HIGH FLOW PUMP IMPELLER FOR LOW NET POSITIVE SUCTION HEAD AND METHOD OF DESIGNING SAME

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ABSTRACT

A centrifugal or axial-flow impeller has its blade elements inclined at a predetermined sweep angle $\gamma$ from the perpendicular to the direction of the approaching fluid being pumped. The sweep angle $\gamma$ is quite large, being in the inlet region of the impeller typically 45° or more.

2 Claims, 6 Drawing Figures
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Fig. 1

Fig. 2

Fig. 3

Fig. 4

INTERSECTION OF BLADE WITH CONICAL SURFACE NORMAL TO THE BLADE ELEMENTS

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HIGH FLOW PUMP IMPELLER FOR LOW NET POSITIVE SUCTION HEAD AND METHOD OF DESIGNING SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to centrifugal and axial-flow impellers for aircraft fuel booster pumps and methods for designing such impellers.

2. The Prior Art

Conventionally designed impeller blades are set so that their blade elements are perpendicular, or nearly so, to the concentric stream surfaces of revolution in the inlet region of the impeller. In other words, the sweep angle $\gamma$ is zero, or nearly so i.e., the blades have zero forward or backward sweep angle.

SUMMARY OF THE PRESENT INVENTION

The velocity relationships for fluid entering an impeller are illustrated by the vector diagrams that can be drawn on planes tangent to concentric stream surfaces of revolution formed by the incoming flow. Such a diagram consists of the fluid absolute inlet velocity $V$ and the impeller blade lineal speed $U$ at the radius (from the axis of rotation of the impeller) of the particular stream surface associated with the diagram in question. The velocity $W$ relative to the rotating impeller completes the vector diagram and is disposed at the flow angle $\beta$ with respect to $U$. The intersection of the impeller blade with this stream surface is set at an angle $\beta_1$ from the peripheral (U-) direction. The blade angle $\beta_1$ is usually equal or nearly equal to the flow angle $\beta$ to enable the impeller to receive the incoming fluid properly. The value of $\beta$ is directly associated with the rate at which fluid flows through the impeller because $\beta$ increases as the absolute inlet velocity $V$ increases.

In order that the nature and advantages of my invention may be understood it should be noted with respect to the geometrical relationship that a blade element is defined as the intersection of the blade surface with a meridional plane section through the impeller; i.e., a plane section containing the axis of rotation. If in this meridional plane a line perpendicular to a blade element at a point $P$ is investigated is rotated about the axis of rotation, it will generate a conical surface of revolution to which the blade element is perpendicular. It has been found that the angle $\beta_1$ between the intersection of the blade with this conical surface and the peripheral (U-) direction must be sufficiently small to insure successful pumping at low net positive suction head.

In a conventional impeller this conical surface coincides (or nearly coincides) with the particular stream surface of revolution that intersects the blade element in the same place because the blade elements are conventionally set so as to be perpendicular, or nearly so, to the stream surfaces. Thus, the blade angles $\beta_1$, and $\beta_2$ are conventionally equal and are in turn set at or near the flow angle $\beta$. The blade angles $\beta_1$ and $\beta_2$ can be said to be formed on planes that are tangent to the said conical and stream surfaces respectively. The same is true of the associated flow angles $\beta_1$ and $\beta_2$. Since the tangent of $\beta$ equals $V/U$ and that of $\beta_1$ equals $V_1/U_1$ where $V_1$ is the component of $V$ projected onto the plane in which $\beta_1$ lies, and since the two aforesaid planes are disposed from each other at the sweep angle $\gamma$, the flow angle $\beta_1$ will be smaller than $\beta$ for $\gamma \neq 0$. The same is true of the blade angles $\beta_{1\perp}$ and $\beta_2$, respectively.

It is the essential feature of this invention to employ large values of $\gamma$ in the design of an impeller. Thus, the impeller will have blades that are considerably swept forward or backward relative to the incoming flow. This allows $\beta_1$ to be much larger than $\beta_{1\perp}$. Since only the blade angle $\beta_{1\perp}$ needs to meet a smallness criterion, this non-conventional use of large inclinations $\gamma$ of the blade elements from perpendicularity to the incoming stream surfaces makes possible a correspondingly much larger maximum flow rate capability for a given impeller diameter and speed of rotation than is possible in conventional booster pump impellers in which $\beta_1$ cannot exceed $\beta_{1\perp}$ (and where correspondingly $\beta_1$ cannot exceed $\beta_{1\perp}$).

By virtue of such design procedure, an impeller of a pump for a low net positive suction head application is provided and maintains the desired low blade angle while at the same time increasing volume flow rate capabilities over those otherwise obtainable at the same rotative speed and inlet diameter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view of an impeller showing the velocity vectors at the inlet tip of the blade elements and the flow angles $\beta$ and $\beta_1$ formed thereby;

FIG. 2 is a view of a meridional (r-z) section through the impeller (i.e., a cross-section containing the axis of rotation) showing a forming step practiced in accordance with the principles of the present invention;

FIG. 3 is a view of the velocity vectors in a plane tangent to a stream surface of revolution along which the fluid flows through the impeller showing the blade angle $\beta_1$;

FIG. 4 is a view of the velocity vectors in the plane tangent to a conical surface of revolution generated by revolving the line X perpendicular to the blade elements in the inlet region of the impeller (and therefore at sweep angle $\gamma$ to the stream surface) about the axis of rotation and shows the inlet blade setting angle $\beta_{1\perp}$ in this plane, which is smaller than $\beta_1$;

FIG. 5 is a view of an impeller with forward swept blades incorporating the principles of the present invention; and

FIG. 6 is a fragmentary view of a helical impeller with swept back blades incorporating the principles of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

This invention allows the impeller of an aircraft fuel booster pump or other pump for low net positive suction head to be capable of operating at higher maximum volume flow rates at both high and low net positive suction head conditions, corresponding respectively to sea level and climb conditions for an aircraft fuel booster pump, while at the same time restricting the impeller inlet and outlet diameters and rotative speed to the same values that produce the lower maximum flow rates of conventionally designed impellers.

Referring specifically to FIG. 1 of the drawings, it will be noted there is shown a velocity diagram for fluid entering a centrifugal impeller at the blade tips. The fluid absolute inlet velocity is $V$, and the impeller blade lineal speed is shown as $U$. The velocity $W$ relative to the rotating impeller completes the vector diagram and it
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will be noted that the vector \( W \) is at an angle \( \beta \) with respect to \( U \).

As shown in FIG. 3, the trace of an impeller blade on a fluid stream surface of revolution is set at the angle \( \beta_0 \) which is equal or nearly equal to the flow angle \( \beta \) to enable the impeller to receive the incoming fluid properly. But it is known that conventional impellers running at maximum allowable tip speed \( U \) for receiving boiling fluid, which, at a given rotative speed, corresponds to the largest possible impeller inlet diameter, cannot have conventional blades set at more than some limiting value of \( \beta_0 \) without impairing the ability of the impeller to pump the associated maximum possible flow rate of such boiling fluid.

Thus, referring to FIG. 2, it will be noted that conventionally designed blades are set so that their elements, or their traces on the \( r-z \) cross-section plane, are perpendicular to the concentric stream surfaces of revolution whose traces on the \( r-z \) plane usually appear as \( z \)-directed axial lines in the inlet region of the impeller and as shown in this illustrative example. Hence, conventional blades have essentially radial elements in the inlet region.

In accordance with this invention, it is contemplated that the blade elements in the inlet region of the impeller will be inclined at a sweep angle \( \gamma \) of about 45° or more to their conventional setting, i.e., they are deliberately made not even nearly perpendicular to the stream surfaces of revolution containing \( V \) (FIG. 3) i.e., swept forward or backward. As a consequence, a larger value of \( \beta_0 \) than conventional designs permit can be accommodated in accordance with this invention so long as the smaller angle \( \beta_{0,1} \) does not exceed the limiting value conventionally associated with \( \beta_0 \).

FIG. 4 shows the projection of the velocity vector diagram of FIG. 3 into the plane perpendicular to the blade element. The flow angle \( \beta_1 \) will be smaller than \( \beta \) if the blade elements in the inlet region of the impeller are inclined at an angle \( \gamma \) in accordance with this invention.

The impeller is made or fabricated by conventional manufacturing techniques, however, the values of central angle \( \theta \) of each blade element are specified by the designer in accordance with this invention. In one means of manufacture, for example, as shown in FIG. 2, a blade cutting tool is utilized and in the inlet region of the impeller the tool is disposed at a cutting angle \( \gamma \) from the radial direction corresponding to the desired angle of the blade element from perpendicularity to the axially approaching flow velocity vector \( V \).

The basis of the discovery disclosed herein is that the ability of a given impeller blade to pumps boiling fluid depends solely on the component of fluid motion perpendicular to its blade elements in the portion of the blading near the inlet. In a conventionally designed pump, regard in setting the blades is had only for the velocity vector \( V \). In the high flow pump impeller of the present invention, regard is had for the velocity component \( V \), at angle \( \gamma \) from \( V \), ignoring the other component of \( V \) parallel to the blade element. It will be noted that tangent

\[ \beta_1 = \gamma \times V_1 / V \times (V_1 / V) = (\cos \gamma) \times (\text{tangent } \beta_1) \]

Thus, for \( \beta > 0 \), \( \beta_1 \) will be less than \( \beta \).

As \( V_1 \) and \( U \) determine the limiting angle \( \beta_1 \), FIG. 2 shows that the larger the sweep or inclination \( \gamma \) of the blade elements, the greater the approaching inlet velocity \( V \) can be for a fixed value of \( \beta_0 \) and therefore of \( V_1 \) at fixed \( U \). Since total volume flow rate is \( V \) times the area normal to it, the greater value of \( V \) provides a correspondingly higher volume flow rate.

Accordingly, the inclination of the impeller blade elements in the inlet region of the impeller at an angle not even nearly perpendicular to the direction of the approaching fluid permits a corresponding increase of fluid volume flow rate over that of conventionally bladed impellers of equal inlet diameter operating at the same rotative speed. As applied to aircraft fuel booster pumps or other pumps operating at or near zero net positive suction head, such increases of attainable fluid volume flow rate are obtainable at both high and low net positive suction head conditions, for example, sea level and boiling fuel conditions in an aircraft fuel booster pump application.

Referring to FIGS. 5 and 6, there is illustrated in each of the respective views a helical impeller constructed in accordance with the principles of the present invention, FIG. 6 showing a helical impeller with swept back blades, i.e., blades having sweep in accordance with the angle \( \alpha \) and Exhibit 1 showing a helical impeller with forwardly swept blades i.e., blades having a forward sweep in accordance with the angle \( \gamma \). The pertinent angles in relationships as well as the direction of fluid flow corresponding to those already identified in the drawings appear on both of the Figures.

Although minor modifications might be suggested by those versed in the art, I wish to embody within the scope of the patent warranted hereon all such modifications as reasonably and properly come within the scope of my contribution to the art.

I claim as my invention:

1. The method of predetermining the structural characteristics of a rotatable impeller for a pump, the fluid entering having an absolute inlet velocity \( V \); impeller blade lineal speed of \( U \) and the velocity relative to the rotating impeller of \( W \); the vector \( W \) being at an angle of \( \beta \) relative to \( U \), which method includes the steps of inclining the blade elements in the inlet region i.e., sweeping the blades forwardly or backwardly at an inclined angle \( \gamma \) such that tangent \( \beta_{\gamma} = (\cos \gamma) \times (\text{tangent } \beta) \), thus providing that \( \beta_{\gamma} \) will be smaller than \( \beta \) and the pump impeller will have increased volume rate capabilities at a low net positive suction head.

2. The method of predetermining the structural characteristics of a rotatable impeller as defined in claim 1 and further characterized by the step of inclining the blade elements in the inlet region comprising sweeping the blades forwardly or backwardly at a sweep angle \( \gamma \) of 45° or greater so as to place said blade elements in a highly non-perpendicular relationship relative to the direction of the approaching fluid being pumped.