from the rotation axis 2a are joined to one another by extending to and intersecting at the rotation axis 2a. Specifically, the six reinforcement ribs 9 intersect one another at the rotation axis 2a to form an axial portion 2b, and connect the axial portion 2b and the plurality of blades 1.

Other configurations are the same as those of the propeller fan according to Embodiment 1.

[0050]

<Advantages>

Although Modification 8 has a simple configuration in which the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 1 are not provided, the reinforcement ribs 9 extend to the rotation axis 2a so that the strength of the blades 1 of the propeller fan can be ensured.

<Modification 9>

Fig. 34 is a perspective view of a propeller fan according to Modification 9 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 34, reinforcement ribs 9 according to Modification 9 include a third intermediate rib 9c disposed between the upstream rib 9a and the downstream rib 9b according to Modification 8.

Specifically, the reinforcement ribs 9 have a shape of linear flat plates extending radially from the rotation axis 2a of the propeller fan, and the upstream rib 9a, the intermediate rib 9c, and the downstream rib 9b are disposed for each blade 1. The nine reinforcement ribs 9 intersect one another at the rotation axis 2a to form an axial portion 2b, and connect the axial portion 2b and the plurality of blades 1.

Other configurations are the same as those of the propeller fan according to Embodiment 1.

[0051]

<Advantages>

In Modification 9, three reinforcement ribs 9 are disposed for each blade 1 so that the strength of the blade 1 can be increased, as compared with the propeller fan according to Modification 8 in which two reinforcement ribs 9 are disposed for each blade 1. Moreover, since a total number of reinforcement ribs is changed to six to nine, the effect of the reinforcement ribs 9 for suctioning the reverse air current 21 near the rotation axis 2a increases. Thus, the wind velocity component Vz, in the direction of the rotation axis 2a, of the outflow air current 20 is relatively increased, whereby the air-blowing efficiency of the fan can be enhanced.

[0052]

<Modification 10>

Fig. 35 is a perspective view of a propeller fan according to Modification 10 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 35, reinforcement ribs 9 according to Modification 10 are not provided with the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 1, and a circular opening 1e for attaching the drive shaft of the motor thereto is provided around the rotation axis 2a. Six

linear-flat-plate-shaped reinforcement ribs 9 (i.e., upstream ribs 9a and downstream ribs 9b) extending radially from the rotation axis 2a extend to the opening edge of the circular opening 1e.

Specifically, a minimum radius portion 1d having a radius defined by the shortest distance between the rotation axis 2a and the connection portion 1c is provided around the rotation axis 2a, and the circular opening 1e with the rotation axis 2a as the central axis and having a radius smaller than the radius of the minimum radius portion 1d is provided in the minimum radius portion 1d. The reinforcement ribs 9 connect the opening edge of the circular opening 1e and the plurality of blades 1.

Other configurations are the same as those of the propeller fan according to Embodiment 1.

[0053]

<Advantages>

Although Modification 10 has a simple configuration in which the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 1 are not provided, the reinforcement ribs 9 extend to the opening edge of the circular opening 1e so that the strength of the blades 1 of the propeller fan can be ensured.

<Modification 11>

Fig. 36 is a perspective view of a propeller fan according to Modification 11 of Embodiment 1, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 36, reinforcement ribs 9 according to Modification 11 include a third intermediate rib 9c disposed between the upstream rib 9a and the downstream rib 9b according to Modification 10.

Specifically, the reinforcement ribs 9 have a shape of linear flat plates extending radially from the rotation axis 2a of the propeller fan, and the upstream

rib 9a, the intermediate rib 9c, and the downstream rib 9b are disposed for each blade 1.

Other configurations are the same as those of the propeller fan according to Embodiment 1.

[0054]

<Advantages>

In Modification 11, three reinforcement ribs 9 are disposed for each blade 1 so that the strength of the blade 1 can be increased, as compared with the propeller fan according to Modification 10 in which two reinforcement ribs 9 are disposed for each blade 1. Moreover, since a total number of reinforcement ribs is changed to six to nine, the effect of the reinforcement ribs 9 for suctioning the reverse air current 21 near the rotation axis 2a increases. Thus, the wind velocity component Vz, in the direction of the rotation axis 2a, of the outflow air current 20 is relatively increased, whereby the air-blowing efficiency of the fan can be enhanced.

[0055]

Although the above-described examples relate to cases where two or three reinforcement ribs 9 are disposed for each blade 1, four or more reinforcement ribs 9 may be provided.

Moreover, the number of blades 1 is not particularly limited so long as there are two or more blades.

[0056]

Embodiment 2

A propeller fan according to Embodiment 2 is only different from the propeller fan according to Embodiment 1 in terms of the shape of the reinforcement ribs 9. Therefore, the configuration of the reinforcement ribs 9 will be described.

Fig. 10 is a front view of the propeller fan according to Embodiment 2, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 10, when viewed from the front in the direction of the rotation axis 2a, each reinforcement rib 9 according to Embodiment 2 has a sirocco blade shape curved and convex toward the trailing edge 7 of the corresponding blade 1.

[0057]

<Advantages>

With the reinforcement ribs 9 having such a sirocco blade shape, the air pressed as a result of the rotation of the reinforcement ribs 9 is collected toward the rotation axis 2a, so that the air is sent in the axial direction. In other words, an effect similar to a case where a mini propeller fan is provided at the center of each blade 1 is exhibited. Thus, the wind velocity component Vz in the direction of the rotation axis 2a is increased, whereby the air-blowing efficiency can be enhanced at a low-pressure-loss operating point to be described later.

[0058]

The following description relates to a difference in effects between the case where the reinforcement ribs 9 have the turbo blade shape convex toward the leading edge 6 or have the shape of radially-extending linear flat plates in accordance with Embodiment 1 and the case where the reinforcement ribs 9 have the sirocco blade shape curved and convex toward the trailing edge 7 in accordance with Embodiment 2.

Fig. 11 is a P-Q diagram illustrating the air-blowing performance of a propeller fan.

Generally, the air-blowing performance of a propeller fan is expressed with the relationship (i.e., P-Q diagram) between the pressure (i.e., static pressure) of the fluid and the amount of air per unit time, as shown in Fig. 11. When there is

large resistance in the air path of the propeller fan, it is known that a pressure loss curve rises from a normal pressure loss curve A to a high pressure loss curve B, causing an operating point serving as an intersection point between the pressure loss curve and a performance characteristic curve C of the propeller fan to move. The high pressure loss curve B is set such that the pressure loss in the flow path is doubled relative that in the normal pressure loss curve A.

An intersection point between the normal pressure loss curve A and the performance characteristic curve C serves as a normal operating point, an intersection point between the high pressure loss curve B and the performance characteristic curve C serves as a high-pressure-loss operating point, and an intersection point between a zero static pressure point and the performance characteristic curve C serves as a low-pressure-loss operating point.

[0059]

In the case where the reinforcement ribs 9 in Embodiment 1 each have the turbo blade shape convex toward the leading edge 6 or have the shape of radially-extending linear flat plates, negative pressure generated as a result of the rotation of the reinforcement ribs 9 causes the turbo blades to forcedly suction the air current in the direction of the rotation axis 2a of the propeller fan. Due to this turbo blade effect, the above-described cases are suitable for use in a condition in which there is flow-path resistance at the normal operating point or high-pressure-loss operating point requiring static pressure.

In the case where the reinforcement ribs 9 in Embodiment 2 have the sirocco blade shape curved and convex toward the trailing edge 7, the air pressed as a result of the rotation of the reinforcement ribs 9 is collected toward the rotation axis 2a, so that the reinforcement ribs 9 send air in the direction of the rotation axis 2a to function similarly to mini propeller fans. Thus, the above-described case is suitable for use at the low-pressure-loss operating point where

there is low flow-path resistance not requiring static pressure but requiring a certain amount of air.

[0060]

Next, modifications in which the reinforcement ribs 9 of the propeller fan according to Embodiment 2 each have a sirocco blade shape will be described.

<Modification 1>

Fig. 37 is a perspective view of a propeller fan according to Modification 1 of Embodiment 2, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 37, reinforcement ribs 9 according to Modification 1 include a third intermediate rib 9c disposed between the upstream rib 9a and the downstream rib 9b according to Embodiment 2 (see Fig. 10).

Specifically, each reinforcement rib 9 has a sirocco blade shape convex toward the trailing edge 7 of the propeller fan, and the upstream rib 9a, the intermediate rib 9c, and the downstream rib 9b are disposed for each blade 1.

Other configurations are the same as those of the propeller fan according to Embodiment 2.

[0061]

<Advantages>

In Modification 1, three reinforcement ribs 9 are disposed for each blade 1 so that the strength of the blade 1 can be increased, as compared with the propeller fan according to Embodiment 2 in which two reinforcement ribs 9 are disposed for each blade 1. Moreover, since a total number of reinforcement ribs is changed to six to nine, the air pressed as a result of the rotation of the reinforcement ribs 9 is collected toward the rotation axis 2a, so that the effect of sending the air in the direction of the rotation axis 2a is improved. In other words, an effect similar to a case where a mini propeller fan is provided at the center of each blade 1 is exhibited. Thus, the wind velocity component Vz in the

direction of the rotation axis 2a is increased, whereby the air-blowing efficiency can be enhanced at the low-pressure-loss operating point.

[0062]

<Modification 2>

Fig. 38 is a perspective view of a propeller fan according to Modification 2 of Embodiment 2, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 38, reinforcement ribs 9 according to Modification 2 are not provided with the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 2 (see Fig. 10), and six sirocco-blade-shaped reinforcement ribs 9 (i.e., upstream ribs 9a and downstream ribs 9b) are joined to one another by extending to and intersecting at the rotation axis 2a. Specifically, the six reinforcement ribs 9 intersect one another at the rotation axis 2a to form an axial portion 2b, and connect the axial portion 2b and the plurality of blades 1.

Other configurations are the same as those of the propeller fan according to Embodiment 2.

[0063]

<Advantages>

Although Modification 2 has a simple configuration in which the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 2 are not provided, the reinforcement ribs 9 extend to the rotation axis 2a so that the strength of the blades 1 of the propeller fan can be ensured.

<Modification 3>

Fig. 39 is a perspective view of a propeller fan according to Modification 3 of Embodiment 2, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 39, reinforcement ribs 9 according to Modification 3 include a third intermediate rib 9c disposed between the upstream rib 9a and the downstream rib 9b according to Modification 2.

Specifically, each reinforcement rib 9 has a sirocco blade shape convex toward the trailing edge 7 of the propeller fan, and the upstream rib 9a, the intermediate rib 9c, and the downstream rib 9b are disposed for each blade 1. The nine reinforcement ribs 9 intersect one another at the rotation axis 2a to form an axial portion 2b, and connect the axial portion 2b and the plurality of blades 1.

Other configurations are the same as those of the propeller fan according to Embodiment 2.

[0064]

<Advantages>

In Modification 3, three reinforcement ribs 9 are disposed for each blade 1 so that the strength of the blade 1 can be increased, as compared with the propeller fan according to Modification 2 in which two reinforcement ribs 9 are disposed for each blade 1. Moreover, since a total number of reinforcement ribs is changed to six to nine, the air pressed as a result of the rotation of the reinforcement ribs 9 is collected toward the rotation axis 2a, so that the effect of sending the air in the direction of the rotation axis 2a is improved. In other words, an effect similar to a case where a mini propeller fan is provided at the center of each blade 1 is exhibited. Thus, the wind velocity component Vz in the direction of the rotation axis 2a is increased, whereby the air-blowing efficiency can be enhanced at the low-pressure-loss operating point.

[0065]

<Modification 4>

Fig. 40 is a perspective view of a propeller fan according to Modification 4 of Embodiment 2, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 40, reinforcement ribs 9 according to Modification 4 are not provided with the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 2, and a circular opening 1e for attaching the drive shaft of the motor thereto is provided around the rotation axis 2a. Six sirocco-blade-shaped reinforcement ribs 9 (i.e., upstream ribs 9a and downstream ribs 9b) extend to the opening edge of the circular opening 1e.

Specifically, a minimum radius portion 1d having a radius defined by the shortest distance between the rotation axis 2a and the connection portion 1c is provided around the rotation axis 2a, and the circular opening 1e with the rotation axis 2a as the central axis and having a radius smaller than the radius of the minimum radius portion 1d is provided in the minimum radius portion 1d. The reinforcement ribs 9 connect the opening edge of the circular opening 1e and the plurality of blades 1.

Other configurations are the same as those of the propeller fan according to Embodiment 2.

[0066]

<Advantages>

Although Modification 4 has a simple configuration in which the cylindrical portion 3, the shaft hole 2, and the connection ribs 4 according to Embodiment 1 are not provided, the reinforcement ribs 9 extend to the opening edge of the circular opening 1e so that the strength of the blades 1 of the propeller fan can be ensured.

<Modification 5>

Fig. 41 is a perspective view of a propeller fan according to Modification 5 of Embodiment 2, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 41, reinforcement ribs 9 according to Modification 5 include a third intermediate rib 9c disposed between the upstream rib 9a and the downstream rib 9b according to Modification 4.

Specifically, each reinforcement rib 9 has a sirocco blade shape convex toward the trailing edge 7 of the propeller fan, and the upstream rib 9a, the intermediate rib 9c, and the downstream rib 9b are disposed for each blade 1.

Other configurations are the same as those of the propeller fan according to Embodiment 2.

[0067]

<Advantages>

In Modification 5, three reinforcement ribs 9 are disposed for each blade 1 so that the strength of the blade 1 can be increased, as compared with the propeller fan according to Modification 5 in which two reinforcement ribs 9 are disposed for each blade 1. Moreover, since a total number of reinforcement ribs is changed to six to nine, the air pressed as a result of the rotation of the reinforcement ribs 9 is collected toward the rotation axis 2a, so that the effect of sending the air in the direction of the rotation axis 2a is improved. In other words, an effect similar to a case where a mini propeller fan is provided at the center of each blade 1 is exhibited. Thus, the wind velocity component Vz in the direction of the rotation axis 2a is increased, whereby the air-blowing efficiency can be enhanced at the low-pressure-loss operating point.

[0068]

Embodiment 3

Embodiment 3 corresponds to a case where the blades 1 of the propeller fan according to Embodiment 1 or 2 are inclined in the fluid flowing direction 10 (i.e., a rearward-inclined type to be described below).

[0069]

Fig. 12 illustrates the position of a blade chord center line 15 in a front view of a propeller fan according to Embodiment 3.

Fig. 13 illustrates the position of the blade chord center line 15 in a side view comparing the rearward-inclined-type propeller fan according to Embodiment 3 with a forward-inclined-type propeller fan.

The blade chord center line 15 is a group of center points on specific circumferences of each blade 1.

In Fig. 13, with regard to the blade chord center line 15 of each rearward-inclined blade 1, when an orthogonal plane 16 extending in a direction orthogonal to the rotation axis 2a is drawn from a contact point 15a at the outer wall surface of the cylindrical portion 3, the blade chord center line 15 is located downstream of the orthogonal plane 16 in the fluid flowing direction 10. In contrast, the blade chord center line 15 of each forward-inclined blade 1 is located upstream of the orthogonal plane 16 in the fluid flowing direction 10.

Thus, in the rearward-inclined-type propeller fan according to Embodiment 3, each blade 1 has a shape in which the blade chord center line 15 is disposed downstream of the orthogonal plane 16 in the fluid flowing direction (referred to as a rearward-inclined type hereinafter).

[0070]

An arrow on the blade 1 shown in Fig. 13 indicates a direction in which the air is pressed when the blade 1 rotates, and is inclined toward the inner periphery of the blade 1 in the rearward-inclined-type propeller fan (= closed flow).

In contrast to the rearward-inclined type, the forward-inclined-type propeller fan in Fig. 13 for a comparison is configured such that the direction in which the air is pressed is inclined toward the outer periphery of the blade 1 (= open flow).

[0071]

Next, the difference in wind velocity component Vz in the direction parallel to the rotation axis 2a between the forward-inclined-type propeller fan and the rearward-inclined-type propeller fan will be described with reference to Fig. 14.

Fig. 14 is a diagram comparing a velocity component 25 of the rearward-inclined-type propeller fan according to Embodiment 3 with a velocity component 26 of the forward-inclined type propeller fan.

Since the direction in which the air is pressed against each blade 1 varies in an area with the maximum wind velocity component Vz (i.e., an area with a large amount of air), the peak position of the velocity component 25 corresponding to the rearward-inclined type tends to be located toward the inner periphery of the blade 1 than that of the velocity component 26 corresponding to the forward-inclined type.

[0072]

As shown in the drawing, the rearward-inclined-type propeller fan according to Embodiment 3 suppresses expansion of the velocity distribution of the air current toward the outer periphery of the blade 1, so that the outflow angle α (α being a positive value as explained with reference to Fig. 8) of the outflow air current 20 can be reduced.

[0073]

Although an example of a blade shape in which the blade chord center line 15 in the rearward-inclined type is entirely disposed downstream of the orthogonal plane 16 in the fluid flowing direction, a function and an effect similar to the above are exhibited so long as the blade 1 has a shape in which 70% or more of the length of the blade chord center line 15 is disposed downstream of the orthogonal plane 16 in the fluid flowing direction.

[0074]

<Advantages>

The propeller fan according to Embodiment 3 employs the rearward-inclined blades 1 so that the outflow angle α of the outflow air current 20 can be reduced, in addition to the effects according to Embodiment 1. Thus, the wind velocity component Vz, in the direction of the rotation axis 2a, of the outflow air current 20 is relatively increased, whereby the air-blowing efficiency of the fan can be enhanced.

[0075]

Embodiment 4

A propeller fan according to Embodiment 4 is an example in which the propeller fan according to any one of Embodiment 1 to Embodiment 3 is applied to an outdoor unit 30 of an air-conditioning apparatus. This propeller fan has a function of sending outdoor air for heat exchange to an outdoor heat exchanger 31.

Fig. 15 is an external perspective view in a case where the propeller fan according to any one of Embodiment 1 to Embodiment 3 is attached to the outdoor unit according to Embodiment 4.

Fig. 16 is an internal perspective view in a case where the propeller fan according to any one of Embodiment 1 to Embodiment 3 is attached to the outdoor unit according to Embodiment 4.

Fig. 17 illustrates the effects of the reinforcement ribs when outdoor air strikes against the propeller fan in the outdoor unit according to Embodiment 4.

When viewed from the front in the direction of the rotation axis 2a, each reinforcement rib 9 of the propeller fan in the outdoor unit 30 according to Embodiment 4 has a curved shape (i.e., turbo blade shape) convex toward the leading edge 6 of the propeller fan, as shown in Fig. 2.

[0076]

As described in Embodiment 1, the reinforcement ribs 9 rotate in the normal rotational direction 11 to form a negative pressure region near the rotation axis 2a, thereby suctioning the reverse air current 21 relative to the outflow air current 20.

It is assumed that strong outdoor wind strikes against the propeller fan when the outdoor unit 30 according to Embodiment 3 is stopped. This strong wind acts on the propeller fan as head wind in the direction opposite to the fluid flowing direction 10 caused to occur during normal operation of the propeller fan.

The strong wind (i.e., head wind) collides against the pressure surfaces 1a of the propeller fan and causes the blades 1 to rotate in a counter rotational direction 12 opposite to the normal rotational direction 11. Then, the reinforcement ribs 9 with the curved shape (i.e., turbo blade shape) convexed in the rotational direction 11 in the case of the normal rotational direction 11 change into a curved shape (i.e., sirocco blade shape) concaved in the counter rotational direction 12 in the case of the counter rotational direction 12.

[0077]

<Advantages>

When strong outdoor wind (i.e. head wind) strikes against the propeller fan provided in the outdoor unit 30, the propeller fan rotates at high speed, sometimes causing the blades 1 to fracture and break due to a centrifugal force. In the propeller fan according to Embodiment 3, when strong wind strikes against the propeller fan, the reinforcement ribs 9 change into the curved shape (i.e., sirocco blade shape) concaved in the counter rotational direction 12, so that air in spaces 40 between the reinforcement ribs 9 shown in Fig. 15 acts as resistance against the rotation due to a parachute effect. Thus, in the normal rotational direction 11, the air-current suction effect according to Embodiment 1 is exhibited. Moreover, in the counter rotational direction 12 caused by strong

wind, the rotational speed of the propeller fan is reduced, so that the propeller fan can be prevented from breaking.

[0078]

<Packaging of Propeller Fan>

Packaging of the propeller fan according to any one of Embodiment 1 to Embodiment 3 will now be described.

Fig. 18 schematically illustrates a packaged state of the propeller fan according to any one of Embodiment 1 to Embodiment 3.

Fig. 19 schematically illustrates a packaged state of the boss-equipped propeller fan in the related art.

In Fig. 18, boss-less propeller fans are stacked and contained within a packaging cardboard box 50, and a base 51 is disposed to support the bottom surface of the cylindrical portion 3 such that a distance L is ensured from the bottom surface of the cardboard box 50 to the leading edges 6 of the blades 1.

[0079]

In the propeller fan according to any one of Embodiment 1 to Embodiment 3, the cylindrical portion 3 in the axial direction is shorter than the boss in the boss-equipped propeller fan in the related art in the direction of the rotation axis. Therefore, as shown in Fig. 18, the dimension in the stacking direction is reduced when the cylindrical portions 3 are stacked with their upper surfaces and lower surfaces in contact with each other, so that a larger number of propeller fans can be contained within the packaging cardboard box 50, as compared with the related art.

[0080]

Embodiment 5

In the propeller fan according to any one of Embodiment 1 to Embodiment 4, two reinforcement ribs 9, that is, the upstream rib 9a and the downstream rib

9b, are provided for each blade 1. In Embodiment 5, only the downstream rib 9b of the two ribs, that is, the upstream rib 9a and the downstream rib 9b, is provided for each blade 1. Other components of the propeller fan are the same as those in Embodiment 1 to Embodiment 4.

[0081]

Fig. 42 is a front view of the propeller fan according to Embodiment 5, as viewed from downstream in the fluid flowing direction.

Fig. 43 is a front view of a propeller fan according to Modification 1 of Embodiment 5, as viewed from downstream in the fluid flowing direction.

Fig. 44 is a front view of a propeller fan according to Modification 2 of Embodiment 5, as viewed from downstream in the fluid flowing direction.

[0082]

For example, as shown in Fig. 42, the propeller fan according to Embodiment 5 is provided with reinforcement ribs 9 having a turbo blade shape convex toward the leading edges 6 of the blades 1. Of the upstream ribs 9a and the downstream ribs 9b described in Embodiment 1 (see Fig. 2), the reinforcement ribs 9 only include the downstream ribs 9b.

[0083]

<Modification 1>

Furthermore, for example, as shown in Fig. 43, the propeller fan according to Modification 1 of Embodiment 5 is provided with reinforcement ribs 9 having a sirocco blade shape convex toward the trailing edges 7 of the blades 1. Of the upstream ribs 9a and the downstream ribs 9b described in Embodiment 2 (see Fig. 10), the reinforcement ribs 9 only include the downstream ribs 9b.

[0084]

<Modification 2>

Furthermore, for example, as shown in Fig. 44, the propeller fan according to Modification 2 of Embodiment 5 is provided with linear-flat-plate-shaped reinforcement ribs 9 extending radially from the rotation axis 2a of the propeller fan. Of the upstream ribs 9a and the downstream ribs 9b described in Modification 1 (see Fig. 9) of Embodiment 1, the reinforcement ribs 9 only include the downstream ribs 9b.

[0085]

<Advantages>

In the propeller fan according to any one of Embodiment 5, Modification 1, and Modification 2 thereof, only a single downstream rib 9b is disposed for each blade 1 so that the propeller fan is reduced in weight. Moreover, the propeller fan according to Embodiment 5 is suitable for use in a low-speed rotation range and can maintain its strength even with the blades 1 being supported only by the downstream ribs 9b.

Furthermore, in the turbo-blade-shaped downstream ribs 9b and the radially-extending linear-flat-plate-shaped downstream ribs 9b according to Embodiment 5 and Modification 1 thereof, the effect of suctioning the reverse air current 21 near the rotation axis 2a can be exhibited. Thus, the wind velocity component Vz, in the direction of the rotation axis 2a, of the outflow air current 20 is relatively increased, whereby the air-blowing efficiency of the fan can be enhanced.

Moreover, with the sirocco-blade-shaped downstream ribs 9b according to Modification 2, the air pressed as a result of the rotation of the downstream ribs 9b is collected toward the rotation axis 2a, so that the effect of sending air in the direction of the rotation axis 2a is improved. In other words, an effect similar to a case where a mini propeller fan is provided at the center of each blade 1 is exhibited. Thus, the wind velocity component Vz in the direction of the rotation

axis 2a is increased, whereby the air-blowing efficiency can be enhanced at the low-pressure-loss operating point.

[0086]

Embodiment 6

In the propeller fan according to any one of Embodiment 1 to Embodiment 4, two reinforcement ribs 9, that is, the upstream rib 9a and the downstream rib 9b, are provided for each blade 1. In Embodiment 6, only the upstream rib 9a of the two ribs, that is, the upstream rib 9a and the downstream rib 9b, is provided for each blade 1. Other components of the propeller fan are the same as those in Embodiment 1 to Embodiment 4.

[0087]

Fig. 45 is a front view of the propeller fan according to Embodiment 6, as viewed from downstream in the fluid flowing direction.

Fig. 46 is a front view of a propeller fan according to Modification 1 of Embodiment 6, as viewed from downstream in the fluid flowing direction.

Fig. 47 is a front view of a propeller fan according to Modification 2 of Embodiment 6, as viewed from downstream in the fluid flowing direction.

[0088]

For example, as shown in Fig. 45, the propeller fan according to Embodiment 6 is provided with reinforcement ribs 9 having a turbo blade shape convex toward the leading edges 6 of the blades 1. Of the upstream ribs 9a and the downstream ribs 9b described in Embodiment 1 (see Fig. 2), the reinforcement ribs 9 only include the upstream ribs 9a.

[0089]

<Modification 1>

Furthermore, for example, as shown in Fig. 46, the propeller fan according to Modification 1 of Embodiment 6 is provided with reinforcement ribs 9 having a

sirocco blade shape convex toward the trailing edges 7 of the blades 1. Of the upstream ribs 9a and the downstream ribs 9b described in Embodiment 2 (see Fig. 10), the reinforcement ribs 9 only include the upstream ribs 9a.

[0090]

<Modification 2>

Furthermore, for example, as shown in Fig. 47, the propeller fan according to Modification 2 of Embodiment 6 is provided with linear-flat-plate-shaped reinforcement ribs 9 extending radially from the rotation axis 2a of the propeller fan. Of the upstream ribs 9a and the downstream ribs 9b described in Modification 1 (see Fig. 9) of Embodiment 1, the reinforcement ribs 9 only include the upstream ribs 9a.

[0091]

<Advantages>

In the propeller fan according to any one of Embodiment 6, Modification 1, and Modification 2 thereof, only a single upstream rib 9a is disposed for each blade 1 so that the propeller fan is reduced in weight. Moreover, as compared with the propeller fan according to Embodiment 3, the propeller fan according to Embodiment 6 is suitable for use in a high-speed rotation range and can maintain its strength due to the upstream ribs 9a being disposed at the leading edge 6 side where the stress on the blades 1 concentrates.

Furthermore, in the turbo-blade-shaped upstream ribs 9a and the radially-extending linear-flat-plate-shaped upstream ribs 9a according to Embodiment 6 and Modification 1 thereof, the effect of suctioning the reverse air current 21 near the rotation axis 2a can be exhibited. Thus, the wind velocity component Vz, in the direction of the rotation axis 2a, of the outflow air current 20 is relatively increased, whereby the air-blowing efficiency of the fan can be enhanced.

Moreover, with the sirocco-blade-shaped upstream ribs 9a according to Modification 2, the air pressed as a result of the rotation of the upstream ribs 9a is collected toward the rotation axis 2a, so that the effect of sending air in the direction of the rotation axis 2a is improved. In other words, an effect similar to a case where a mini propeller fan is provided at the center of each blade 1 is exhibited. Thus, the wind velocity component Vz in the direction of the rotation axis 2a is increased, whereby the air-blowing efficiency can be enhanced at the low-pressure-loss operating point.

[0092]

Although one of the upstream rib 9a and the downstream rib 9b is disposed for each blade 1 in Embodiment 5 and Embodiment 6, the position where the single reinforcement rib 9 is disposed may be a freely-chosen position instead of a position near the leading edge 6 or the trailing edge 7 of the corresponding blade 1. In other words, the single reinforcement rib 9 may be disposed at a freely-chosen position so long as it is interposed between the leading edge 6 and the trailing edge 7 of the corresponding blade 1.

[0093]

Embodiment 7

In the propeller fan according to any one of Embodiment 1 to Embodiment 6, the reinforcement ribs 9 used each have a flat plate shape with uniform thickness. Alternatively, each reinforcement rib 9 according to Embodiment 7 is provided with an expansion portion 60 having a large joint area with the corresponding blade 1 and located at the outer peripheral edge 8 side of the blade 1.

Other components of the propeller fan are the same as those in Embodiment 1 to Embodiment 6.

[0094]

Fig. 48 is a front view of the propeller fan according to Embodiment 7, as viewed from downstream in the fluid flowing direction.

Fig. 49 is a front view of a propeller fan according to Modification 1 of Embodiment 7, as viewed from downstream in the fluid flowing direction.

Fig. 50 is a front view of a propeller fan according to Modification 2 of Embodiment 7, as viewed from downstream in the fluid flowing direction.

[0095]

For example, as shown in Fig. 48, the propeller fan according to Embodiment 7 is provided with reinforcement ribs 9 having a turbo blade shape convex toward the leading edges 6 of the blades 1. As shown in Fig. 48, when viewed from the direction of the rotation axis 2a, the end at the outer peripheral edge 8 side of each reinforcement rib 9 is provided with an expansion portion 60 that expands in a Y shape in the thickness direction of the reinforcement rib 9. Specifically, the end at the outer peripheral edge 8 side of the reinforcement rib 9 is provided with the expansion portion 60 whose joint area with the corresponding blade 1 increases per unit length.

[0096]

The shape of each expansion portion 60 is not limited to the Y shape shown in Fig. 48 so long as the end at the outer peripheral edge 8 side of the reinforcement rib 9 has a shape with which the joint area between the reinforcement rib 9 and the corresponding blade 1 increases. For example, the end at the outer peripheral edge 8 side of the reinforcement rib 9 may have a cylindrical shape or a polygonal columnar shape with an outer diameter larger than the thickness of the reinforcement rib 9. Specifically, when compared with the joint area between the blade 1 and the reinforcement rib 9 per unit length in the radial direction of the blade 1, the expansion portion 60 is defined as a

section with a joint area larger than that of a portion other than the end at the outer peripheral edge 8 side of the reinforcement rib 9.

[0097]

<Modification 1>

For example, as shown in Fig. 49, the propeller fan according to Modification 1 of Embodiment 7 is provided with reinforcement ribs 9 having a sirocco blade shape convex toward the trailing edges 7 of the blades 1. As shown in Fig. 49, when viewed from the direction of the rotation axis 2a, the end at the outer peripheral edge 8 side of each reinforcement rib 9 is provided with an expansion portion 60 that expands in a Y shape in the thickness direction of the reinforcement rib 9. Specifically, the end at the outer peripheral edge 8 side of the reinforcement rib 9 is provided with the expansion portion 60 whose joint area with the corresponding blade 1 increases per unit length. Similar to the above, the shape of the expansion portion 60 is not limited to the Y shape.

[0098]

<Modification 2>

Furthermore, for example, as shown in Fig. 50, the propeller fan according to Modification 2 of Embodiment 7 is provided with linear-flat-plate-shaped reinforcement ribs 9 extending radially from the rotation axis 2a of the propeller fan. As shown in Fig. 50, when viewed from the direction of the rotation axis 2a, the end at the outer peripheral edge 8 side of each reinforcement rib 9 is provided with an expansion portion 60 that expands in a Y shape in the thickness direction of the reinforcement rib 9. Specifically, the end at the outer peripheral edge 8 side of the reinforcement rib 9 is provided with the expansion portion 60 whose joint area with the corresponding blade 1 increases per unit length. Similar to the above, the shape of the expansion portion 60 is not limited to the Y shape.

[0099]

<Advantages>

In the propeller fan according to any one of Embodiment 7, Modification 1, and Modification 2 thereof, each reinforcement rib 9 is provided with the expansion portion 60 whose joint area with the corresponding blade 1 increases at the outer peripheral edge 8 side of the blade 1. Thus, stress can be distributively received by the end at the outer peripheral edge 8 side of the reinforcement rib 9 where the stress acts on the blade 1 the most. Specifically, a large joint area with the blade 1 is ensured at the expansion portion 60, so that the reinforcement rib 9 can receive the stress from the blade 1 as a distributive load, thereby preventing the joint between the reinforcement rib 9 and the blade 1 from breaking. In particular, when strong outdoor wind strikes against the propeller fan in, for example, an outdoor unit and causes the propeller fan to rotate at high speed, the blades can be prevented from cracking.

[0100]

Embodiment 8

With regard to the reinforcement ribs 9 according to any one of Embodiment 1 to Embodiment 7, the flat surfaces of the reinforcement ribs 9 are disposed parallel to the rotation axis 2a of the propeller fan. Alternatively, in a propeller fan according to Embodiment 8, the flat surfaces constituting the turbo-blade-shaped reinforcement ribs 9 are inclined such that the upper edges 9ah and 9bh thereof are inclined toward the leading edge 6 side.

Other components of the propeller fan are the same as those in Embodiment 1 to Embodiment 7.

Fig. 51 is a partial perspective view of the propeller fan according to Embodiment 8, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 51, each reinforcement rib 9 according to Embodiment 8 has a curved shape (i.e. turbo blade shape) convex toward the leading edge 6. Similar to Embodiment 1, the reinforcement ribs 9 include two ribs, that is, an upstream rib 9a and a downstream rib 9b. The flat surfaces constituting the reinforcement ribs 9 are inclined such that the upper edges 9ah and 9bh of the upstream rib 9a and the downstream rib 9b are inclined toward the leading edge 6 of the corresponding blade 1. An angle formed between the flat surface constituting each reinforcement rib 9 and the rotation axis 2a is $\beta 1$, as shown in Fig. 51.

[0101]

<Advantages>

In the propeller fan according to Embodiment 8, the turbo-blade-shaped reinforcement ribs 9 are inclined such that the upper edges 9ah and 9bh of the reinforcement ribs 9 are inclined toward the leading edge 6 side, whereby the effect of suctioning the reverse air current 21 near the rotation axis 2a can be further enhanced, as compared with an example in which the flat surfaces of the reinforcement ribs 9 are disposed parallel to the rotation axis 2a.

[0102]

<Modification 1>

Next, Modification 1 of the reinforcement ribs 9 according to Embodiment 8 will be described with reference to Fig. 52.

Fig. 52 is a partial perspective view of a propeller fan according to Modification 1 of Embodiment 8, as viewed from downstream in the fluid flowing direction.

In Embodiment 8, the turbo-blade-shaped reinforcement ribs 9 are inclined such that the upper edges 9ah and 9bh of the reinforcement ribs 9 are inclined toward the leading edge 6 side. In Modification 1, the flat surfaces constituting

the turbo-blade-shaped reinforcement ribs 9 are inclined such that the upper edges 9ah and 9bh thereof are inclined toward the trailing edge 7 side.

As shown in Fig. 52, each reinforcement rib 9 has a curved shape (i.e. turbo blade shape) convex toward the leading edge 6. Similar to Embodiment 1, the reinforcement ribs 9 include two ribs, that is, an upstream rib 9a and a downstream rib 9b. The flat surfaces constituting the reinforcement ribs 9 are inclined such that the upper edges 9ah and 9bh of the upstream rib 9a and the downstream rib 9b are inclined toward the trailing edge 7 of the corresponding blade 1. An angle formed between the flat surface constituting each reinforcement rib 9 and the rotation axis 2a is $\beta 2$, as shown in Fig. 52.

[0103]

<Advantages>

When strong outdoor wind during, for example, a typhoon strikes against the propeller fan according to Modification 1, the reinforcement ribs 9 change into a curved shape (i.e., sirocco blade shape) concaved in the counter rotational direction 12, so that the wind acts as resistance against the rotation due to a parachute effect. Thus, in the normal rotational direction 11, the air-current suction effect according to Embodiment 1 is exhibited. Moreover, in the counter rotational direction 12 caused by strong outdoor wind, the rotational speed of the propeller fan is reduced, so that the propeller fan can be prevented from breaking.

[0104]

<Modification 2>

Next, Modification 2 of the reinforcement ribs 9 according to Embodiment 8 will be described with reference to Fig. 53.

Fig. 53 is a partial perspective view of a propeller fan according to Modification 2 of Embodiment 8, as viewed from downstream in the fluid flowing direction.

In Modification 1 of Embodiment 8, the turbo-blade-shaped reinforcement ribs 9 are inclined such that the upper edges 9ah and 9bh of the reinforcement ribs 9 are inclined toward the trailing edge 7 side. In Modification 2, the flat surfaces constituting sirocco-blade-shaped reinforcement ribs 9 are inclined such that the upper edges 9ah and 9bh thereof are inclined toward the trailing edge 7 side.

As shown in Fig. 53, each reinforcement rib 9 has a curved shape (i.e. sirocco blade shape) convex toward the trailing edge 7. Similar to Embodiment 1, the reinforcement ribs 9 include two ribs, that is, an upstream rib 9a and a downstream rib 9b. The flat surfaces constituting the reinforcement ribs 9 are inclined such that the upper edges 9ah and 9bh of the upstream rib 9a and the downstream rib 9b are inclined toward the trailing edge 7 of the corresponding blade 1. An angle formed between the flat surface constituting each reinforcement rib 9 and the rotation axis 2a is $\gamma 1$, as shown in Fig. 53.

[0105]

<Advantages>

In the propeller fan according to Modification 2, the sirocco-blade-shaped reinforcement ribs 9 are inclined such that the upper edges 9ah and 9bh of the reinforcement ribs 9 are inclined toward the trailing edge 7 side. Thus, a mini-propeller-fan effect by the reinforcement ribs 9 becomes larger so that the amount of air increases, as compared with an example in which the flat surfaces of the reinforcement ribs 9 are disposed parallel to the rotation axis 2a in accordance with Embodiment 2. Consequently, the wind velocity component Vz

in the direction of the rotation axis 2a increases, whereby the air-blowing efficiency can be enhanced.

[0106]

Embodiment 9

Although the reinforcement ribs 9 according to any one of Embodiment 1 to Embodiment 8 support the blades 1 beyond the circular minimum radius portion 1d having a radius defined by the shortest distance between the rotation axis 2a of the propeller fan and the peripheral edge of the connection portion 1c, each reinforcement rib 9 according to Embodiment 9 has a length defined within the minimum radius portion 1d.

Other components are the same as those in Embodiment 1 to Embodiment 8.

Fig. 54 is a front view of a propeller fan according to Embodiment 9, as viewed from downstream in the fluid flowing direction.

As shown in Fig. 54, the reinforcement ribs 9 according to Embodiment 9 are configured such that each turbo-blade-shaped reinforcement rib 9 has a length, in the radial direction, defined within the minimum radius portion 1d. Specifically, the length in the radial direction is smaller than that of each reinforcement rib 9 according to Embodiment 1.

In Fig. 54, assuming that the maximum outer diameter of each blade 1 of the propeller fan is defined as ϕD and the length of each reinforcement rib 9 in the radial direction is defined as L (i.e., the length between the rotation axis 2a and the upstream-rib contact point 9as or downstream-rib contact point 9bs), it is preferable that L be set such that the value of $L/\phi D$ is between 0.025 and 0.1 inclusive.

[0107]

<Advantages>

The propeller fan according to Embodiment 9 is suitable for use at the low-pressure-loss operating point where there is low flow-path resistance not requiring static pressure but requiring a certain amount of air between the normal operating point and the low-pressure-loss operating point in Fig. 11. Thus, since each reinforcement rib 9 is structurally defined to have a length within the minimum radius portion 1d, the propeller fan can be reduced in weight.

[0108]

The blade shape of the propeller fan described above in any one of Embodiment 1 to Embodiment 9 can be applied to various air-blowing devices. For example, in addition to an outdoor unit of an air-conditioning apparatus, the blade shape can be applied to an air-blowing device of an indoor unit. Furthermore, the blade shape can be widely applied as a blade shape of a fluid-conveying axial-flow compressor, such as an air-blowing device, a ventilation fan, or a pump.

Reference Signs List

[0109]

1 blade 1a pressure surface 1b suction surface 1c connection portion 1d minimum radius portion 1e circular opening 2 shaft hole 2a rotation axis 2b axial portion 3 cylindrical portion 3a indicator 4 connection rib 6 leading edge 7 trailing edge 8 outer peripheral edge 9 reinforcement rib 9a upstream rib 9ah upper edge 9as upstream-rib contact point 9b downstream rib 9bh upper edge 9bs downstream-rib contact point 9c intermediate rib 9c1 first circular arc 9c2 second circular arc 10 fluid flowing direction parallel to rotation axis 11 rotational direction 12 counter rotational direction 15 center line 15a contact point 16 orthogonal plane 20 outflow air current 21 reverse air current

22 inflow air current 23 inverted air current 25 velocity component of rearward-inclined-type propeller fan 26 velocity component of forward-inclined-type propeller fan 30 outdoor unit 31 outdoor heat exchanger 40 space 50 cardboard box 51 base 60 expansion portion

$\alpha 1$, $\alpha 2$ outflow angle $\beta 1$, $\beta 2$, $\gamma 1$ angle of reinforcement rib