June 1, 1943. J. T. McINTYRE 2,320,733

SCREW TYPE FLUID PROPELLING APPARATUS

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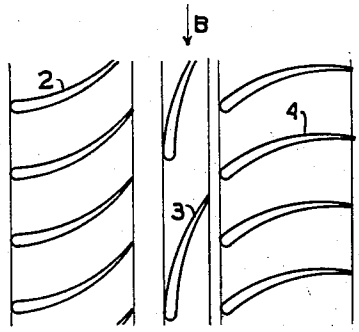


Fig I

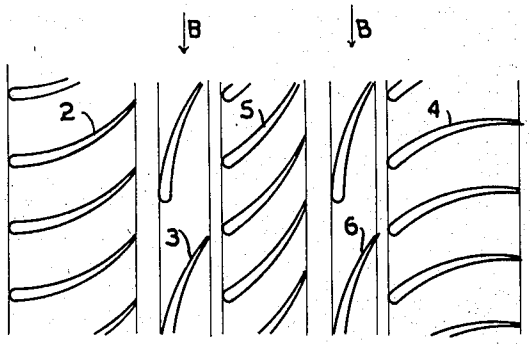


Fig II

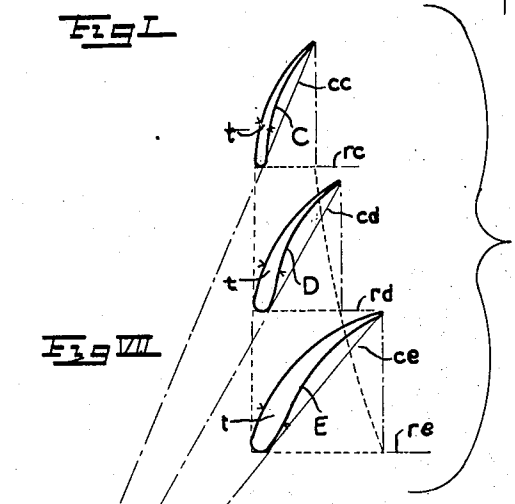


Fig VIII

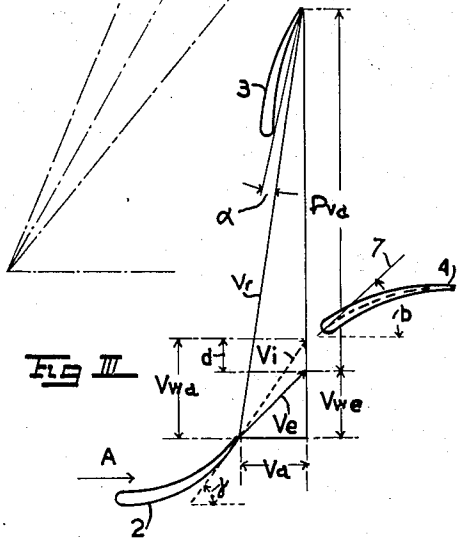


Fig III

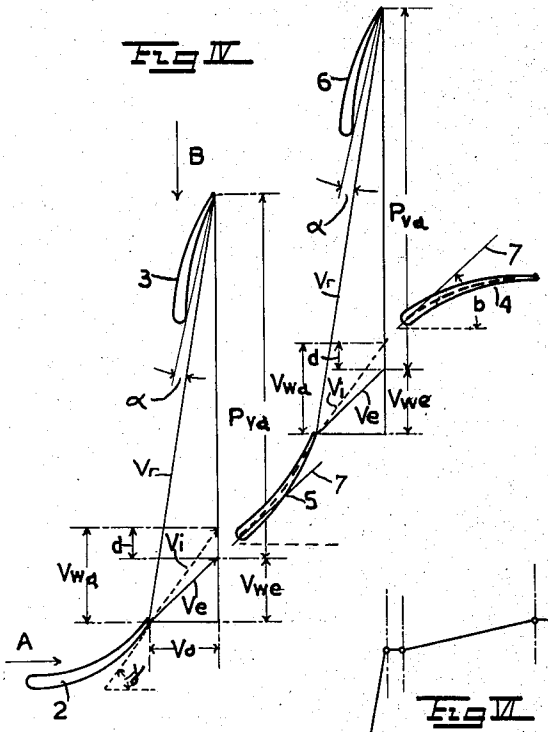


Fig IV

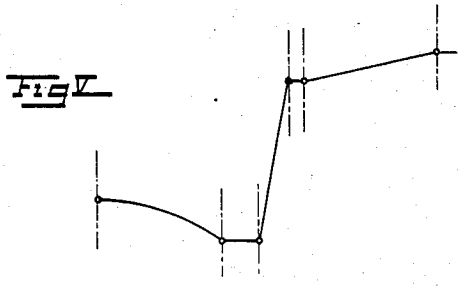


Fig V

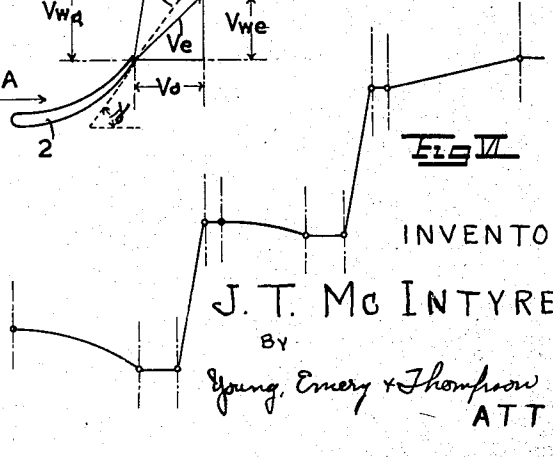


Fig VI

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SCREW TYPE FLUID PROPELLING APPARATUS

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Fig. VIII

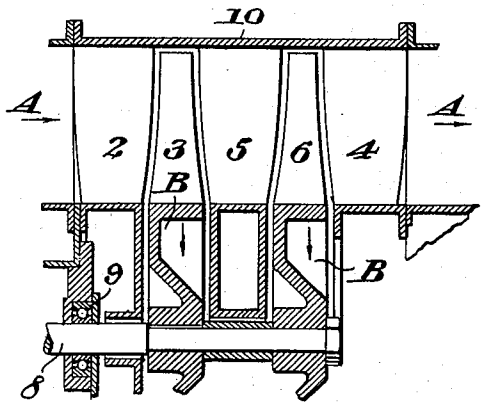
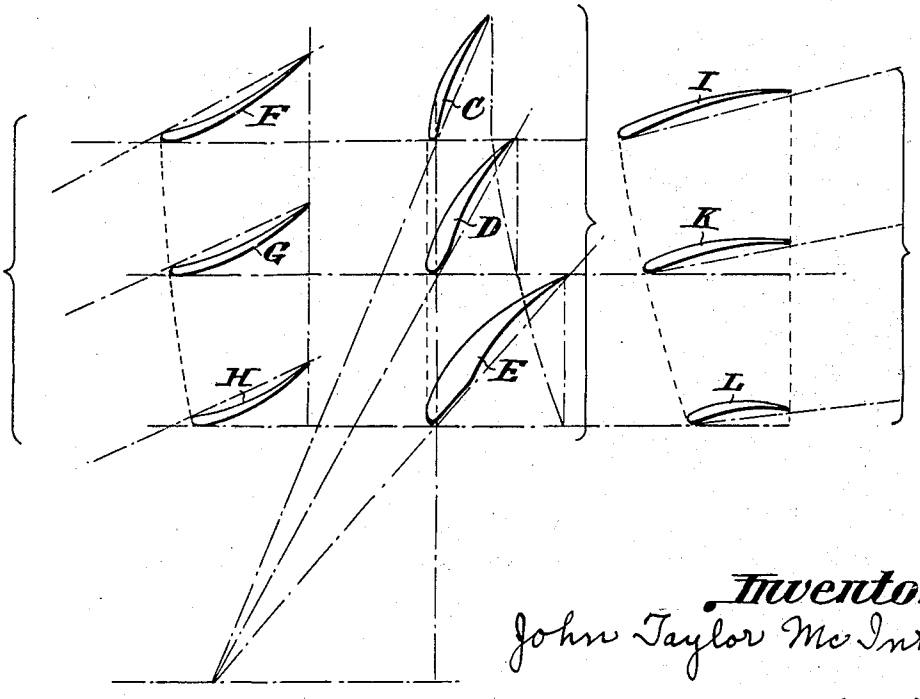


Fig. IX



Inventor,
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Patented June 1, 1943

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UNITED STATES PATENT OFFICE

2,320,733

SCREW TYPE FLUID PROPELLING APPARATUS

John Taylor McIntyre, Johannesburg, Transvaal, Union of South Africa, assignor to Macard Screws, Limited, Johannesburg, Transvaal, Union of South Africa

Application November 4, 1938, Serial No. 238,908
In Union of South Africa January 7, 1938

2 Claims. (Cl. 230—122)

The invention relates to screw propeller type fans, pumps and the like, and the object of the invention is to increase the manometric efficiency of such apparatus.

This application is a continuation in part of my prior application Serial No. 195,629, filed on March 12, 1938, now abandoned. However, the subject matter of the claims of the present application was part of the subject matter of the aforesaid application and was never abandoned.

In this specification, "manometric efficiency" means the ratio of the pressure actually obtained, to the theoretical pressure corresponding to the impeller tip speed. The term "geometric pitch" is used in its ordinary sense of the axial length of one turn of the helix formed by helical extension of the chord of a section of an impeller blade or guide vane; but its use is restricted to discussion of different geometric pitches at the varying radii of a blade or vane. A helix is either right-handed or left-handed accordingly as it is generated by clockwise or by counter-clockwise rotation of its generating radius moving forward along its axis; and the term "helical hand" is used herein for comparing—in this respect—different helical elements or formations, or elements or formations when considered as portions of helices. The use of the words "relative curvature" is restricted to the description of impeller blades to denote the ratio of the maximum ordinate between the median camber line of an aerofoil element and the chord joining the two ends of said median camber line, to the length of this chord.

Concavity as discussed in this specification has reference only to the relationship of the concave surface of a blade or vane to pure circumferential direction, for the purpose of specifying whether said concave surface faces, in that limited respect, in the same way as, or in the opposite way to, the sense of rotation of the impeller. Angularity of the chord of the concave surface to said circumferential direction or to the axis of the machine is absent from the meaning of the term. The concavity of the impeller blades faces in the same way as the sense of rotation of the impeller.

When in apparatus of the kind in question, a stream of fluid passes through the rotor, it acquires from the latter a drag velocity which, in direction, is circumferential, and, in sense, is the same as that of the rotor velocity, and the total magnitude of which is determined principally by the profile and number of the rotor blades and their rotational speed. According to the present invention, in apparatus of the kind in question, the whole of the fluid incoming to the rotor is given a circumferential velocity component which in sense is opposite to that of the rotor velocity and of the drag velocity and in magnitude is substantially in excess of the drag velocity. The result is that said circumferential component (after neutralizing the drag) persists, unaltered in direction and sense, and in substantial magnitude; and as the pressure imparted to the fluid outgoing from the rotor is proportional to the square of the velocity of the rotor blade relative to the fluid ingoing thereto, the circumferential velocity component produces a very substantial gain of pressure in the outgoing fluid. Accordingly in a given apparatus, the invention enables a greater pressure gain to be attained without increase of rotor blade velocity or a given pressure gain to be attained with a lower rotor blade velocity.

According therefore to the present invention a screw type fluid propelling apparatus comprises an impeller having blades of aerofoil cross-section increasing in width and in total area progressively in the direction from tip to hub with conforming relative curvature, in combination with fluid inlet means comprising a helical guide vane assembly co-axial with the impeller and arranged to impart to the whole of the fluid ingoing to the impeller a counterswirl which, in magnitude, is substantially in excess of the impeller drag.

If the fluid outgoing from the rotor is to pass through another rotor stage, its remaining circumferential velocity may be increased to the circumferential velocity originally imparted to the fluid. If, however, the fluid is to leave the apparatus and is to leave it without rotational movement, said remaining circumferential velocity must be counteracted, e. g., by outlet vanes tending to set up rotation in the opposite direction. This results in a decrease of energy of motion and therefore in a gain of pressure.

The invention will be further described with reference to the appended drawings in which:

Figure I is a developed plan of some of the vanes and blades of a single stage apparatus embodying the invention.

Figure II is a developed plan of some of the vanes and blades of a multi-stage apparatus embodying the invention.

Figures III and IV show the velocity diagrams of the arrangement of Figure I and Figure II respectively.

Figures V and VI show graphically the course of the static pressure variations of the fluid cor-

responding to the velocity variations indicated in Figures III and IV respectively.

Figure VII is a diagram in which blade sections are shown correlated to the radii of the blade elevation at which they occur.

Figure VIII is a longitudinal section of part of a portion of a cased multi-stage fan.

Figure IX is a diagram in which cross-sections of a rotor blade, an inlet guide vane, and an outlet guide vane are shown collated to the radii of the blade elevation at which they occur and so as to exhibit the geometric pitch of the blade and the variations in the inclination of the inlet and outlet guide vanes in the direction from tip to hub with respect to the axis.

With reference to Figures I, III and V, **2** indicates cross-sectional elements of inlet guide vanes; **3** cross-sectional elements of rotor blades; and **4** cross-sectional elements of outlet guide vanes, all at the same radial distance. α (alpha) indicates the angle of attack, and γ (gamma) the angle at which the fluid enters the rotor, i. e., the angle of inflow.

The general direction of fluid flow through the apparatus is parallel with the axis, and in the illustrated example its sense is assumed to be left to right, as indicated by arrows A. The sense of the rotation of the impeller or impellers is clockwise when viewed from the left and is indicated in some of the figures by arrows B.

The function of the inlet guide vanes **2** is to impart to the fluid entering the impeller blades a movement component which is circumferential and contrary in sense to the circumferential movement of the blades; that is, in the illustrated example, an anti-clockwise circumferential movement component. This movement component is referred to as counterswirl. The vanes may be assisted in performing this function by other means for changing fluid motion direction; but in all cases the inlet guide vanes **2** are arranged to determine the final direction of the fluid when it is delivered to the impeller. In order to produce the counterswirl the guide vanes **2** are helical and co-axial with the impeller and of the same helical hand as the impeller; and their concave surfaces face against the concave surfaces of the impeller blades. They are preferably of aerofoil cross-section in order to promote streamline flow. Moreover they usually decrease in width in the direction from tip to hub.

The proposal has been made to provide a screw impeller with inlet guide vanes which deliver the fluid to the impeller with a counterswirl of such magnitude as to counter-balance the impeller drag and so to cause the fluid to leave the impeller with pure axial movement; but in the present invention counterswirl is employed as an essential factor in pressure building, being for that purpose substantially in excess of the drag and applied to the whole of the fluid ingoing to the impeller, and utilized with an impeller which is structurally capable of producing and utilizing a counterswirl of such magnitude and so differentiated radially as to attain in practice the pressure rise latent in the counterswirl principle.

This principle may be explained with reference to Figures III and V which are respectively velocity and pressure diagrams of some arbitrarily chosen annular element of the fluid stream.

Let Va represent in magnitude and direction, the axial velocity set up by the impeller, in the fluid flowing to it. The guide vanes **2** divert the flow into direction Vi, thus tending to add to the axial component Va a circumferential component represented in magnitude by Vwa and opposite in sense to the sense of rotation of the impeller. Rotation of the impeller however tends to set up in the fluid the circumferential drag velocity represented by d, in the same sense as such rotation. The effective circumferential component of the velocity of the incoming fluid is therefore the algebraic sum of Vwa and d, represented by Vwe. Pva indicates the absolute linear velocity of the impeller blade at the chosen radius; so that $Pva+Vwe=Q$ is the effective fluid to blade circumferential velocity; and the resultant of Q and Va, viz. Vr is the velocity of inflow of the fluid relative to the blade. Provided the blade is of aerofoil section and the angle of attack α is maintained within proper limits, the pressure set up by the blade varies as the square of said velocity Vr; so that, to the extent that Pva is increased by addition of Vwe, so does the pressure set up by the impeller increase in a greater proportion. The circumferential velocity component Vwa being—at all radii—considerably greater than the drag velocity d, their algebraic sum, Vwe, is a velocity of substantial magnitude contrary in sense to the velocity of the blades. This results in a high value of Q and so of Vr; and the production by the impeller of very high fluid pressures. It is believed that the production of high pressures by the aid of counterswirl in excess of drag has not heretofore been attempted. By means of it and the other characteristics of the invention a cased screw fan can be built up which produces pressures comparable with those of centrifugal fans, for instance with manometric efficiencies ranging from 0.3 to 0.5 and more; while having considerably greater mechanical efficiency than a centrifugal fan.

However, velocity and pressure changes of the kind indicated by the above-mentioned diagrams cannot be obtained in magnitude sufficient to build up pressures substantially greater than those produced by fans of known design, or alternatively sufficient to obtain heretofore usual pressures with substantially less angular impeller speed, unless the impeller blade sections at the various radii are made adequately powerful.

Accordingly, the impeller blades are made throughout their length of a form known per se, viz., of aerofoil section, by which is meant a section defined by back and front surfaces so differently cambered that the section is curved in the direction of the blade width and so also as to make the section of substantial thickness relatively to its chord length and with its leading edge thicker than its trailing edge; such section progressively increasing, in the direction from tip to hub, in its structural thrust-producing factors, viz., its blade section width, total area, and preferably also the ratio of thickness to chord length, and the relative curvature at all sections being in conformity with the varying values of said factors.

Such increase is shown in Figure VII where C, D, E represent the cross-section of the blade at three different radii viz. the tip radius rc, an intermediate radius rd and the hub radius re respectively. It will be seen that the chords of the aerofoil sections, indicated at the different radii by cc, cd, ce, increase in length progressively from section C to section E and that the ratio of thickness t to chord length, that is, the relative thickness of the aerofoil section, also progressively increases so that the whole blade section area increases in the same direction. The relative curvature of the thus varying sections is adjusted in

the manner well known in aerofoil designing, to ensure that the factors mentioned co-operate to give the required lift or thrust combined with the optimum drag/lift ratios for the various sections of the blade. In practice the relative curvature remains constant, or, as is shown, increases in the direction from tip to hub.

The fluid leaves the rotor 3 with the absolute outlet velocity Ve of which the circumferential component has the value *Vwe* and direction opposite to the rotation of the rotor. According to the invention provision is made at the outlet end of the apparatus for converting said residual counterswirl *Vwe* into axial movement, with gain of pressure, by means of a helical guide vane assembly 4 co-axial with the impeller. Said assembly differs from any outlet guide vane assembly known to the inventor in two respects. Firstly its helical hand—or more particularly the helical hand of the tangent 7 (Figure III) to the median line at the receiving ends of its vanes—is the same as that of the chords of the impeller blades and of the inlet vane assembly 2. Secondly its concavity faces with the concavity of the impeller blades. A further characteristic of the assembly 4 is that the said tangent 7 makes a substantial angle, *b* Figure III, with the rotor axis so as to receive without shock the residual counterswirl from the impeller.

Figure V shows graphically the static pressure variations of the fluid during its passage through the apparatus.

The pressure drops during the passage of the fluid through the guide vanes 2, where the circumferential velocity is imparted to it. This drop of pressure is followed by a very considerable gain of pressure during its passage through the rotor, and by a further increase of pressure during the passage of the fluid through the vanes 4, where its remaining circumferential velocity is counteracted.

Figures III and V refer to conditions at the one stream element selected. Since the rotor blade velocity and the drag vary in magnitude according to the radial position of the blade element at which they occur, and the pitch angle of the blade is usually also different at different radii, the circumferential velocity component *Vwa* and the angle γ (gamma) may also be varied correspondingly at different radii. For instance assuming a rotor design with constant geometric pitch from tip to root of blade and constant angle of attack, then the angle γ (gamma) would decrease from tip to root of the inlet guide vane with corresponding rotation of the outlet guide vane, if present, toward parallelism with the axis in order to maintain the same proportionate increase in manometric efficiency over the whole working area.

Double-stage apparatus (Figure II) comprises inlet vanes 2, primary rotor blades 3, interstage vanes 5, secondary rotor blades 6 and outlet vanes 4.

The inlet vane elements 2, primary rotor blade elements 3 and outlet vane elements 4 correspond to the inlet vane elements 2, rotor blade elements 3 and outlet vane elements 4 of Figure I.

As illustrated in Figure IV the fluid entering the rotor 3 has imparted to it by the inlet vanes 2 a velocity *Vi* composed of the axial velocity component *Va* and the circumferential velocity component *Vwa*. During the passage of the fluid through the rotor 3 the circumferential velocity component *Vwa* is decreased by the drag *d* to *Vwe*; and the fluid thus leaves the rotor with the smaller absolute velocity Ve composed of the axial velocity component *Va* and the circumferential velocity component *Vwe*. The interstage vane assembly 5 (Figure II) is of the same helical hand as the inlet assembly 2 and as the impeller blades: and its component vanes have concave surfaces facing oppositely to the concavity of the impeller blades, and said vanes have the feature in common with the outlet vanes 4 that their tangents 7 (Figure IV) make a substantial angle *b* with the rotor axis. They thus receive fluid with aboslute velocity Ve and deliver it with an absolute velocity which, in most cases, is similar in direction and magnitude to *Vi*. During its passage through the second rotor the drag *d* decreases its circumferential velocity component *Vwa* to *Vwe*; thus the fluid leaves the second rotor with an absolute velocity Ve comprising the circumferential component *Vwe*. Thereafter the outlet vanes 4 impart to the fluid a circumferential velocity equal to and opposite to *Vwe* and thus counteract the circumferential velocity component *Vwe* so that the fluid leaves the vanes 4 substantially without circumferential velocity.

The pressure (see Figure VI) decreases during the passage of the fluid through vanes 2: is considerably increased in the first rotor 3: is somewhat decreased in the interstage vanes 5: is again considerably increased in the second rotor 6: and an additional gain in pressure is attained by the action of the outlet vanes 4.

In Figure VIII the rotors 3 and 6 are carried by the driving shaft 8 mounted in bearings 9 and positioned axially within the casing 10. The latter also encloses the inlet guide vanes 2, the interstage guide vanes 5, and the outlet guide vanes 4, if present: and is substantially cylindrical about said parts in order to keep the flow free from radial component.

In Figure IX, C, D and E represent the cross-sections of the rotor blade at three different radii, in the same manner as they are illustrated in Figure VII. F, G and H represent three aerofoil cross-sections of an inlet guide vane at the same radii. It will be seen that the inclination of the aerofoil section chords of said inlet guide vane to the axis decreases from tip to root, the chord inclination of the tip section F being the greatest and the chord inclination of the root section H being the smallest. I, K and L represent corresponding aerofoil cross-sections of an outlet guide vane, and it will be seen from the figure that the inclination of the aerofoil section chords to the axis decreases correspondingly with the decrease of chord inclination of said inlet guide vane sections. The decrease of chord inclination of the inlet guide vanes is, such that the angle of attack is substantially constant along the whole length of the rotor blade.

It is preferred to make the ratio of blade tip diameter to hub diameter such as itself to avoid reentry of air into the rotor, e. g., 3 or less to 1.

The present invention is concerned with the provision of excess counterswirl in screw propeller type machines, irrespective of the kind of pitch of the impeller blades. This invention is thus, to a certain extent, generic to the invention of my copending application, Serial No. 231,428, now matured into Patent No. 2,224,519, which deals with such apparatus in which counterswirl is produced and in which the impeller blades are of decreasing pitch towards the hub.

I claim:

1. A multi-stage screw type fluid propelling apparatus, comprising in each stage the combination of an impeller having blades of aerofoil cross-

section increasing in width and total area progressively in the direction from tip to hub with fluid inlet means comprising helical inlet guide vanes coaxial with the impeller, the concavity of which vanes faces in the circumferential direction opposite from that of the impeller blades to impart to the whole of the fluid ingoing to the impeller a counterswirl substantially in excess of the impeller drag to increase the difference between the velocity of the rotor and that of the incoming fluid, to consequently increase the pressure of fluid discharged by the rotor; the guide vanes being of the same helical hand as that of the impeller blades, and the tangents to the median lines of the interstage vanes, at their receiving ends, making a substantial angle with the axis.

2. A cased screw type fluid propelling apparatus, comprising an impeller having blades of aerofoil cross-section increasing in width and total area progressively in the direction from tip to hub, in combination with fluid inlet means comprising helical inlet guide vanes coaxial with the impeller, the concavity of which vanes faces, in the circumferential direction opposite from that of the impeller blades, to impart to the whole of the fluid ingoing to the impeller a counterswirl substantially in excess of the impeller drag to increase the difference between the velocity of the rotor and that of the incoming fluid, to consequently increase the pressure of fluid discharged by the rotor; and comprising a helical final outlet guide vane assembly coaxial with the rotor, the helical hand of said assembly being the same as that of the impeller blades, and the tangents to the median lines of the vane sections of said assembly at the receiving end making a substantial angle with the axis to convert the remaining excess counterswirl into an axial component and a consequent increase in pressure.

JOHN TAYLOR McINTYRE.