July 27, 1965 J. SALLOU 3,197,124

CENTRIFUGAL PUMP IMPELLERS

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FIG. 1.

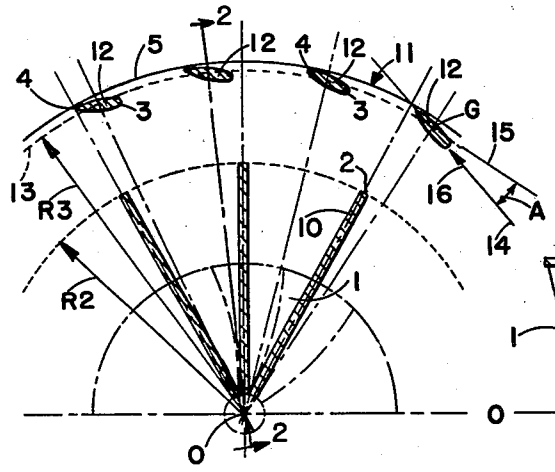


FIG. 2.

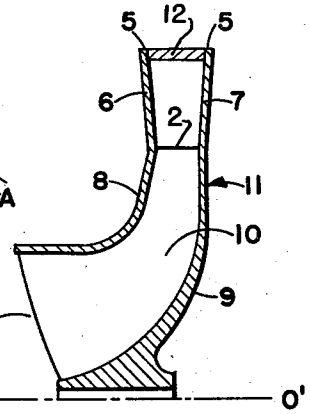


FIG. 3.

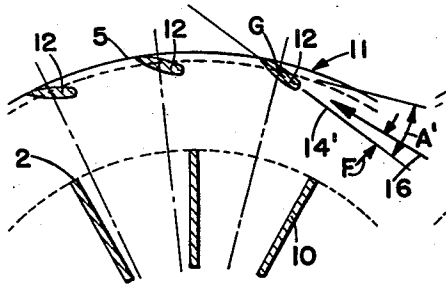


FIG. 4.

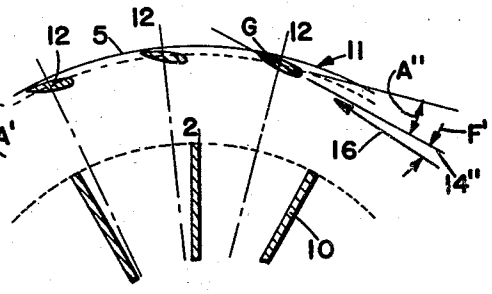
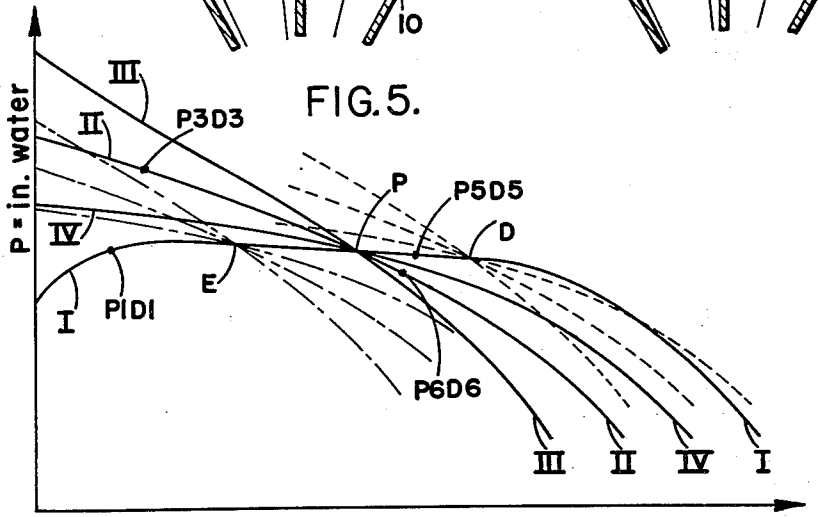


FIG. 5.



I---- N x L = 0
II---- N x L = K
III---- N x L > K
IV---- N x L < K

$\frac{ft^3}{min}$ – free air

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FIG. 6.

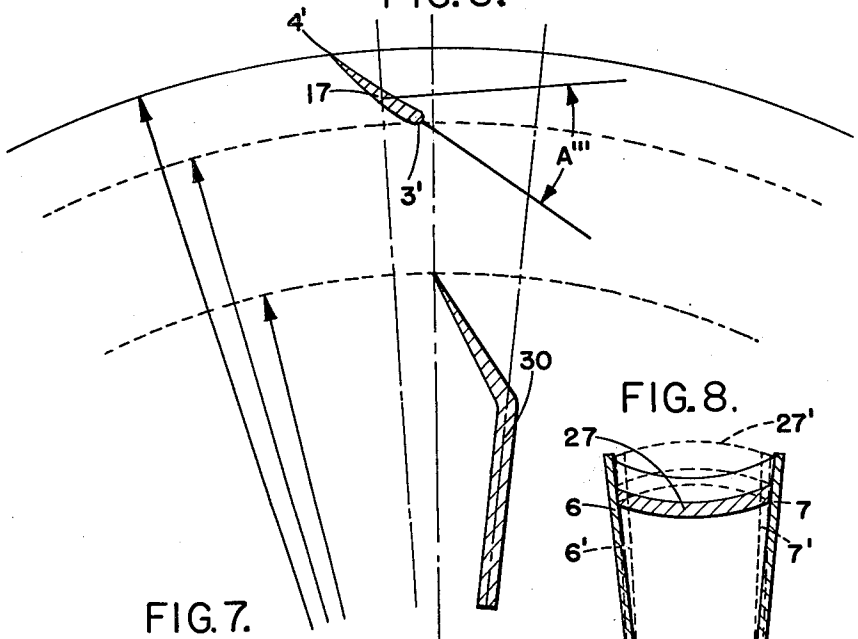


FIG. 8.

FIG. 7.

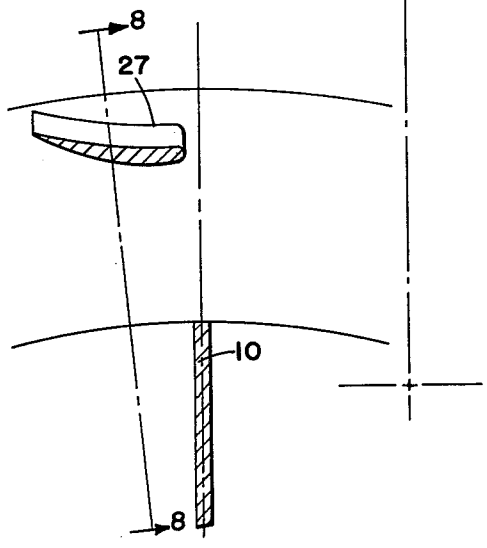
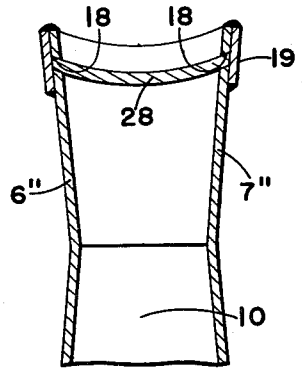


FIG. 9.



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FIG. 10.

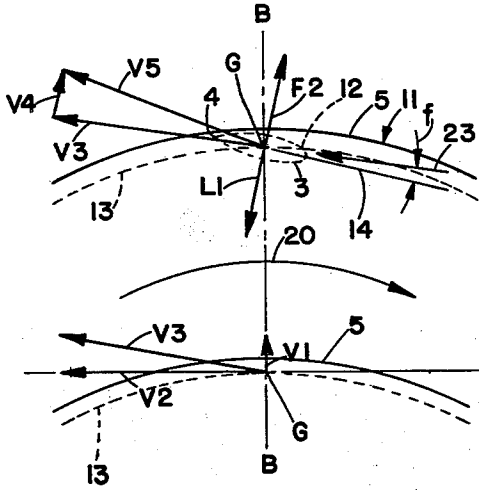


FIG. 11.

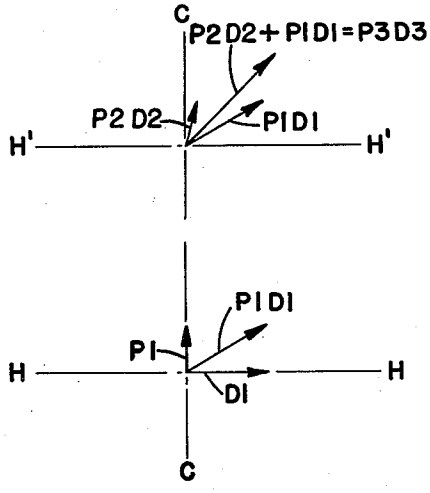


FIG. 12.

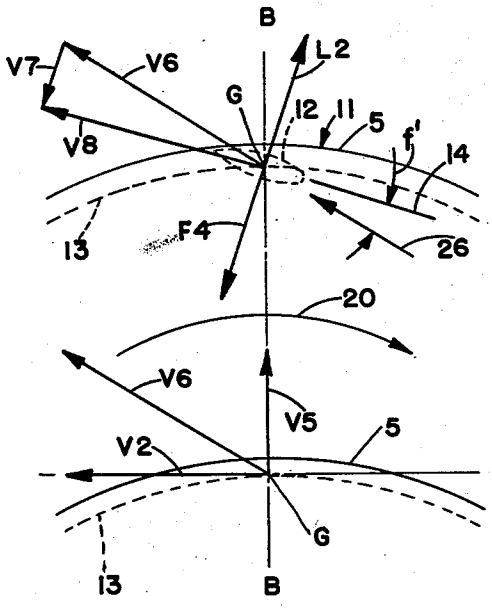
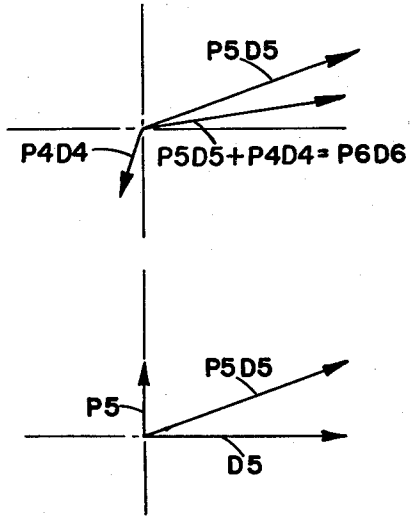


FIG. 13.



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3,197,124

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3,197,124

CENTRIFUGAL PUMP IMPELLERS

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Filed Apr. 3, 1962, Ser. No. 184,763
11 Claims. (Cl. 230—134)

This invention relates to centrifugal pumps, compressors, superchargers and like apparatus and more particularly to an impeller for such devices having a rotary diffuser and provided with auxiliary blades to improve the aerodynamic efficiency thereof and provide for ready accommodation of different operating conditions such as various impeller speeds, fluid pressures and delivery rates.

This application is a continuation in part of U.S. Patent application, Serial No. 701,832, filed December 10, 1957, now abandoned entitled Wheels of Centrifugal Fans, Compressors, Superchargers, Pumps and the Like, Provided with a Rotary Diffuser.

Those concerned with the development of centrifugal pumps and the like have long recognized the need for impellers which rendered them readily variable to accommodate different rotational speeds and delivery rates. Impellers are also needed which would greatly reduce or eliminate the condition known as surging. This is a condition (hereinafter more fully described) characterized by low delivery pressure and by dangerous vibratory actions set up in the impeller when the delivery rate of a centrifugal pump is reduced below a certain rate typical of a particular machine.

Although aerodynamic devices, as presently disclosed, are designed to have certain predetermined characteristics, actual experimental determination of such characteristics often times shows deviations from desired design performance. The principle of this invention is directed toward correction of this inherent condition in an efficient and simple manner.

Certain convention impellers are formed of a plurality of generally radially extending formed impeller blades being confined for rotation in a casing having an axial inlet and a radial discharge. With such impellers only two adjustments are possible after the machine has been built namely, an alteration in the blade discharge angle or a reduction in blade length. It is to be noted that an alteration of the blade discharge angle is practically precluded and the reduction in the blade length results in a reduction of the discharge pressure of the machine which, in many cases, is an undesirable alteration of the machine characteristics.

Impellers of the rotary diffuser type are fundamentally, structurally and functionally, dissimilar to those above described. Structurally, the axially opposed radially extending edges of the respective impeller blades are rigidly secured to discs having an appropriate surface of revolution which forms a casing rotatable with the impeller blades. Suitably secured to the circumferential edge of the respective discs, annular discs circumferentially coextensive with respective discs are provided to form a diffuser extending a relatively large distance from the discharge of the impeller blades.

To achieve correspondence between design and actual characteristics, the impeller of the present invention has a plurality of auxiliary blades having the opposite longitudinal ends thereof secured to the confronting surfaces of the discs of the rotary diffuser so that they extend generally parallel to the axis of rotation of the impeller. The auxiliary blades are adapted to be oriented at any desired angle relative to a plane tangent to the periphery of the impeller. The auxiliary blades are susceptible of a variety of alterations such as differences in blade angle, changes in lateral length and location and

since these auxiliary blades have no direct numerial relationship to the main blades even the number of auxiliary blades can be changed without major alterations to the rest of the machine.

The alterations which can be readily applied to the auxiliary blade of this invention make it possible to adjust the centrifugal machine to give high efficiency at a predetermined speed of rotation without major changes in the design of the machine. Thus a single major machine design is adaptable to provide pumps for various speeds of rotation as well as various delivery rates and pressures.

A further advantage residing in the auxiliary blade of this invention is the mechanical bracing afforded to the discs of the rotary diffuser to prevent damaging vibrations such as sometimes develop in such rotating discs.

Still further advantages residing in the use of the impeller of this invention are apparent in the aerodynamic characteristic of a centrifugal pump incorporating impellers of this design. It is well known to those skilled in the art that centrifugal pumps are subject to the damaging and sometimes dangerous phenonoma of surging. Such surging occurs when the delivery rate of a centrifugal pump, operating at a constant speed of rotation, is restricted to a point where aerodynamic stall occurs within some of the air passages within the machine with concomitant rapid fluctuation of the internal fluid pressure. Such pressure fluctuations give rise to the aforementioned surge vibrations which, if persistent can damage the machine to the extent that rotating parts may be projected out of the machine with consequent danger to personnel and extensive damage to the machinery. In normal operation of a centrifugal pump the pressure rises as the delivery rate is restricted but as the surging condition is approached further restriction of the delivery rate results in, at first, no rise in pressure and finally, a falling pressure as the delivery rate is further restricted. Air pumps incorporating the impeller of the present invention have been found to have a continuously rising pressure associated with continuous reduction of the delivery rate so that such a machine provides maximum pressure at shut-off without the danger of surging. It has further been found that the rate of change of pressure in relation to the change of delivery rate can be adjusted by changing the number or length of the auxiliary blades and that the delivery rate at a given pressure can be adjusted by varying the angle of the auxiliary blades with relation to the direction of air flow within the diffuser.

It is therefore an object of this invention to provide a new and improved impeller for centrifugal pumps, compressors, superchargers and like apparatus.

It is another object of this invention to provide a new and improved impeller of the rotary diffuser type for centrifugal apparatus as above.

It is a further object of this invention to provide a new and improved impeller of the rotary diffuser type for centrifugal apparatus having a continuously rising pressure as the delivery rate is reduced to shut-off.

It is a more specific object of this invention to provide a new and improved impeller for centrifugal apparatus having a rotary diffuser with auxiliary blades therein to provide a mechanically stabilized impeller of the rotary diffuser type.

It is another specific object of this invention to provide a new and improved impeller for centrifugal apparatus having a rotary diffuser in which auxiliary blades mechanically stabilize the rotary diffuser and provide improved delivery rate to delivery pressure characteristic for the machine.

It is still another specific object of this invention to

provide a new and improved impeller on the rotary diffuser type for centrifugal apparatus such as pumps, compressors, superchargers and the like which is provided with auxiliary blades mounted within the rotary diffuser to provide for ready accommodations of the apparatus to different conditions of operation such as various rotational speeds and various pressure versus delivery rate characteristics by varying the angle of the auxiliary blades in relation to the direction of air flow in the peripheral portion of the rotary diffuser.

These and other objects and advantages of this invention will become readily apparent upon consideration of the following description and drawings, in which:

FIG. 1 is a fragmentary diagrammatic sectional view of an impeller constructed in accordance with the principles of this invention sectioned along a plane normal to the axis of rotation of the impeller;

FIG. 2 is a radial section of the impeller of FIG. 1;

FIG. 3 is a fragmentary sectional view similar to FIG. 1 showing a variation in the device of FIG. 1;

FIG. 4 is a view similar to FIG. 3 showing a further variation in the device of FIG. 1;

FIG. 5 is a diagrammatic illustration of the characteristic delivery curves plotted as pressure versus delivery rate for several different machines;

FIG. 6 is a diagrammatic view illustrating a second embodiment of the impeller of this invention;

FIG. 7 is a diagrammatic view of a typical mounting of an auxiliary blade within a rotary diffuser;

FIG. 8 is a fragmentary diagrammatic sectional view taken on line 8—8 of FIG. 7; and

FIG. 9 is a view similar to FIG. 8 showing a second embodiment of the auxiliary blade of FIGS. 7 and 8;

FIG. 10 is a diagrammatic view showing two steps in the vectorial addition of air velocities at low delivery rates;

FIG. 11 is a diagrammatic view showing the vectorial addition of pressures and delivery rates derived from the conditions of FIG. 10;

FIG. 12 is a diagrammatic view similar to FIG. 10 but applied to high delivery rates;

FIG. 13 is a diagrammatic view similar to FIG. 11 but applying pressures and delivery rates derived from FIG. 12.

In FIGS. 1 and 2 there is shown a portion of an impeller wheel **11** constructed according to the principles of this invention being of the rotary diffuser type comprising a pair of shroud members **8** and **9**, having coaxial surfaces of revolution and outer peripheries **5** of equal radius, mounted to rotate about a common axis O—O′ when mounted on a shaft (not shown) having the same axis O—O′. The shroud members **8** and **9** are axially and radially spaced and rigidly secured to a plurality of radially extending flat blade members **10** which are equally, circumferentially spaced and preferably lie in planes containing the axis O—O′. The blades **10** extend from the radially inward edges of the shroud members **8** and **9** and terminate in outer edges **2** at a distance R2 from the axis O—O′ (shown as center O in FIG. 1) substantially inward from the outer periphery **5** of the shroud members **8** and **9**. Portions of the shroud members **8** and **9**, indicated as diffuser portions **6** and **7**, respectively, extend outwardly beyond the outer edges **2** of the blade members **10** and are preferably slightly axially divergent to form an integral rotary diffuser. The portions of the shroud members **8** and **9** nearest to the axis O—O′ are radially spaced to form an inlet opening **1**. For further description of such impellers refer to copending application Serial No. 112,310 filed May 24, 1961, now abandoned, which application is assigned to the same assignee as is this application.

Referring again to FIGS. 1 and 2 there are shown generally rectangular, auxiliary blades **12** having trailing edges **4** inwardly adjacent the radially outer periphery **5** of the diffuser portions **6** and **7** and extending

therebetween. The auxiliary blades **12** are shown in FIG. 1 to be of symmetrical airfoil cross section, having a center G, a lateral chord and a leading edge **3** and so oriented that the thicker or leading edge **3** of the airfoil section is turned to the right or in a clockwise direction of rotation about the axis O—O′ as viewed in FIG. 1, which is taken for purposes of illustration as the direction of rotation of the impeller of this invention. It is to be appreciated that the principles of this invention contemplate the use of other shapes for auxiliary blades including unsymmetrical airfoils and also flat plate members. It is further to be appreciated that locating the auxiliary blades with their trailing edges **4** at some distance radially inward from the periphery **5** is within the scope of this invention. The leading edge **3** of the auxiliary blade **12** is inwardly displaced from the periphery **5** of the rotary diffuser so that a plane **14** which is parallel to the axis O—O and containing the chord of the airfoil section makes an angle A, of approximately 17°, with a tangent **15** to a circle 13 having a radius R3 which is the circle of the centers of the airfoil cross sections. This angle, chosen for illustration, is taken as that angle which most nearly aligns the chord of the auxiliary blade **12** with the direction of air flow relative to the impeller in that portion of the rotary diffuser where the auxiliary blade **12** is located. For purposes of clarification this angle can also be defined as an angle of approximately 73° between the chord of the airfoil section and the radius drawn from the axis O—O′ to the center G of the auxiliary blade **12**. This angle A, relative to the tangent of circle **13**, shown in FIG. 1 as 17°, is shown in FIG. 3 as angle A′ of approximately 23°, in FIG. 4 as angle A″ of approximately 14°, and in FIG. 6 as A‴ of approximately 40° for reasons which shall hereinafter be made evident. It is to be noted that in FIGS. 3 and 4 the chords of the blades **12** lie in planes **14′** and **14″**, respectively, and that the auxiliary blades **12** have no direct angular relationship with the main blades **10**.

As seen in FIG. 1 the angle between the main blades **10** indicates that thirteen blades are being used in this particular embodiment while the angle between the auxiliary blades **12** shows that nineteen auxiliary blades **12** are being used on the same impeller. Preferably, the number of main blades **10** in such impeller is usually a prime number such as thirteen for reasons consistent with aerodynamic theory. In like manner it is considered that the number of auxiliary blades **12** is most desirably some other prime number such as eleven, seventeen or nineteen. It is further to be pointed out that the orientation of the blades **12** substantially parallel to the relative flow of air in that portion of the diffuser where the blades **12** are located precludes the possibility that the auxiliary blades **12** function to maintain or increase the air velocity in that part of the device. It is further to be realized that the chordal length of the auxiliary blades **12** from the trailing edge **4** to the leading edge **3** is related to the number of such blades in such manner that the number of blades multiplied by the chordal length of a blade is not greater than $\frac{4}{10}$ of the circumference of the circle **13**.

In describing the operation of this device it will be assumed that a conventional velocity diagram at point **2** of blades **10** comprises the absolute tangential blade velocity; the absolute radial velocity of the fluid; and the absolute resultant velocity of the fluid. The motion imparted to the fluid by rotation of the impeller results in a rotational velocity equal to the velocity of the outlet edges **2** of the blades **10**. The fluid passes outwardly from the inlet **1** past the outlet edge **2** into the diffuser section under the influence of centrifugal force as is well known. The air entering the diffuser section has a tangential velocity equal to that of the outer edges **2** of the blades **10** as determined by the distance R2 from the center O to the outer edges **2**. This tangential velocity is maintained substantially unchanged as the fluid acted upon by

centrifugal force passes outward through the diffuser section. The outer periphery of the diffuser has a greater tangential velocity due to the fact that the periphery 5 has a greater radial dimension R3 from the center O to the periphery 5. Such greater velocity results in a relative backward motion of the air in relation to that portion of the diffuser which begins at the outer edge 2 of the blade 10 and increases as the air approaches the outer periphery 5. It will be appreciated that when the fluid reaches the circle 13 the absolute tangential velocity of the air and the absolute velocity of the auxiliary blades 12 results in a relative tangential velocity of the fluid which will be proportional to the ratio of R2 to R3. The difference in velocity constitutes a relative motion of the fluid moving across the blades section 12, which, depending on their attitude, may have an effect upon the flow of air in this region.

The effect of the auxiliary blades 12 upon the air flow in the portion of the rotary diffuser where they are located will be only very slightly in the direction of increased tangential velocity, due mainly to surface friction. The main effect of the auxiliary blades 12 upon the air flow is due to an angle of incidence F or F' between the planes 14' or 14'', respectively and the line of motion 16 of the air with respect to the blades 12. It is to be noted that the direction of the line 16 is that of a resultant V3 (FIG. 10) obtained by vectorially adding the radial component of velocity VI (proportional to the delivery rate of the machine) and a tangential component of velocity V2 as shown in the lower vector diagram of FIG. 10, hereinafter more fully explained. The angle F, defined by the plane 14; containing the chord of blade 12, and the line of action of the fluid 16, will be referred to as counter clock-wise when using the plane 14' as a reference.

As shown in FIG. 3 air stream 16 would be subject to an increased delivery pressure due to the angle F of the blade 12. In similar manner (see FIG. 4) the angle of incidence F' of the auxiliary blades 12 relative to the direction of air motion 16 is clockwise and will result in a decrease in delivery pressure. It is to be noted that in FIG. 1 the plane 14 and the line 16 coincide so that the angle of incidence is zero and the delivery pressure is not increased or decreased by the blades 12.

FIG. 10 is a diagrammatic representation of a portion of the apparatus of FIG. 1 in which the parts shown in FIG. 1 carry the same numbers in FIGS. 1 and 10. The line B—B of FIG. 10 represents a radial line joining the center O of FIG. 1 to the center G of an auxiliary blade 12 shown in dotted outline in FIG. 10. It is to be noted that the blade 12 of FIG. 10 is oriented in the same manner as shown in FIG. 1 and that the rotation of the impeller 11 as shown by arc 20 is in the same direction as shown in FIG. 1. It is further to be noted that the velocities V1 through V5 hereinafter described are to be taken as velocities relative to the portion of the impeller 11 defined by the circle 13 and are represented by vectors having lengths proportions to the velocities referenced to the point G which is the center of blade 12. The velocity represented by vector V1 is the radial component of the air motion associated with a low delivery rate for the impeller 11. The velocity V2 is the tangential velocity of the fluid at R3 relative to the diffuser. The addition of the vectors V1 and V2 yield a sum indicated as V3 which is transferred to the upper vector diagram of FIG. 10 and represents the direction and magnitude of the motion of the air with respect to the auxiliary blade 12 before the action of blades 12 is applied. The direction of the velocity V3 is also indicated by arrowed line 23 and is shown to be at an angle f with the chord contained in the plane 14 and being analogous to the angle F of FIG. 3 in that such angle is counter clockwise from the direction of motion 23 to the plane 14. The angle of incidence f will produce a velocity component of air motion V4 normal to the chord of the blade 12. The addition of vectors V3 and V4 results in a vector V5 having an increased radial component. Air impinging upon a surface at an angle such as the angle of incidence f produces a force normal to the blade 12 and directed substantially inward, here indicated as vector L1. An equal and opposite outwardly directed reaction force indicated as F2 is applied to the air impinging upon the blade 12 and becomes an added pressure P_2 (of FIG. 11) in the delivery portion of the machine.

FIG. 12 is in all manner similar to FIG. 10 excepting only that the velocities indicated are proportional to a much higher delivery rate than that indicated for FIG. 10. Addition of the radial component V5 proportional to the higher delivery pressure and the tangential component V2 give a resultant V6 which is transferred to the upper vector diagram in FIG. 12. The direction of air motion impinging upon the auxiliary blades 12 is shown by the arrowed line 26 and makes an angle with the plane 14 indicated as f' which angle is analogous to the angle F' of FIG. 4 in that such angle f' is directed clockwise from the plane 14 to the line 26. Impingement of the air upon the blades 12 at such an angle results in a velocity component V7 inwardly directed normal to the plane 14. Addition of the vectors V6 and V7 results in a vector V8 having a smaller outward component than the velocity V6. With such an angle of impingement, a force develops on the auxiliary blade 12 directed outward, normal to the plane 14 and represented by the vector L2. An equal and opposite reaction force shown as F4 is a force applied to the air in the vicinity of auxiliary blade 12 resulting in a pressure P4 (in FIG. 13) opposite to the pressure derived from the centrifugal force and reducing the delivery pressure of this machine below that which would be normal to a machine otherwise the same as that equipped with impellers 11 excepting that it had no auxiliary blades. The added delivery pressure at low rates of flow is of primary importance as it is in the area of low or zero delivery that the hereinbefore described surging effects are developed and become most violent.

It is of course to be realized that the effects of added or subtracted delivery pressure can be varied over wide ranges by making small changes in the orientation of the auxiliary blades 12. Such small changes are relatively easily accomplished as compared to changes in the length or outlet angle of the main blades required by the impellers of the prior art for correcting design and manufacturing errors or adapting the machine for use in conditions other than that for which it was designed.

It is further to be noted that the above described effects vary with the speed of rotation and can be adjusted to adapt the machine to various rotational speeds as desired.

In FIG. 5 there is shown a series of curves identified by Roman Numerals, I, II, III and IV which are analogous to the curves developed by plotting delivery pressures as ordinates against a series of delivery rates Q as the abscissa. These curves are of course idealized and do not represent actual plotting of any values but are being used merely for purposes of illustration. The curve I represents the variations in delivery rate and pressure produced by a centrifugal pump rotating at a constant speed and not equipped with the auxiliary blades of this invention. It will be noted that the left hand portion of curve I has an increasing downward slope to the left where a decrease in the delivery rate is accompanied by a decrease in pressure. This portion of the characteristic curve of a centrifugal pump is known, to those well versed in the art, as the surge region and represents those conditions of delivery rate in which surging can take place with the aforementioned undesirable or dangerous effects.

Curve II of FIG. 5 represents the characteristic delivery rate and pressure curve of a machine equipped with an impeller having the auxiliary blades of a size and number such as that shown in FIG. 1 where the product of the number N of auxiliary blades 12 by the chordal length L of such blades gives a relationship expressed by the equation $N \times L = .35 \times$ the circumference of the circle

13 which will hereinafter be referred to as the factor K. Curve II then represents a machine characterized by auxiliary blades according to the formula $N \times L = K$, while curve I represents a machine having a formula $N \times L = O$. By inspection of the curve II it will be seen that a machine equipped with the auxiliary blades of this invention has a characteristic curve which is without a downward sloping leftward portion or surge region but on the contrary has a continuous increase of pressure as delivery rate is decreased so that such machine has maximum pressure at shut-off. Curve III represents the characteristic delivery rates and pressures for a machine having more or wider auxiliary blades 12 and is characterized by the formula $N \times L$ is greater than K. By inspection of the curve III it will be seen that a still greater slope is produced in the characteristic curve, with again, no downward sloping, leftward trending, surge region at any point in the curve. Such a machine would be even less liable to surging, but, under some circumstances would suffer from the disadvantage of an undesirably high shut-off pressure and a likewise undesirably low pressure at high rate of delivery. Curve IV represents the characteristic delivery rates and pressures for a machine equipped with an impeller characterized by the formula $N \times L$ is less than K. It will be seen that this curve IV has a lower slope than that of curve II and very closely approaches surging conditions at shut-off. The machine represented by curve IV would, however, have the advantages of relatively low shut-off pressure and relatively high pressure at maximum delivery rate as compared with the machines characterized by curves II and III. It is to be appreciated that variations in the angle of incidence of the auxiliary blades 12 in relation to the direction of air flow in their regions will introduce other variables into the curves hereinbefore described. With such a variety of characteristic delivery pressure and rate curves it is possible to design a single basic machine suitable for any combination of a wide variety of conditions. These conditions include shut-off pressure, maximum delivery rate pressure, rotational speed, and economic factors such as efficient use of power and the rate of delivery required from a given size of machine. It is to be noted that the product $N \times L$ can be increased by either of two methods; namely, by increasing the number of blades 12 on a particular impeller 11 or the chordal length thereof. In like manner the product $N \times L$ can be decreased by reducing the number of blades or more readily by reducing the chordal length of the blades 12. Since variation of the product $N \times L$ is readily achieved after fabrication of the impellers 11 it follows that impellers constructed according to the principles of this invention are readily adapted to different requirements as regards pressures at shut-off and maximum delivery rate.

A further property of the impellers of this invention is illustrated by a point P on FIGURE 5 where all of the curves intersect. As stated above the curves II, III and IV represent the characteristic delivery rates and pressures developed by impellers 11 in which the auxiliary blades 12 all have the same angle A relative to the tangent of the circle 13 it will be obvious that the abscissa of point P represents a particular delivery rate at which the direction of air flow 16 is exactly aligned with the plane 14 of the blades 12. As the particular delivery rate corresponding to the abscissa of point P is exceeded, an angle of incidence F' (see FIG. 4) of the air stream relative to the plane 14 is developed in a counter clockwise direction. The angle of incidence F' of the air stream against the blades 12 results in a pressure reduction which is illustrated by the fact that the portion of the curves II, III and IV to the right of point P are below the curve I. In like manner the portions of the curves II, III and IV to the left of point P are above the curve I showing that an increase in delivery pressure has been attained when using the impellers of this invention. The important result here illustrated is that at a particular delivery rate the auxiliary blades of this invention have no appreciable effect and that therefore the auxiliary blades 12 of this invention do not act as extensions of the main blades but have an independent action based upon an entirely different principle.

Referring again to FIG. 5 it will be realized that a decrease in the angle A hereinabove defined (as in FIG. 4) will move the point P to the left in such diagram illustrating the fact that reduced pressures will be developed by the auxiliary blades of this invention at lower delivery rates than those represented by the abscissa of point P. This fact is illustrated by the dot and dash lines through a point E on curve I to the left of point P, which dot and dash lines represent curves II, III and IV in a new position resulting from the reduction of the angle A between the plane 14 of the auxiliary blades 12 and the tangent 15. In like manner an increase in the angle A (shown as A' in FIG. 3) will displace the curves II, III and IV to the right, shown as dotted lines, giving them a new point of intersection D, to the right of point P, which point D represents a delivery rate greater than that represented by point P. The point D, being also on curve I, likewise represents the delivery rate at which no effect of the blades 12 is observable and beyond which, in the direction of increasing delivery rates, the effect of the blades upon the pressure is negative or in the direction of lower pressure (see FIG. 12). From the fact that the angle A can be changed without altering any of the major components of the pump, it is to be realized that application of the auxiliary blades of this invention is of great service in increasing the adaptability of a single pump or impeller design to various desired conditions of delivery rates and pressures.

FIGS. 11 and 13 show a plot applied to values such as those represented in FIG. 5 with delivery rates of a centrifugal machine indicated as distances to the right of the vertical line C—C while delivery pressures of such a machine are indicated as increasing upwardly along the line C—C from the horizontal line H—H or H'—H' respectively in the lower and upper diagrams of FIG. 11. Referring to the lower diagram of FIG. 11 a line D1 indicates a particular delivery rate for such centrifugal machine equipped with impellers similar to impellers 11 but without the auxiliary blades 12 of this invention (such a machine will hereinafter be referred to as a prior machine). Referring again to the lower diagram of FIG. 11, P1 represents the delivery pressure of such prior machine at the delivery rate represented by D1. The line P1—D1 represents the sum of P1 and D1 and is transferred to the upper diagram of FIG. 11 where it carries the same designation. In the upper diagram of FIG. 11 a line P2—D2 proportional to the additional pressures hereinbefore shown in FIG. 10 as being developed by the blades 12 of this invention and represented by the line F2 and including a slight added delivery rate D2 is added to the line P1—D1 and gives a resultant indicated as P2—D2 plus P1—D1 or P3—D3. These points have been plotted on FIG. 5 to further clarify the above explanation.

In like manner FIG. 13 shows a high rate of delivery indicated by the line D5 for a prior art machine while P5 represents the delivery pressure associated with such delivery rate. P5—D5 represents the sum of these two quanta and is transferred to the upper diagram of FIG. 13 in which line P4—D4 represents the pressure developed by the force F4 of auxiliary blade 12 at high delivery rate such as that shown in FIG. 12 and a slight decrease in delivery rate. It will be recalled from the explanation of FIG. 12 that the pressure P4 due to the presence of the auxiliary blades 12 is in the negative direction in relation to the normal delivery pressures of a prior machine. The addition of the two lines P5, D5 and P4—D4 is represented by the line P6—D6 and indicates a slightly smaller delivery rate and a substantially lower delivery pressure than that of the prior machine under the same

conditions. The point P5—D5 and P6—D6 are again shown in their proper relationship on the graph of FIG. 5.

In FIG. 6 there is shown a portion of an impeller similar to that of FIGS. 1 and 2 having blades 30 which have backward curving tips in relation to the direction of rotation such that the tip of the blade 30 makes an angle of approximately 60° with a tangent to the circle of tips. In FIG. 6 there is also shown the use of an auxiliary blade 17 which forms a curved rather than a symmetrical airfoil section with the concavity facing outward from the center of the wheel so that a lift force directed inwardly of the wheel upon the auxiliary blades 17 is developed even when the angle of the air stream relative to the tangent 15 is equal to the angle of inclination A''' of the blade relative to the same tangent. Or in other words when the blade is parallel to the stream of air surrounding it there is a lift developed upon the blade 17 inwardly toward the center of the wheel with a resultant increase in delivery pressure. The blade 17 is also shown at a greater angle of inclination A''' than those shown in FIGS. 1–4. Such greater angle of inclination has been shown both theoretically and in practice to be necessary in the case of backward curving main blades 30 as illustrated in FIG. 6 in order to attain the same adjustment of delivery pressures versus delivery rates as was attained in the FIGS. 1–4 with straight radial blades 10.

In FIGS. 7 and 8 is shown one embodiment of an auxiliary blade 27 having a longitudinal cross section similar to that shown in FIG. 6 with a transverse cross section as shown in FIG. 8 being of a concave-convex form with the concavity facing outward from the center of the wheel. This concavity transversely oriented with relation to the direction of rotation gives an arch effect which resists the deformation of the blade 27 by the large centrifugal forces developed upon such blades when the impeller rotates at the high speeds necessary for efficient air pumping. As shown in FIG. 8 the blade 27 under the aforementioned centrifugal stress has a tendency to take the shape shown in broken outline as 27' but in order to do so it must be obvious that the ends of the blade 27 must move apart to allow the blade 27 to become straight before it can assume the shape shown as 27'. Under the same centrifugal force the sides of the diffuser 6 and 7 respectively, develop an inward force tending to move them into the position shown as 6' and 7' in dotted outline. Since these two forces are oppositely directed they tend to counter-balance each other with the result that a blade 27 of much thinner cross section and lighter weight can be used than would be possible without this bracing effect, thus reducing the centrifugal loading on the impellers or alternatively permitting the impellers to be used at a higher speed of rotation without exceeding the strength of the materials in the impellers.

FIG. 9 shows a further embodiment of the auxiliary blades in which blades 28 similar to blades 27 are inserted into slots 18 in the near peripheral portion of rotary diffuser extensions 6'' and 7'' the slots 18 being covered on the outer surface of the diffuser extension 6'' and 7'' by arcuate, flat plates 19 which are shown as turned over portions of the diffuser extensions 6'' and 7'' but can be separate plates of metal welded to the exterior of the diffuser extensions 6'' and 7''. With such design it is possible to insert the blades 12 into the impeller without welding so that they can be removed and altered in shape and size more readily than is the case of those auxiliary blades 12 which are welded or otherwise rigidly secured. The design according to FIG. 9 also raises the possibility of using blades of light material such as aluminum or even plastic substances. It will be realized that the forces as described in relation to FIG. 8 will tend to hold the blades 12 of FIG. 9 in place by utilizing components of the centrifugal force developed during high speed rotation, so that the greater the speed of the impeller the more tightly the blade 12 of FIG. 9 will be held in place.

Preferred embodiments of the principles of this invention having been described and illustrated herein, it is to be realized that modification thereof can be made without departing from the broad spirit and scope of this invention. It is therefore respectfully requested that this invention be interpreted as broadly as possible and be limited only by the prior art.

What I claim is:

1. In a centrifugal fan, a radial flow impeller including impeller blades adapted for rotation about a predetermined axis, annular plate means secured on opposite sides of the circumferential discharge of said impeller and extending radially thereof for decelerating the fluid passing therethrough, elongated auxiliary blade means having the central longitudinal axes thereof respectively parallel to such predetermined axis, said blade means having the ends thereof secured to said decelerating means and located in the flow path of such fluid radially outwardly from the terminal edge of said impeller blades, the number (N) of said auxiliary blade means and the chordal lengths (L) thereof respectively are related by the following equation: $N \times L = .35 \times C$ wherein the constant .35 is the percent reduction of peripheral flow area due to the blades and permitted to have a maximum value of 0.4; and C is the circumference of the impeller taken along a circle passing through the longitudinal axes of the auxiliary blades.

2. In a centrifugal fan, a radial flow impeller rotatable about a predetermined axis, elongated auxiliary blade means secured to a diffuser connected to and rotatable with said impeller with the longitudinal axes of said auxiliary blades being parallel to such predetermined axis, said blade means having the opposed longitudinal ends thereof secured in such diffuser and located in the flow path of such fluid radially outwardly from the discharge of said impeller, tthe number (N) of said blade means and the chordal lengths (L) thereof respectively are related by the following equation: $N \times L = .35 \times C$ wherein the constant .35 is the percent reduction of peripheral flow area due to the blades and permitted to have a maximum value of 0.4; and C is the circumference of the impeller taken along a circle passing through the respective longitudinal axes of said blade means.

3. An apparatus for controlling the discharge pressure of a centrifugal impeller rotatable about an axis and having impeller blades extending radially outwardly with respect to said axis and terminating in outer edges, an integral outwardly divergent rotary diffuser having axially spaced sides extending circumferentially about and radially outwardly from said outer edges, respectively; the improvement which comprises a plurality of additional blade means for controlling the delivery pressure with varying rates of delivery, the additional blade means having the end portions thereof secured to the confronting surfaces of said rotary diffuser near the maximum cross-sectional area of said rotary diffuser, said additional blade means being spaced radially outwardly from the outer edges of the impeller blades and circumferentially from each other.

4. The combination of claim 3 wherein the additional blade means are spaced circumferentially from each other an equal distance.

5. An apparatus for controlling the discharge pressure of a centrifugal impeller rotatable about an axis and having impeller blades extending radially outwardly with respect to said axis and terminating in outer edges, an outwardly divergent integral rotary diffuser having axially spaced sides extending circumferentially about and radially outwardly from said outer edges, respectively; the improvement which comprises a plurality of elongated blade means for producing a characteristic curve having a negative slope from shut-off to maximum delivery, the elongated blade means having the end portions thereof secured to the confronting surfaces of said rotary diffuser near the maximum cross-sectional area of said rotary

diffuser, said elongated blade means being spaced radially outwardly from the outer edges of the impeller blades and circumferentially spaced from each other.

6. The combination of claim 5 wherein the elongated blade means have their central longitudinal axes respectively equidistantly spaced from the axis of rotation of said impeller and parallel thereto.

7. The combination of claim 6 wherein the elongated blade means are contained in planes respectively which are disposed at an angle with lines tangent to said circle at the intersection of said central longitudinal axes and such circle, and wherein such angles, respectively, have value capable of producing a predetermined delivery rate at a first value of pressure and an increasing value of pressure concurrent with a proportional reduction of delivery rate to shut-off.

8. The combination of claim 7 wherein decreasing values of such angles produce at said first value of pressure a reduced delivery rate while increases in the value of pressure concurrent with a proportional reduction of delivery rate of shut-off is maintained.

9. The combination of claim 7 wherein increasing values of such angles produce at said first value of pressure an increased delivery rate while increases in the value of pressure concurrent with a proportional reduction of delivery rate to shut-off is maintained.

10. An apparatus for controlling the discharge pressure of a centrifugal impeller rotatable about an axis and having impeller blades extending radially outwardly with respect to said axis and terminating in outer edges, an integral outwardly divergent rotary diffuser having axially spaced sides extending circumferentially about and radially outwardly from said outer edges, respectively; the improvement which comprises a plurality of additional blade means for controlling the delivery pressure with varying rates of delivery, the additional blade means having the end portions thereof secured to the confronting surfaces of said rotary diffuser, said additional blade means being spaced radially outwardly from the outer

edges of the impeller blades and circumferentially from each other, the radial distance of said additional blade means from said axis being substantially greater than the radial distance of said outer edges of said impeller blades from said axis.

11. An apparatus for controlling the discharge pressure of a centrifugal impeller rotatable about an axis and having impeller blades extending radially outwardly with respect to said axis and terminating in outer edges, an integral outwardly divergent rotary diffuser having axially spaced sides extending circumferentially about and radially outwardly from said outer edges, respectively; the improvement which comprises a plurality of additional blade means for controlling the delivery pressure with varying rates of delivery, the additional blade means having the end portions thereof secured to the confronting surfaces of said rotary diffuser near the maximum cross-sectional area of said rotary diffuser, said additional blade means being spaced radially outwardly from the outer edges of the impeller blades and circumferentially from each other, said additional blade means having elongated configurations with the central longitudinal axes thereof respectively equidistantly spaced from the axis of rotation of said impeller and parallel thereto.

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