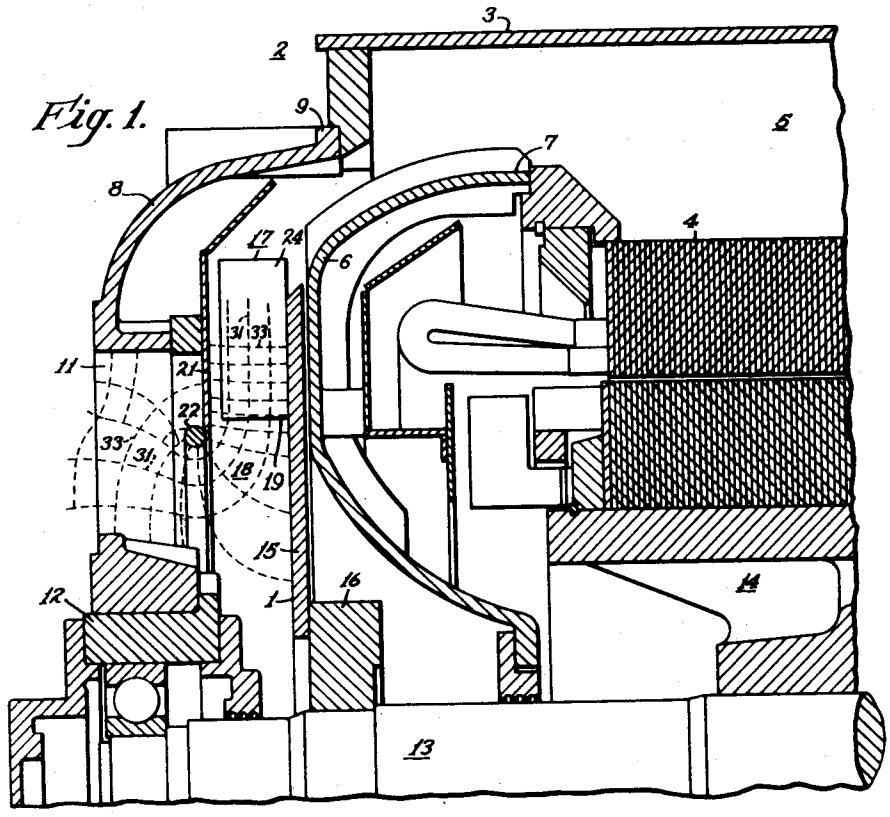
Jan. 4, 1949. L. A. KILGORE 2,458,006

BIDIRECTIONAL BLOWER

Filed Oct. 24, 1946

Fig. 1.



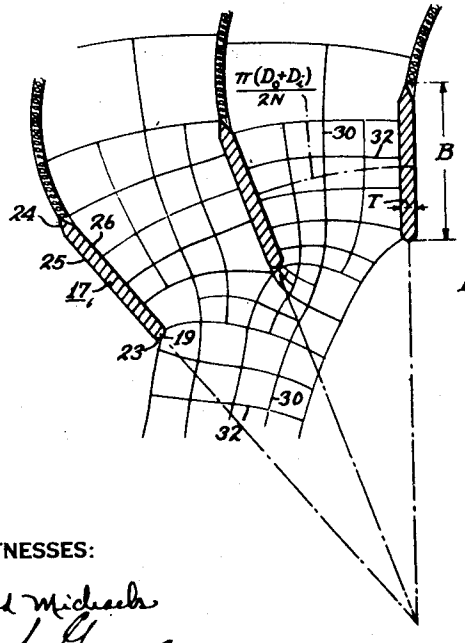


Fig. 2.

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2,458,006

BIDIRECTIONAL BLOWER

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19 Claims. (Cl. 230—134)

1

My invention relates to radial-blade blowers, such as are necessary for direct-mounting on most motors, since most motors have to rotate in either direction.

Heretofore, radial-blade blowers, for the purpose stated, have generally had a maximum efficiency of only about 13%, and they have also had a low output, as shown on curve 5, page 298 of the American Society of Mechanical Engineers Proceedings for 1924, in a paper by C. J. Fechheimer on "Performance of centrifugal fans for electrical machinery."

An object of my present invention is to greatly improve the efficiency, pressure, and volume-output of bidirectional or radial-blade blowers.

A more specifically stated object of my invention is to apply certain principles of aeronautical design, and more particularly, to apply practical criteria which I have discovered, for preventing stalling or separation of the airflow from the surfaces of the blades and the shrouds of bidirectional blowers.

A further object of my invention is to provide a bidirectional blower-means comprising at least 16 radially disposed blades, each having a rounded entrance-edge, at the inner periphery of the blades, and a pointed trailing-edge at the outer periphery of the blades, in combination with an annular outer shroud-means having a rounded entrance-edge.

With the foregoing and other object in view, my invention consists in the parts, elements, combinations, design-constants and systems hereinafter described and claimed, and illustrated in the accompanying drawing, wherein:

Figure 1 is a longitudinal sectional view of the top left quarter of a motor embodying my improved blower; and

Fig. 2 is a diagrammatic cross-sectional view of the blower, with airflow-lines and velocity-pressure lines as subsequently described.

My invention is applicable to any mechanism having a bidirectionally rotatable shaft. By way of example, the invention is illustrated, in Figure 1, as being applied to the construction of an external fan 1 for a fan-cooled motor 2. The motor is illustrated as having a cylindrical stator-frame 3, within which is supported a laminated stator-core 4 which is spaced, for the most part, from the frame 3, so as to provide a plurality of axially extending stator-vents 5 between the outer periphery of the stator-core 4 and the inside of the stator-frame 3. An imperforate bracket or enclosing over 6 is utilized, at each end of the machine, having a peripheral

2

portion 7 in a substantially air-tight relation to the outer portion of the stator-core 4. The stator-member of the machine also includes, at each end of the machine, a perforated bracket or hood 8, having a peripheral portion 9 in a substantially air-tight relation to the end of the frame-ring 3, and having one or more ventilating-openings 11 for the ventilation of the machine. Either one of the brackets 6 or 8 carries a centrally disposed bearing 12 for supporting the shaft 13 of the rotor-member 14 of the motor. The details of the electrical design of the motor are immaterial to my present invention.

The external blower 1 is disposed between the two brackets 6 and 8 at the air-inlet end of the motor, as shown. It comprises a blade-supporting shroud-means 15 which is carried by a hub 16, mounted on the shaft 13 for rotation therewith. Since, in general, the motor is bidirectional, the blower is bidirectional, and it is so designed that it may be placed on a bidirectional motor or other machine. The blade-supporting shroud-means may have any shape or configuration, depending upon the desired airflow direction of the air, as it passes through the blower. In the particular motor illustrated, the airflow conditions are such as to be satisfied by a simple radially disposed disc, for the blade-supporting rotating shroud 15.

The blower 1 has a plurality of radially disposed blades 17, which are supported, at one end, by one side of the blade-supporting shroud 15. These blades 17 are disposed in a ring, with a fluid-entrance space 18 between the inner periphery 19 of the blades and the shaft 13.

The blower-assembly is completed by means of an outer shroud-means, either stationary or rotating, for providing, in effect, an annular shroud 21 which is operatively associated with the outer ends of the blades 17. In the particular motor illustrated, this outer annular shroud 21 is a stationary shroud. It has an inner fluid-entrance bore or opening 22 having a diameter approximating the inner periphery 19 of the blades, and if the inner periphery 19 of the blades is not parallel to the shaft 13, then the shroud entrance-diameter at 22 will approximate the inner blade-diameter at the outer ends of the blades 17, or the portions of the blades which come close to the annular shroud 21.

In accordance with my invention, I have developed design-details for the blades 17, and for the annular shroud 21, designed to prevent stalling or separation of the airflow from the surfaces of the blades or the shroud. The chief features

of the new fan are an airfoil blade-shape or section, and a rounded inlet edge 22 on the annular shroud, and preferred design-limitations for these elements.

The simplest form of airfoil blade-shape is a blade having flat sides, a rounded leading or entrance-edge 23, at the inner periphery 19 of the blades, and a pointed trailing-edge or tail 24, at the outer ends of the blades, as shown in Fig. 2. It will be understood, of course, that the blades 17 may have curved or bulged sides, but since the blower is bidirectional, the blades cannot be flat on one side and bulging on the other, as in a conventional airplane wing-section. Accordingly, the preferred blade-section will generally have two approximately plane, approximately parallel, sides 25 and 26, although I am not limited to this precise detail.

It is necessary for the entrance-edges 23 and 22 of the blades and shroud to have mean effective radii of curvature which are sufficiently large to prevent stalling or separation, and it is necessary for the blades 17 to have a blade-depth, from the entrance-edge 23 to the trailing-edge 24, which is sufficiently large to prevent stalling. Stalling may be defined as the separation of the air-stream from the boundary-surface by more than the normal thin turbulent air-layer which is necessary to separate the moving air-stream from the relatively stationary surface. In terms of aeronautical design, stalling has been defined as occurring when the lift-coefficient has broken away 5% from the straight-line value, when the lift is plotted against the air-speed or the angle of attack.

A test which I have devised for avoiding separation of the airflow from the blades, is that the deceleration dv/dx should not be greater than Kv/x, where v is the velocity of the air-stream at distance x beyond the point of maximum velocity over the surface, and K is a constant which is unity, within plus or minus 20%. I refer, here, to the phenomenon whereby the air which passes over the low-pressure side of the blade first accelerates and then decelerates. It is in the decelerating region where stalling is likely to occur, at any point from the maximum-velocity airflow-point, to the tip of the blade. When stalling occurs, the blade-pressure is reduced, and hence the air-pressure; and the air-volume is greatly reduced, so that the efficiency is affected very adversely. If the blade has not a sufficient length, in the direction of airflow, stalling will be obtained.

Air-pressures and air-velocity are best studied by the plotting of airflow-lines 30, 31, and velocity-potential lines 32, 33. The airflow-lines 30, 31 may be defined as stream-lines representing the path of the air, or more specifically, equal tubes of flow, representing equal masses of airflow through the several tubes, between adjacent airflow lines. The velocity-potential lines 32, 33 may be defined as air-front lines representing equal velocity-potentials of the air, defining the velocity-potentials such that the reciprocal of the length, or distance between successive velocity-potential lines, shall represent the air-velocity. The velocity-potential lines are orthogonal, or at right angles, to the flow-lines, representing air-fronts or cross-sections of the flow.

The plotting of the flow-lines 30, 31 and the velocity-potential lines 32, 33 is a matter requiring extreme care, and painstaking work, requiring several hours' time, by a person who has familiarized himself with such work; and even with extreme care, a 5% accuracy is a reasonably expectable accuracy. A suitable scale is chosen, at some reference-point where the airflow is uniform, and squares are drawn, at this point, representing the airflow-lines and the velocity-potential lines. At the points where air-disturbances occur, or where boundary surfaces are to be followed, these lines must be carefully studied and plotted, using subdivisions of the squares wherever necessary, and realizing that, if the subdivisions are sufficiently small, orthogonal lines will always be obtained, and the ratio of the length to the width of any rectangle will represent the relative air-density at that point, as compared to the air-density at the reference-point where the rectangles are squares. In plotting these lines, it is important to make sure that the crossing-points of all lines are exactly at right angles to each other, and the plotted lines must be shifted and rearranged until such a result is obtained.

As a result of studies by the methods hereinbefore outlined, checked with tests, I have arrived at certain practical criteria, representing designs which satisfy, or approach reasonably closely to, the best blower-operation in accordance with my invention.

The depth of each blade 17, at substantially all airflow-lines 30, should be more than approximately nineteen-twentieths of the mean pitch of the blades, that is, the pitch at the mean diameter of the blades at that airflow-line. This is believed to be the best design, or the design which is safest, from the standpoint of the design-engineer who is confronted with the problem of designing a good blower. Fair results may possibly be obtained, however, in which the blade-depth is approximately four-fifths of the mean pitch, or any depth greater than this limit. The pitch may be either the circular pitch or the chord-pitch, the two being substantially identical, for within the accuracy-tolerances of the design, in laying out any blower-design in accordance with my invention. In Fig. 2, the mean pitch is shown at

$$\frac{\pi(D_0+D_i)}{2N}$$

where D_0 and D_i are the outer and inner peripheral diameters of the blades, and N is the number of blades; while the blade-depth is shown at B, being equal to

$$\frac{D_0-D_i}{2}$$

The formula stating that the blade-depth B should be greater than a certain constant, K, times the average pitch may be written.

$$B>\frac{K\pi(D_0+D_i)}{2N} \qquad (1)$$

But since

$$B=\frac{D_0-D_i}{2}$$

$$D_0=D_i+2B, \text{ and } (D_0+D_i)=2(D_i+B)$$

$$B>\frac{K\pi(D_i+B)}{N} \qquad (2)$$

$$N>(1+D_i/B) \qquad (3)$$

which is another way of saying that the minimum blade-number N is dependent upon the ratio B/D_i of the blade-depth to the inner diameter of the blades, which depends upon whether the blades are close in towards the shaft,

in a small-blower design, or far out, as in a larger blower.

There is also a practical minimum limit on the possible number of blades N, because this number affects the angle between successive blades, and if this angle is too large, stalling will occur. My invention has been successfully applied, in various designs having 16, 18, and 24 blades, respectively, and, in fact, there is no theoretical limit as to the maximum number of blades, up to the point where the blade-number is raised so high that there is practically no room for air to flow between them. As blades cost money, no designer would choose a blade-number which would be so unreasonably high. Within practical limits, therefore, the blade-number can be considerably larger than in the blowers which I have already tested. I consider that my invention is mainly applicable, in general, only to blowers having 16 blades, or more.

The thickness T of each blade 17, or if the blade does not have uniform thickness, the thickness T of each blade at a point near its entrance-edge 23, should be more than approximately one-twelfth of the pitch near the entrance-edges of the blades, which may be represented by the pitch

$$\frac{\pi(D_i+T)}{N}$$

This determines the average effective radius of curvature at the rounded entrance-edge 23. The figure just given represents the preferred blade-thickness T, and the ratio 12 may be decreased to such values as 8.4 and 6.5, or even smaller values, without approaching a value which will unduly throttle the air, or become impractical mechanically. This preferred lower limit of blade-thickness, which is expressed as one-twelfth of the pitch near the entrance-edge, could be reduced to one-sixteenth of the pitch near the entrance-edge, with a fair approximation to my preferred design-conditions, in some cases.

The mean effective radius of curvature of the rounded entrance-edge 22 of the annular shroud 21 should be greater than approximately one-twelfth of the effective width of the blower, that is, the axial distance, or the air-front distance, between the two shrouds 21 and 15 at the inner periphery 19 of the blades 17. This minimum radius of curvature of the shroud entrance-edge 22 is needed, in order to prevent separation as a result of the air-velocity of the air which enters the entrance-space 18 underneath the blower. While the ratio, one-twelfth, represents the preferred minimum mean effective curvature-radius for the annular shroud 21, this ratio could be reduced to one-sixteenth, with a fair approximation to the preferred design-constants of my blower.

There is one other design-feature which is on the preferred list of my design-requirements, although it is not obligatory, and small departures from it seem to be largely immaterial. This requirement is the requirement that substantially all parts of the entrance- and trailing-edges of the blades shall approximate a right-angular relation to the airflow-lines 31 at the respective points. This approximation need not, by any means, be accurate; as a small angle of difference between the entrance- or trailing-edge and the corresponding velocity-potential line 33, at that point, will be largely immaterial. It is theoretically desirable, however, for the entrance- and exit-edges of the fan-blades 17 to approximately conform to the air-fronts at these points, so that the parallel tubes of airflow, through the blower, will all be operated upon at the same time, by the blades. This approximation is to be taken with a wide margin of tolerance, however.

The foregoing discussion has had more particular reference to blowers in which the air-velocity does not exceed the velocity of sound, which is the usually understood design-limit of blowers, at the present day.

The practical effect of my invention will be appreciated by comparison with the best previously known form of radial-blade blowers, which, for a long time, have had a performance which has remained substantially stationary at the figures shown in the above-mentioned Fechheimer paper. As compared with a previous maximum efficiency of about 13%, my new fan has a 40% efficiency, or better. It develops about twice the air-pressure, and it delivers about 40% more volume, than the generally used, previously known, form of radial-blade blower. My new radial-blade fan or blower is even better than the inclined-blade fans and the curved-blade fans which are shown in the Fechheimer paper, and which were good for operation in only one direction of rotation.

While I have described my invention in a single illustrative form of embodiment, and while I have explained its principles in accordance with my best present understanding, I wish it to be understood that my invention is of fairly general application. I desire, therefore, that the appended claims shall be accorded the broadest construction consistent with their language.

I claim as my invention:

1. A bidirectional blower-means, comprising the combination, with a bidirectionally rotatable shaft, of a blade-supporting shroud-means for providing, in effect, a running shroud carried by the shaft; at least sixteen radially disposed blades, supported, at one end, by one side of said blade-supporting shroud-means, with a fluid-entrance space between the inner periphery of the blades and the shaft; and an outer shroud-means for providing, in effect, an annular shroud operatively associated with the outer ends of the blades, said annular shroud having an inner peripheral fluid-entrance diameter approximating the inner periphery of the blades at the outer ends of the blades; each blade having two approximately plane, approximately parallel, sides; each blade also having a rounded entrance-edge at the inner periphery of the blades, and a pointed trailing-edge at the outer periphery of the blades, substantially all parts of the entrance- and trailing-edges of the blades approximating a right-angular relation to the airflow-lines at the respective points.

2. The invention as defined in claim 1, characterized by such a number of blades, and such a depth of blade between the inner and outer peripheries of the blades, that the depth of each blade, at substantially all fluid-flow lines, is more than approximately four-fifths of the pitch at the mean diameter of the blades at that fluid-flow line.

3. The invention as defined in claim 1, characterized by the thickness of each blade at a point near its entrance-edge being more than approximately one-sixteenth of the pitch near the entrance-edges of the blades.

4. The invention as defined in claim 1, characterized by such a number of blades, and such a depth of blade between the inner and outer

peripheries of the blades, that the depth of each blade, at substantially all fluid-flow lines, is more than approximately four-fifths of the pitch at the mean diameter of the blades at that fluid-flow line, and the thickness of each blade at a point near its entrance-edge being more than approximately one-sixteenth of the pitch near the entrance-edges of the blades.

5. The invention as defined in claim 1, characterized by the annular shroud having a rounded entrance-edge.

6. The invention as defined in claim 1, characterized by such a number of blades, and such a depth of blade between the inner and outer peripheries of the blades, that the depth of each blade, at substantially all fluid-flow lines, is more than approximately four-fifths of the pitch at the mean diameter of the blades at that fluid-flow line, and the annular shroud having a rounded entrance-edge.

7. The invention as defined in claim 1, characterized by the thickness of each blade at a point near its entrance-edge being more than approximately one-sixteenth of the pitch near the entrance-edges of the blades, and the annular shroud having a rounded entrance-edge.

8. The invention as defined in claim 1, characterized by such a number of blades, and such a depth of blade between the inner and outer peripheries of the blades, that the depth of each blade, at substantially all fluid-flow lines, is more than approximately four-fifths of the pitch at the mean diameter of the blades at that fluid-flow line, the thickness of each blade at a point near its entrance-edge being more than approximately one-sixteenth of the pitch near the entrance-edges of the blades, and the annular shroud having a rounded entrance-edge.

9. The invention as defined in claim 1, characterized by the annular shroud having a rounded entrance-edge having a mean effective radius of curvature greater than approximately one-sixteenth of the effective width of the blower, between the two shrouds at the inner periphery of the blades.

10. The invention as defined in claim 1, characterized by such a number of blades, and such a depth of blade between the inner and outer peripheries of the blades, that the depth of each blade, at substantially all fluid-flow lines, is more than approximately four-fifths of the pitch at the mean diameter of the blades at that fluid-flow line, and the annular shroud having a rounded entrance-edge having a mean effective radius of curvature greater than approximately one-sixteenth of the effective width of the blower, between the two shrouds at the inner periphery of the blades.

11. The invention as defined in claim 1, characterized by the thickness of each blade at a point near its entrance-edge being more than approximately one-sixteenth of the pitch near the entrance-edges of the blades, and the annular shroud having a rounded entrance-edge having a mean effective radius of curvature greater than approximately one-sixteenth of the effective width of the blower, between the two shrouds at the inner periphery of the blades.

12. The invention as defined in claim 1, characterized by such a number of blades, and such a depth of blade between the inner and outer peripheries of the blades, that the depth of each blade, at substantially all fluid-flow lines, is more than approximately four-fifths of the pitch at the

mean diameter of the blades at that fluid-flow line, the thickness of each blade at a point near its entrance-edge being more than approximately one-sixteenth of the pitch near the entrance-edges of the blades, and the annular shroud having a rounded entrance-edge having a mean effective radius of curvature greater than approximately one-sixteenth of the effective width of the blower, between the two shrouds at the inner periphery of the blades.

13. The invention as defined in claim 1, characterized by such a number of blades, and such a depth of blade between the inner and outer peripheries of the blades, that the depth of each blade, at substantially all fluid-flow lines, is more than approximately nineteen-twentieths of the pitch at the mean diameter of the blades at that fluid-flow line.

14. The invention as defined in claim 1, characterized by the thickness of each blade at a point near its entrance-edge being more than approximately one-twelfth of the pitch near the entrance-edges of the blades.

15. The invention as defined in claim 1, characterized by such a number of blades, and such a depth of blade between the inner and outer peripheries of the blades, that the depth of each blade, at substantially all fluid-flow lines, is more than approximately nineteen-twentieths of the pitch at the mean diameter of the blades at that fluid-flow line, and the thickness of each blade at a point near its entrance-edge being more than approximately one-twelfth of the pitch near the entrance-edges of the blades.

16. The invention as defined in claim 1, characterized by the annular shroud having a rounded entrance-edge having a mean effective radius of curvature greater than approximately one-twelfth of the effective width of the blower, between the two shrouds at the inner periphery of the blades.

17. The invention as defined in claim 1, characterized by such a number of blades, and such a depth of blade between the inner and outer peripheries of the blades, that the depth of each blade, at substantially all fluid-flow lines, is more than approximately nineteen-twentieths of the pitch at the mean diameter of the blades at that fluid-flow line, and the annular shroud having a rounded entrance-edge having a mean effective radius of curvature greater than approximately one-twelfth of the effective width of the blower, between the two shrouds at the inner periphery of the blades.

18. The invention as defined in claim 1, characterized by the thickness of each blade at a point near its entrance-edge being more than approximately one-twelfth of the pitch near the entrance-edges of the blades, and the annular shroud having a rounded entrance-edge having a mean effective radius of curvature greater than approximately one-twelfth of the effective width of the blower, between the two shrouds at the inner periphery of the blades.

19. The invention as defined in claim 1, characterized by such a number of blades, and such a depth of blade between the inner and outer peripheries of the blades, that the depth of each blade, at substantially all fluid-flow lines, is more than approximately nineteen-twentieths of the pitch at the mean diameter of the blades at that fluid-flow line, the thickness of each blade at a point near its entrance-edge being more than approximately one-twelfth of the pitch near the entrance-edges of the blades, and the annular

shroud having a rounded entrance-edge having a mean effective radius of curvature greater than approximately one-twelfth of the effective width of the blower, between the two shrouds at the inner periphery of the blades.

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