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SILENT PRESSURE FAN

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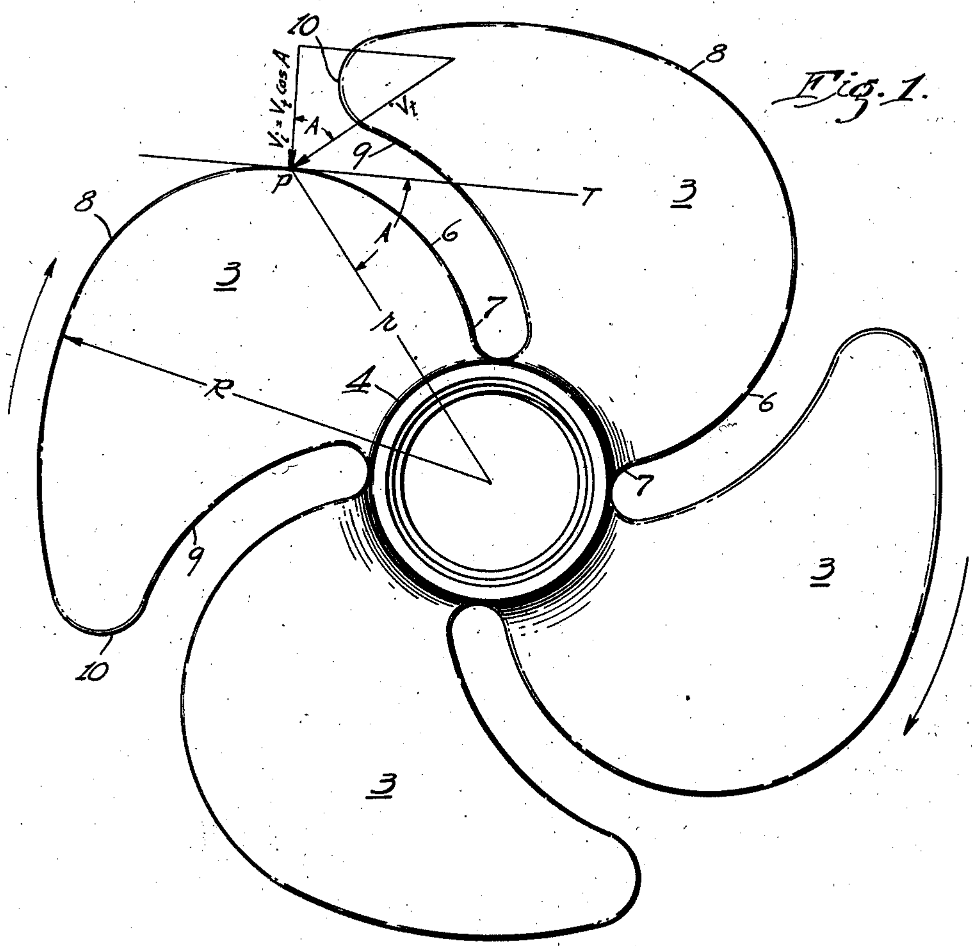
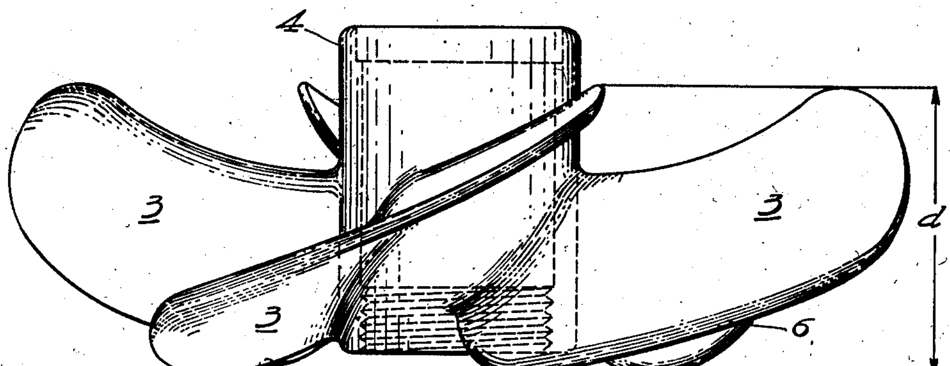


Fig. 1.



WITNESSES:

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Fig. 2.

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SILENT PRESSURE FAN

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12 Claims. (Cl. 170—159)

My invention relates to silent, propeller-type, pressure-fans which are especially developed for air-conditioning apparatus, such as a room-cooler or a portable humidifier, the same being adapted also for use on other appliances which are utilized in living rooms or other places where the greatest possible quietness is required.

By "pressure" fan I mean a fan which has to create an air pressure, either to overcome a back pressure due to devices, disposed in front of the fan, which create a resistance to the air-flow, such as heating or cooling coils, or even changes in direction of flow, or to overcome a suction due to such devices disposed behind the fan. A "pressure" fan is distinguished, therefore, from a fan which runs in free air or with open-air delivery, wherein the pressure which is necessary to accelerate the air introduces only an exceedingly small amount of difference between the axial component of the air-flow and the axial component corresponding to the motion of the propeller blades. As long as the air flows freely, the direction of the air relative to the blades is coincident with the surface of the blades so that the air hits only the edge of the blade, and produces a comparatively small amount of noise. For this reason, it is comparatively easy to design an open-air fan, such as an ordinary desk fan or exhaust fan, so as to be fairly quiet, but such a fan quickly becomes not only very inefficient but also very noisy when its air-flow is restricted, because the air-velocity relative to the blades is then such that the air strikes the fronts of the blades at an angle, thus creating far more noise when only striking the edge.

While the calculation of the fluid motion from first principles is far beyond our powers in the present state of the art, the main principles of design being largely empirical, so that I do not wish to be limited altogether to any particular theory of design, my present fan is based on the theory or assumption that, in any pressure-fan, the air will strike the front surfaces of the blades at an agle, thus producing noise. I believe that the noise is approximately proportional to the area impinged upon or to the length of the leading edges of the fan-blades, and that the amount of noise increases in proportion to a high power of the velocity, much higher than the first power of the velocity. With this thought in mind, I have built a fan in which an effort has been made to keep down the component of the air-velocity, relative to the blade, which is normal to the leading edge of the blade, in a plane transverse to the axis of the fan. Whether my theories are absolutely correct or not, the result has proved to be a pressure-fan which is remarkably silent in its operation.

Further objects and advantages of my invention will be apparent from the detailed description and claiming thereof hereinafter given, with reference to the accompanying drawing, wherein:

Figure 1 is a view showing the projected plan form of the blades embodying my invention; and

Fig. 2 is a view taken at right angles to Fig. 1, showing the inclination and axial depth of the blades.

The drawing shows my invention, by way of example, as being embodied in a fan having four blades 3 which are preferably cast integrally with a hub 4, being made of any suitable alloy, such as an aluminum-silicon alloy. The fan is adapted to rotate in the direction indicated by the curved arrows in Fig. 1. It will be observed that the leading edge 6 of each blade is curved backwardly in a curve such that the projection of the curve on a plane at right angles to the axis of the shaft of the fan, as shown in Fig. 1, shall be substantially radial at the root of the blade, as indicated at 7, and shall merge smoothly into the circumference of the fan blades, at the tip of the blade as indicated at 8. The leading edge 6 cuts the air first and pushes the air forwardly in an axial direction through the fan, by reason of the angular disposition of the blades, as shown in Fig. 2, the blades having a considerable axial depth, as indicated by the dimension *d* marked in Fig. 2.

The essential characteristic of my fan is its extreme quietness, and I obtain this quality in a propeller-type fan, such as that just described, even though the fan must develop air-pressure in order to drive or draw the air through an air-conditioner or the like. In order for any material amount of air-pressure to be developed, it is necessary for the total projected area of the blades, as shown in Fig. 1, to constitute at least about 60% or more of the area swept out by the fan blades, that is, the total projected area of the fan blades (including the cross-sectional area of the hub), as shown in Fig. 1, should be more than about $2R^2$, where R is the outer radius of the fan blades, as indicated in Fig. 1. This is necessary in order to prevent the air which has just left one blade from jumping back to the open space between that blade and the next adjoining blade, due to the pressure against which the air must work.

In order that the fan may be quiet in accordance with my invention, it is necessary to observe two essentials. The first essential is that the number of blades shall be small. If, for example, an effort is made to redesign a desk fan in order to deliver air against back pressure, the simplest way of doing this is to increase the number of blades so as to increase, at the same time, the total projected area of the fan blades. It will be found, however, that the fundamental frequency of the noise produced by the fan is increased in proportion to the number of blades. But the energy of the noise is increased in proportion to the square of the frequency; hence, in proportion to the square of the number of blades. In addition to this, with the usual fan speeds, the increase in the number of blades will shift the basic frequency of the noise into a range of greater ear-sensitivity, with the result that the higher-pitch noise is more annoying than a noise of equal energy but lower pitch or frequency.

Therefore, in order to produce quiet operation, it is necessary to utilize a fan having a small number of wide blades rather than a fan having a large number of narrower blades. This means a sacrifice in the volumetric dimensions of the fan, because the axial depth or pitch of the fan-blades is approximately inversely proportional to the number of blades utilized, for any given fan-performance. Thus, the 7⅛ inch fan shown in the drawing has an axial depth of 2¼ inches, in a four-blade design as shown. If six blades had been utilized, the axial depth could be reduced to something like 1½ inches, whereas if only two blades had beeen utilized the axial depth would have been something like 4½ inches. I should say, in general, that the number of blades should not be greater than six, if the noise is to be kept within reasonable limits. This means a rather unusual blade having a much greater radial depth than is common in ordinary fan-designs.

The second essential for quiet operation is that the component of the air-velocity, which represents the impact-velocity of the air against the fan blade, in a plane at right angles to the axis, shall be made as small as reasonably possible, even at the expense of increasing the length of the leading edge on which this impact-velocity operates. As a matter of fact, the length of any section of the leading edge of the blade must be increased inversely proportionally to the reduction of the impact-velocity of the air relative to the blade. This increase in length would alone tend to increase the noise, so that if the energy of the noise which is generated by an air-current flowing against the leading edge of the blade were directly proportional to the first power of the velocity of this air-current, nothing could be gained by the expedient resorted to in my invention. I have found, however, that the noise of the energy increases in accordance with a much higher power than the first power of the velocity, so that more is gained by the reduction of the impact-velocity of the air than is lost by the increase in the length of the leading edge of the blade.

In the consideration of impact velocities, it is convenient to consider the velocity of the air relative to the fan blades. As an actual fact, the fan blades are moving with a rotational velocity, whereas the intake air has relatively little rotational velocity. It is convenient to assume, however, that the blades are stationary and that the air is rotating against the blades.

In the consideration of the relative velocity of the air, it is necessary to distinguish also as to the plane in which that motion is being considered, because the motion is a three-dimensional function, having three components, only two of which can generally be considered at the same time.

In considering the axial progress or movement of the air through the fan, it is convenient to consider a development of a cylindrical surface passing through any point P (Fig. 1) on the leading edge 6 of any fan-blade, in which case two of the three components of the air-velocity may be studied, namely, the axial component V_a which is parallel to the axis, and the tangential velocity V_t due to the rotation of the fan blades. In any pressure-fan, it will be assumed that there will be an inevitable discrepancy between the axial component V_a and the ideal value which would permit the air-stream to impinge edgewise upon the leading edge of the blade, without impinging angularly upon the face of the blade. I assume, therefore, that I am necessarily going to get an axial component V_a of the air-velocity impinging against the face of my blades, because of the necessity of building an air-pressure to drive the air through the air-conditioner or other apparatus in which the fan is utilized. My invention has nothing to do with this axial-velocity component of the air movement. I assume that such axial component is inevitably present, and I seek to minimize its harmful effects, as will now be described.

The other plane in which two of the three components of the air-movement may be studied is a plane at right angles to the axis of the fan, that is, the plane of the projection of the fan-blades, as shown in Fig. 1. In this plane, it will be observed that the impact-velocity V_i of the air against the leading edge of the fan blades will be normal to the projection of that leading edge onto the transverse plane, as indicated by the vector V_i for the point P in Fig. 1. The tangential velocity V_t of the air, corresponding to the rotation of the point P on the fan blade, is, of course, at right angles to the radius r of the point P or the line connecting the point P with the axis. In Fig. 1, I have given the letter A to the angle between the velocity-vectors V_i and V_t, or to the angle between the radius r and the tangent PT to the projected plan form at the point P. It will readily be observed that the impact-velocity V_i is equal to V_t cos A.

The tangential velocity V_t is, of course, equal to $2\pi rN$, where N is the number of revolutions per minute of the fan.

In accordance with my invention, I make the impact-velocity V_i small at all portions of the leading edge, and I make the extreme outer end of the leading-edge curve, at the tip 8, merge smoothly into the circumference corresponding to the outer radius R. The extreme inner end of the curve, at the root of the blade as indicated at 7, is also curved so as to merge smoothly with the circumference of the hub 4, so that sharp corners or angles, where sudden changes in the velocity of air-currents might be produced, are avoided. The same end is served also by the utilization of cast blades which have relatively thick and rounded edges, as distinguished from pressed sheet-metal blades which are thin and have sharp edges.

The impact-velocity V_i is given by

$$V_i = V_t \cos A = 2\pi r N \cos A.$$

If this velocity is to be small at all points of the curve, it necessarily follows that $r \cos A$ must be small, as all the other coefficients are fixed. I have found that the leading edge of the blade should curve backwardly in a curve such that the angle A at each point P shall make $r \cos A$ less than about 0.7 R, and preferably even less than about 0.57 R, for all points along the leading edge.

It is advantageous to have the leading edges of the fan-blades curve backwardly rather than forwardly, because the backward curve can merge smoothly into the outer circumference, without any sharp points or edges, whereas a forward curvature would result in either a sharp edge at the tip of the blade, where it joins the outer circumference, or if this sharp edge were rounded off, there would result a section of the blade at which the leading edge is radial, or $\cos A=1$, at a point close to the outer radius R where the tangential velocity is the greatest, thereby producing considerable noise which is avoided in my invention.

By my arrangement, also, it will be noted that all of the air does not leave the fan-blades along a straight or radial edge, but the trailing edge 9 also curves backwardly, so that air leaves the blades at definitely different points along this rear edge 9. Thus the air leaves each blade from the tip end or narrow end 10. If it may be assumed that at least some of the noise is caused by the number of air-particles leaving the extreme rear ends 10 of the blades, the design of a fan with an extremely narrow rear end 10, and a blunt front end 7, instead of the other way around, as in the case of forwardly curved blades, results in fewer particles of air leaving the rear edge at the outer portion 10 thereof, thus producing less noise.

In order to insure that my fan shall be capable of developing a reasonable air-pressure, it is desirable that the axial depth of the blades, multiplied by the number of blades, shall be more than about 2R. Thus, in the fan which is shown in the drawing and which has a normal speed of about 1700 r.p.m., the diameter of the blades is 7⅛ inches and the axial depth is 2¼ inches. In another embodiment of my invention which was designed for a normal speed of about 1100 r.p.m., the diameter of the blades is 12 inches and the axial depth is 4 inches, the number of blades being four in each case.

In the foregoing description and in the following claims, when I speak of the leading edges of the blades curving backwardly, I mean that at least the outer portions of the leading edges curve backwardly, so that the blade presents its blunt edge or wide end first, at the inner portion of the blade, and enters the air at this blunt edge. It is not essential that this blunt inner portion of the leading edge, that is, the portion nearest the hub, shall have a backward curvature, as the blade-velocity is relatively small there, due to the small radius r at points close to the hub.

While I have illustrated my invention in a preferred form of embodiment and explained the same according to my present theories of its operation, it is to be understood that I am not limited to any particular theory of operation. It will also be obvious that many changes and departures from the exact values which have been given for illustrative purposes may be made by those skilled in the art, while still taking advantage of the features or design-principles which contribute to the quiet operation of propeller pressure-fans, and without departing from the spirit of my invention. I desire, therefore, that the appended claims shall be accorded the broadest construction consistent with their language and the prior art.

I claim as my invention:

1. A propeller fan having blades the leading edges of which curve backwardly in a curve such that the projection of the curve onto a plane at right angles to the axis of the shaft of the fan shall make $r \cos A$ less than about 0.7 R for all points along the leading edge, where r is the radius represented by the distance of any point in said projection from said axis, A is the angle between the projection of said curve and said radius at that point, and R is the maximum radius of the fan blades.

2. A propeller fan having blades the leading edges of which curve backwardly in a curve such that the projection of the curve onto a plane at right angles to the axis of the shaft of the fan shall make $r \cos A$ less than about 0.7 R for all points along the leading edge, where r is the radius represented by the distance of any point in said projection from said axis, A is the angle between the projection of said curve and said radius at that point, and R is the maximum radius of the fan blades, the extreme outer end of the curve bending back more severely so that $r \cos A$ becomes considerably less than 0.7 R and so that the projection merges smoothly into the circumference of the fan.

3. A propeller fan having blades the leading edges of which curve backwardly in a curve such that the projection of the curve onto a plane at right angles to the axis of the shaft of the fan shall make $r \cos A$ less than about 0.57 R for all points along the leading edge, where r is the radius represented by the distance of any point in said projection from said axis, A is the angle between the projection of said curve and said radius at that point, and R is the maximum radius of the fan blades.

4. A propeller fan having blades the leading edges of which curve backwardly in a curve such that the projection of the curve onto a plane at right angles to the axis of the shaft of the fan shall make $r \cos A$ less than about 0.57 R for all points along the leading edge, where r is the radius represented by the distance of any point in said projection from said axis, A is the angle between the projection of said curve and said radius at that point, and R is the maximum radius of the fan blades, the extreme outer end of the curve bending back more severely so that $r \cos A$ becomes considerably less than 0.57 R and so that the projection merges smoothly into the circumference of the fan.

5. A propeller pressure-fan having less than seven blades the leading edges of which curve backwardly, the axial depth of the blades, multiplied by the number of blades, being more than about 2R, and the total projected area of said blades being more than about $2R^2$, where R is the maximum radius of the fan blades.

6. A propeller fan having blades the leading and trailing edges of which curve backwardly, the axial depth of the blades, multiplied by the number of blades, being more than about 2R, and the total projected area of said blades being more than about $2R^2$, where R is the maximum radius of the fan blades.

7. A propeller fan having blades the leading and trailing edges of which curve backwardly, the extreme outer end of the leading edge bending back more severely than the rest of the leading edge so that the projection of this edge onto a

plane at right angles to the shaft of the fan shall merge smoothly into the circumference of the fan, the axial depth of the blades, multiplied by the number of blades, being more than about 2R, and the total projected area of said blades being more than about $2R^2$, where R is the maximum radius of the fan blades.

8. A propeller pressure-fan having less than seven blades the leading edges of which curve backwardly in a curve such that the projection of the curve onto a plane at right angles to the axis of the shaft of the fan shall make $r \cos A$ less than about 0.7R for all points along the leading edge, where r is the radius represented by the distance of any point in said projection from said axis, A is the angle between the projection of said curve and said radius at that point, and R is the maximum radius of the fan blades, the axial depth of the blades, multiplied by the number of blades, being more than about 2R, and the total projected area of said blades being more than about $2R^2$.

9. A propeller pressure-fan having less than seven blades the leading edges of which curve backwardly in a curve such that the projection of the curve onto a plane at right angles to the axis of the shaft of the fan shall make $r \cos A$ less than about 0.7 R for all points along the leading edge, where r is the radius represented by the distance of any point in said projection from said axis, A is the angle between the projection of said curve and said radius at that point, and R is the maximum radius of the fan blades, the extreme outer end of the curve bending back more severely so that $r \cos A$ becomes considerably less than 0.7 R and so that the projection merges smoothly into the circumference of the fan, the axial depth of the blades, multiplied by the number of blades, being more than about 2R, and the total projected area of said blades being more than about $2R^2$.

10. A propeller pressure-fan having less than seven blades the leading edges of which curve backwardly in a curve such that the projection of the curve onto a plane at right angles to the axis of the shaft of the fan shall make $r \cos A$ less than about 0.57 R for all points along the leading edge, where r is the radius represented by the distance of any point in said projection from said axis, A is the angle between the projection of said curve and said radius at that point, and R is the maximum radius of the fan blades, the axial depth of the blades, multiplied by the number of blades, being more than about 2R, and the total projected area of said blades being more than about $2R^2$.

11. A propeller pressure-fan having less than seven blades the leading edges of which curve backwardly in a curve such that the projection of the curve onto a plane at right angles to the axis of the shaft of the fan shall make $r \cos A$ less than about 0.57 R for all points along the leading edge, where r is the radius represented by the distance of any point in said projection from said axis, A is the angle between the projection of said curve and said radius at that point, and R is the maximum radius of the fan blades, the extreme outer end of the curve bending back more severely so that $r \cos A$ becomes considerably less than 0.57 R and so that the projection merges smoothly into the circumference of the fan, the axial depth of the blades, multiplied by the number of blades, being more than about 2R, and the total projected area of said blades being more than about $2R^2$.

12. A propeller pressure-fan having a hub and less than seven integrally joined blades thereon, the total projected area of the blades being nearly as great as the sweep of the fan, the blades having rounded edges, the leading edges curving backwardly, merging substantially smoothly with the circumference of the hub at the roots of the blades, and merging substantially smoothly with the outer circumference of the blades at the tips of the blades, the projected plan form of said leading edges being substantially radial at an intermediate point close to the hub.

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