May 26, 1931. C. J. FECHHEIMER 1,807,397

PROPELLER TYPE PUMP OR FAN

Filed May 20, 1927 3 Sheets-Sheet 1

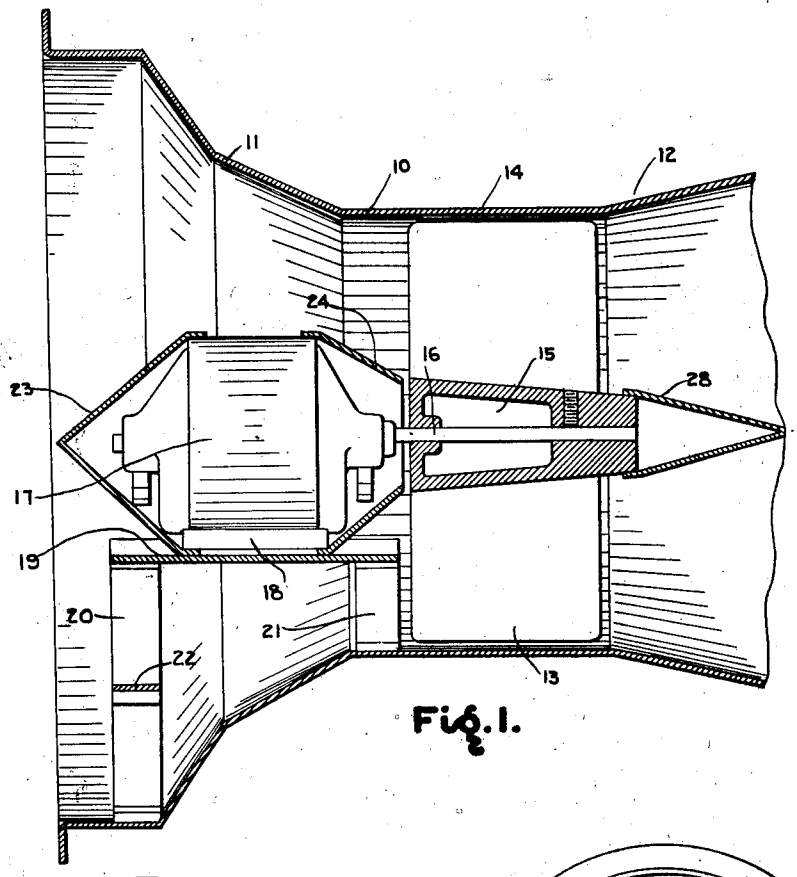

Fig. 1.

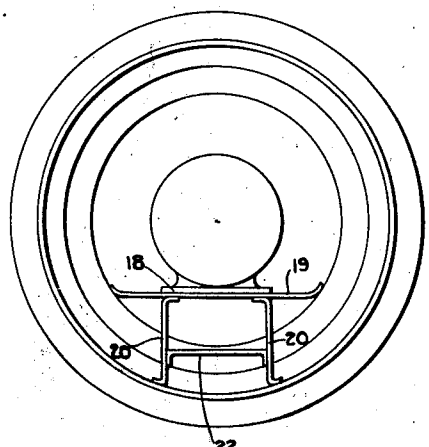

Fig. 2.

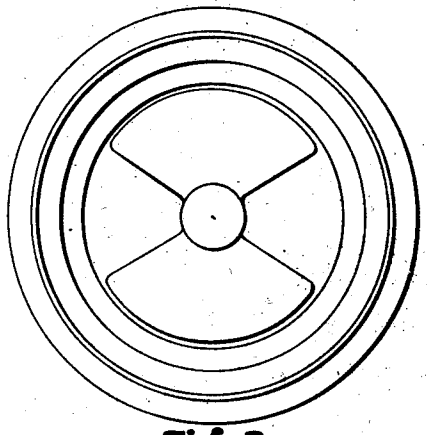

Fig. 3.

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PROPELLER TYPE PUMP OR FAN

Filed May 20, 1927 3 Sheets-Sheet 2

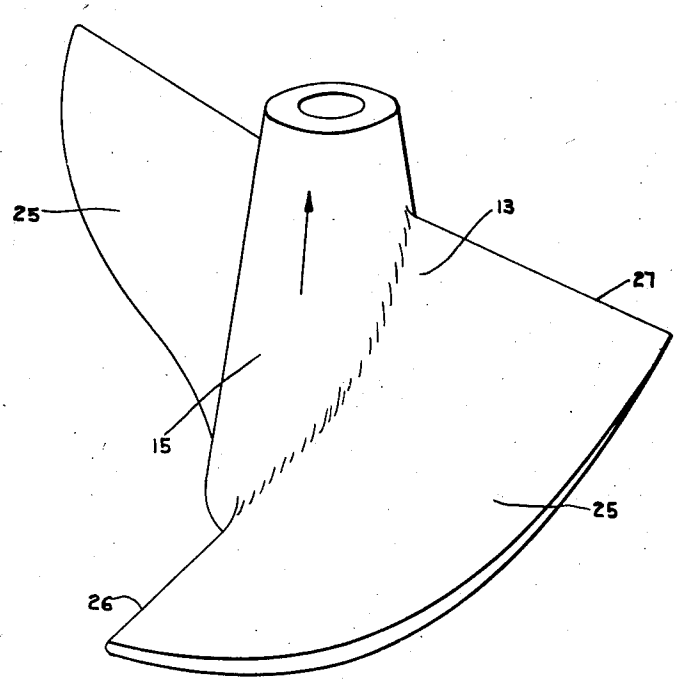

Fig. 4.

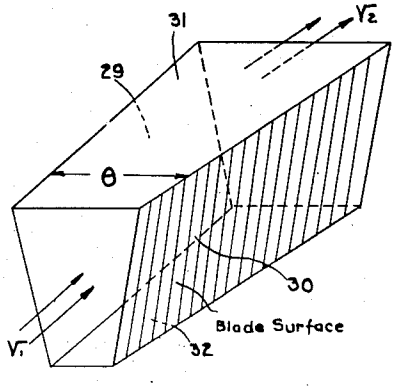

Fig. 9.

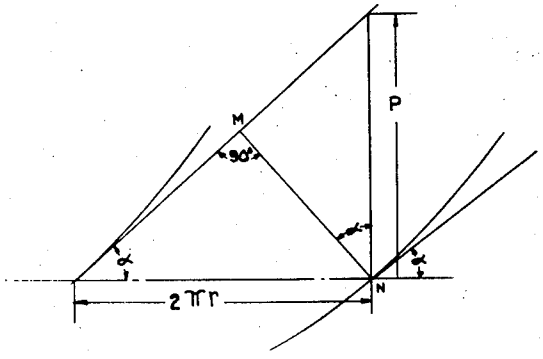

Fig. 7.

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PROPELLER TYPE PUMP OR FAN

Filed May 20, 1927 3 Sheets-Sheet 3

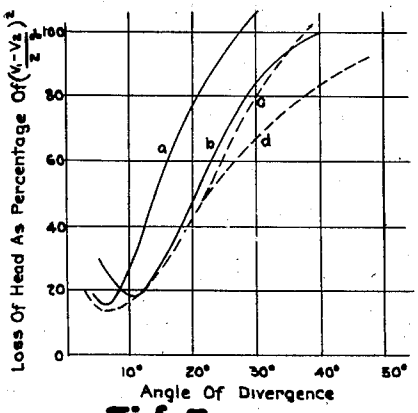


Fig.5.

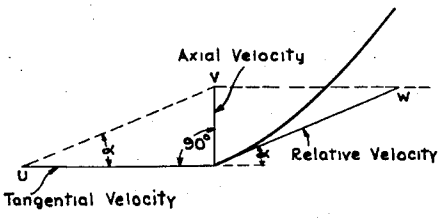


Fig.10.

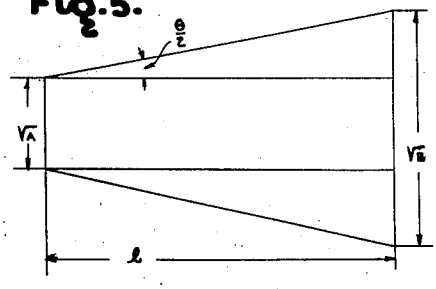


Fig.12

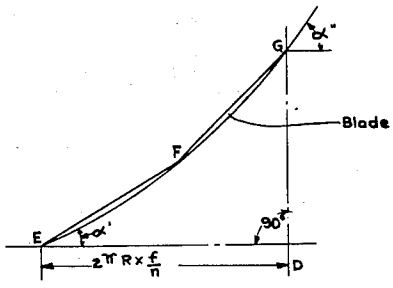


Fig.11.

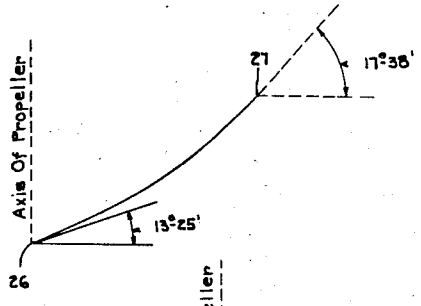


Fig.6.

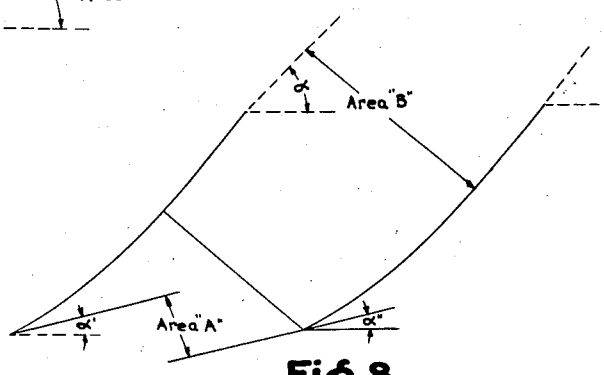
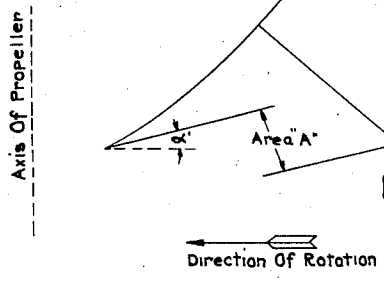


Fig.8.



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Patented May 26, 1931

1,807,397

UNITED STATES PATENT OFFICE

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PROPELLER TYPE PUMP OR FAN

Application filed May 20, 1927. Serial No. 192,967.

This application is a continuation in part of subject matter divided from my abandoned application, Serial No. 128,680, filed August 11, 1926, for propeller type pump or fan.

My invention relates to pumps of the propeller type and it has for an object to provide a pump of this type which shall be simple in construction and efficient in operation.

My invention relates to that type of propeller pump wherein velocity pressure conversion takes place both in the passages between blades as well as in the duct immediately following the propeller. I find that the efficiency of a propeller pump may be greatly improved if the passages between the blades, as well as the diffuser passage, are properly designed. I have, therefore, provided a pump of this character wherein these passages are designed in accordance with well-established hydraulic determinations pertaining to the optimum degree of divergence of ducts or passages for minimum loss in head.

These and other objects, which will be made more clear throughout the description of my invention, are attained by means of a pump employing the features herein described and illustrated in the accompanying drawings, forming a part of this application, in which: Fig. 1 is a somewhat diagrammatic longitudinal, sectional view of a propeller pump of my improved type; Fig. 2 is an inlet end elevational view of the apparatus shown in Fig. 1; Fig. 3 is an exit end elevational view of the apparatus shown in Fig. 1; Fig. 4 is a perspective view of the propeller; Fig. 5 is a diagrammatic view illustrative of principles employed in my improved pump; Figs. 6 and 7 are diagrammatic views illustrating certain principles involved in the construction of the propeller; Figs. 8 and 9 are diagrammatic views illustrating the feature of divergence; Fig. 10 shows a vector analysis of velocities; Fig. 11 is a diagrammatic view showing the method of determining the equivalent angle of divergence; and Fig. 12 is a diagrammatic view showing the method of determining the angle of divergence.

Referring now to the drawings more in detail, in Fig. 1, I show a duct or casing 10 having a converging portion 11 and a diverging portion 12. A propeller 13 is arranged within and coaxially of the duct or casing 10 and is disposed for rotation within the portion 14 of the latter, the propeller 13 having its hub 15 secured in any suitable manner to a shaft 16 connected to a motor 17 of any suitable type, preferably an electric motor.

The motor 17 is preferably arranged within the converging portion 11 of the duct or casing construction. The motor is supported in any suitable manner, for example, I show such a motor disposed on a bedplate or member 18 supported by cross members 19, the latter member being reinforced by vertical struts 20 and 21, the strut 20 being disposed in a part of the converging portion 11 of larger diameter and preferably being braced by a horizontal cross member 22.

In order to minimize shock and eddying of fluid passing through the converging portion 11, I preferably provide the motor 17 with fairing members 23 and 24.

Referring to Fig. 4, it will be noted that the propeller 13 is provided with two blades 25 and that the hub 15 converges from the inlet to the exit side thereof, the inlet or leading edge of the blades being indicated at 26 and the exit or trailing edge of the blades being indicated at 27. While I have shown a fan having only two blades, nevertheless it is apparent that any number of blades may be provided. Due to the design of the blades 25 and of the hub 15, passages are provided between the blades which have the proper degree of divergence of a proper rate of increase in cross sectional area normal to the direction

of flow, to provide for the passage of fluid with conversion of velocity into pressure with a minimum loss in head. The immediately following diverging portion 12 of the casing or housing 10 is also designed to give the proper degree of divergence, the fairing cone 28 carried by the propeller hub cooperating with the diverging portion 12 to accomplish this result.

Referring to Fig. 6, it will be noted that the leading edges 26 of the blades define a relatively small angle with respect to the plane of rotation of the leading edges, whereas the exit or trailing edges 27 define a larger angle with respect to the plane of rotation passing therethrough. Upon referring to Fig. 7, it will be noted that the angle of the leading or inlet edge 26 provides for an absolute or space velocity of a particle substantially in an axial direction, thereby substantially avoiding shock losses, and that, due to the increasing axial pitch of the blade from the leading to the trailing edges, the absolute particle velocity is increased and the relative velocity decreased and a building up of pressure takes place as fluid flows along the passage between blades. In other words, as a particle of fluid passes between the blades of the propeller, its velocity relative to a stationary part of the pump increases while its velocity relative to the propeller blades decreases.

Referring to the principle of divergence involved in the design of passages in my pump, attention is called to the fact that experiments have been conducted in the past with stationary ducts or passages having varying angles of divergence, for the purpose of determining losses in head. Such ducts have had various cross-sectional shapes, for example, square, circular and rectangular. Fig. 5 has been prepared from authoritative experimental data of this character, the curves shown in this view being taken from Gibson's Hydraulics and its Applications (1920), pages 85 and 86. In these curves, the loss as given is a percentage of

$$\frac{(V_1 - V_2)^2}{2_g}$$

where V_1 and V_2 are respectively the velocities at entrance to and discharge from the duct. Four curves are shown, *a* for ducts of square section, in which the exit area is four times the entrance area; *b* for ducts of rectangular cross section, in which two sides are parallel and the other two sides diverged by the angle indicated, the exit area being four times the entrance area; *c* for ducts of circular area; and *d* for ducts of circular section in which the exit area is nine times the entrance area. It should be noted that curves *c* and *d* coincide over a part of their length. It appears that for circular and square ducts, the loss is a minimum when the angle between opposite divergent sides is from about 5.5 to 7 deg. The angle for minimum loss for rectangular ducts with two sides parallel is about 10.5 deg. to 11.5 deg.

The reason why the rectangular ducts have a different optimum angle from square to circular ducts is that in one case the ducts diverge in one direction only while in the other they diverge in both directions. The reason why the loss increases for angles smaller than the optimum is that the duct becomes so long that the friction loss becomes a matter of consequence.

In Fig. 9, I show the solid outline of a diverging channel or passage between blades. In this view, the sides 29 and 30 correspond to opposing surfaces of the pair of blades and the top and bottom sides 31 and 32 correspond to the arcuate surfaces defined by the blade tips and by the hub 15. From this view, as well as from Fig. 4, it will be noted that each passage between blades diverges transversely. While no data are available for a duct having the general shape disclosed in these views, nevertheless, if the square roots of the areas of sections normal to the direction of flow at the entrance and at the exit be taken, the results are the sides of equivalent squares; and on that basis, the equivalent angle of divergence may be easily computed. While, in any particular case, the exact extent of divergence to secure efficient conversion of velocity to static head is a matter of computation or experiment depending upon the particular shape of diverging passage, nevertheless, from authoritative published data, this optimum range of divergence will be found to be contained between the limits of 5.5 and 8 deg.

The necessary divergence of the passages between blades may be secured (1) by a suitable increase in axial pitch from the leading to the trailing edges of the blades, (2) by diminishing the thickness of the blades from the leading to the trailing edges, or (3) by having a converging propeller hub which converges toward the exit side, or by a combination of these features of design.

Referring to Fig. 8, the manner of increasing the axial pitch from the leading to the trailing edge of a blade is such that the areas normal to the direction of flow provide for the proper degree of divergence in the passageways. In this view, the area A indicates the normal inlet area while the area B indicates the normal exit area. It will be apparent from this view, that the propeller blades may be made of uniform thickness from edge to edge and the axial pitch increased in such a way that the passages between blades will have the correct degree of divergence.

In Figs. 1 and 4, the propeller is shown with a hub 15 which converges towards the

exit side and with blades 25 which diminish in thickness from the leading edges 26 to the trailing edges 27. Aside from the mode of increasing the axial pitch so as to provide for the proper amount of divergence, it will be apparent that the features of convergence of the hub and of thinning of the blades toward the trailing edges are capable in themselves of contributing to produce the proper degree of divergence.

The duct passage immediately following the propeller and bounded by the diverging portion 12 also incorporates this principle of design of optimum extent of divergence in order to secure conversion of static head with a minimum of loss. Stationary guide vanes may also be employed in order to increase the efficiency.

From the foregoing, it will be apparent that I have provided a pump of the propeller type which operates with a high degree of efficiency due to the fact that the passages between the blades thereof as well as the passage in the casing immediately following the propeller are designed in accordance with well-established hydraulic principles, that is, they are so designed as to incorporate the principle of optimum of divergence for the purpose of minimizing loss of head while converting velocity into static head.

In order that my invention may be readily practised by one skilled in this art, I have derived the following equations which are useful in designing and constructing a pump or fan according to my invention:

A. The space velocity and volume before entrance

If in Fig. 10, the parallelogram of velocities is applied at entrance, and "u" is the tangential velocity ($=2\pi RN$), "v" is the space velocity just before entrance in quadrature with "u", and "w" is the velocity relative to the blades, "α" being the blade angle at entrance, then: $v=u\tan\alpha$. But, by definition,

$$\tan\alpha=\frac{P'}{2\pi r}$$

where "P'" is the inlet pitch and "r" is any radius. Substituting for tan α and for $u=2\pi rN$, where N is the revolutions per unit time.

$$v=P'N \quad (1)$$

Thus, since P' is uniform from the hub to the outside radius, v is uniform throughout the projected disc area.

Again, assuming that the parallelogram of velocities is applicable at entrance, the volume per unit of time is the velocity times the area=

$$Q=P'N\pi(R_2^2-R_1^2) \quad (2)$$

Here R_2 and R_1 are the external and hub radii, respectively.

B. The area between blades normal to the direction of flow

In the following, the thickness of the blade is neglected.

α=blade angle at any radius r, and at any position axially.

As indicated in Fig. 7, the two blades are the same, the circumferential distance between them being given as $2\pi r$. Actually, there may be one or more blades of like form interposed.

It will readily be seen that the area normal to the flow at the position shown is

$$\int_{r=R_1}^{r=R_2} MN\,dr,$$

where R_1 and R_2 are the hub and external radii, respectively. Evidently, $MN=2\pi r\sin\alpha$.

From definition,

$$\tan\alpha=\frac{P}{2\pi r},$$

where "P" is the pitch at the particular axial position.

$$\text{Now } \sin\alpha=\sqrt{1-\cos^2\alpha}=\sqrt{1-\frac{1}{\sec^2\alpha}}=$$

$$\sqrt{1-\frac{1}{1+\tan^2\alpha}}=\frac{\tan\alpha}{\sqrt{1+\tan^2\alpha}}=\frac{\frac{P}{2\pi r}}{\sqrt{1+\left(\frac{P}{2\pi r}\right)^2}}$$

$$=\frac{P}{\sqrt{P^2+(2\pi r)^2}}$$

$$\text{Then area}=\int_{R_1}^{R_2}\frac{2\pi r\,P\,dr}{\sqrt{P^2+(2\pi r)^2}}=$$

$$\frac{P}{2\pi}\left[\sqrt{P^2+(2\pi R_2)^2}-\sqrt{P^2+(2\pi R_1)^2}\right] \quad (3)$$

Equation 3 may also be written:

$$\text{Area}=P\left[\sqrt{\left(\frac{P}{2\pi}\right)^2+R_2^2}-\sqrt{\left(\frac{P}{2\pi}\right)^2+R_1^2}\right] \quad (3a)$$

$$\text{Or area}=P\left[R_2\sqrt{\left(\frac{P}{2\pi r_2}\right)^2+1}-R_1\sqrt{\left(\frac{P}{2\pi R_1}\right)^2+1}\right]$$

$$=P\left[R_2\sqrt{\tan^2\alpha''+1}-R_1\sqrt{\tan^2\alpha'+1}\right]$$

$$=P\left[R_2\sec\alpha''-R_1\sec\alpha'\right] \quad (4)$$

Now α'' and α' are the blade angles at the external and internal radii, respectively.

C. The velocities between blades and volumes computed therefrom

From Fig. 10, $w = \sqrt{u^2+v^2}$

Substituting for $u=2\pi rN$ and for $v=P'N$.

$$w=N\sqrt{(P')^2+(2\pi r)^2} \quad (5)$$

Let A=area.

Evidently, the volume$=Q=\int_{R_1}^{R_2} wd\,A$

From the previous derivation,

$$dA=\frac{2\pi r\,P'dr}{\sqrt{(P')^2+(2\pi r)^2}}$$

Then $Q=$

$$\int_{R_1}^{R_2} N\sqrt{(P')^2+(2\pi r)^2}\cdot\frac{2\pi r\,P'dr}{\sqrt{(P')^2+(2\pi r)^2}}=$$

$$NP'\int_{R_1}^{R_2}2\pi r dr$$

$$Q=P'N\pi(R_2^2-R_1^2) \quad (6)$$

It will be seen that Equations (2) and (6) are identical, although arrived at in different ways.

Divergence between blades

In order to compute the equivalent angle of divergence, the areas normal to the flow between blades at discharge and at entrance are, for simplicity, considered as squares, and, having the square roots of their areas, the sides of the equivalent squares are found. The rate of divergence is also dependent upon the length of the path, and again, to simplify calculations, the length is taken at the mean radius.

Referring to Fig. 11, α' and α'' are respectively, the blade angles at mean radius at entrance and discharge. For simplicity, the length of the arc of the blade is regarded as the sum of the two chords $(EF+FG)$. The circumference at means radius R is 2πR, and the projected length of one blade on that circumference is

$$\frac{f}{n}\times 2\pi R,$$

where "f" is the projected area ratio, and "n" is the number of blades. Then, if the blade were a continuous straight line, $EF+EF$ produced until it intersects GD) its length would be

$$\frac{2\pi Rf}{n}\sec\alpha'.$$

If it were $GF+GF$ produced to ED, its length would be

$$\frac{2\pi Rf}{n}\sec\alpha''.$$

The mean radius R is

$$\frac{R_2+R_1}{2}.$$

So that the mean is

$$l=2\pi\left(\frac{R_2+R_1}{2}\right)\frac{f}{n}\,\frac{\sec\alpha'+\sec\alpha''}{2} \quad (7)$$

This may also be written:

$$l=\pi\,\frac{(R_2+R_1)}{2}\,\frac{f}{n}\left[\sqrt{1+\tan^2\alpha'}+\sqrt{1+\tan^2\alpha''}\right] \quad (8)$$

Where $\tan\alpha'=\frac{P'}{\pi(R_2+R_1)}$ and $\tan\alpha''=\frac{P''}{\pi(R_2+R_1)}$

Referring to Fig. 12, it will be seen that, if "B" is the area normal to the blades at discharge, and "A" at entrance, the equivalent half angle of divergence is

$$\frac{\theta}{2}=\tan^{-1}\left(\frac{\sqrt{B}-\sqrt{A}}{2l}\right) \quad (9)$$

Usually, the error introduced by taking the angle in radians equal to the tangent is negligible. Then,

$$\frac{\theta}{2}=\left(\frac{\sqrt{B}-\sqrt{A}}{2l}\right)\text{ radians or}$$

$$\theta=\frac{\sqrt{B}-\sqrt{A}}{l}\times 57.3\text{ degrees} \quad (10)$$

While I have shown my invention in but one form, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various changes and modifications, without departing from the spirit thereof, and I desire, therefore that only such limitations shall be placed thereupon as are imposed by the prior art or as are specifically set forth in the appended claims.

What I claim is:—

1. A propeller type pump or fan comprising a casing and a bladed propeller having a hub tapered in the direction of flow and mounted within the casing, the blades of the propeller having an increasing axial pitch from their leading to their trailing edges, said blades being also relatively thickened toward their leading edges, whereby the passages between the casing and the hub and the respective blades are divergent in the direction of flow, the angle of divergence of said passages being between 5.5 degrees and 8.0 degrees for efficient conversion of velocity into static head in ducts of similar section.

2. A propeller type pump or fan comprising a casing and a bladed propeller mounted within the casing, the blades of the propeller having an increasing axial pitch from their leading toward their trailing edges, said blades being also relatively thickened to-

ward their leading edges, whereby the passages between the casing and the hub and the respective blades are divergent in the direction of flow, the angle of divergence of said passages being between 5.5 degrees and 8 degrees for efficient conversion of velocity into static head in ducts of similar section.

3. A propeller type pump or fan comprising a casing and a bladed propeller mounted within the casing, the blades of the propeller having such increasing axial pitch from their leading to their trailing edges as to provide passages intervening between the blades which diverge in the direction of flow, the angle of divergence of said passages being between 5.5 degrees and 8 degrees so as to effect efficient conversion of velocity energy into energy in the form of increased static pressure.

In testimony whereof, I have hereunto subscribed my name this 5th day of May, 1927.

CARL J. FECHHEIMER.