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FLOATING NON-STICKING BLADES

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This invention relates to floating non-sticking blades and more specifically to doctor blades or vanes adapted for use in fluid pumps, fluid motors, journal bearings and the like, operating on the viscosity or fluid wedge principle, as exemplified by the pumps shown in Modrovsky and Sherwood application Ser. No. 465,078, filed Oct. 27, 1954, now Patent No. 2,777,394, and in Fazekas and Modrey application Ser. No. 563,750, filed Feb. 6, 1956.

It is an object of the invention to provide such blades which will effectively serve the purpose of forming a sufficiently positive stop for the fluid entrained by relative motion of a rotor and a stator separated by a small clearance space, and which will embody self-contained and self-actuating means to adjust the blades automatically for rapidly or slowly changing conditions in order to maintain proper blade position relative to the rotor to accomplish the first object, i. e., the blades should close, to a considerable extent, the clearance space but must be free to float and not be rigidly fixed in position or subject to binding or jamming under any possible operating conditions.

The desired result is attained, in the devices shown and described herein (where the blades are assumed to be mounted in a fixed stator to float on a thin fluid film on the surface of a cylindrical rotor), by drawing from the blade surface nearest the rotor a fluid stream which is conducted to another blade surface and utilized there to form a fluid cushion, under pressure, which enables the blade to "float" as just explained.

Practical embodiments of the invention are shown in the accompanying drawings, wherein:

Fig. 1 represents a detail section through a stator, rotor and blades, taken in a plane perpendicular to the axis of the rotor;

Fig. 1a represents a diagram and graph showing the pressure pattern associated with a blade of the type shown in Fig. 1;

Fig. 2 represents a side elevation of a blade;

Fig. 3 represents a detail section, as in Fig. 1, but showing a modified form of blade;

Fig. 3a represents a diagram and graph showing the pressure pattern associated with a blade of the type shown in Fig. 3;

Fig. 4 represents a detail section, as in Fig. 1, but showing another modified form of blade;

Fig. 5 represents a side elevation of the blade shown in Fig. 4, and

Fig. 6 represents a detail section of a blade slightly modified from that shown in Fig. 4.

Referring to the drawings, a rotor R of cylindrical form is assumed to be rotating in a cylindrical chamber in the stator C with a clearance, for instance, of several thousandths of an inch, the stator being provided with one or more axially disposed slots 1 each adapted to accommodate a doctor blade 2 (or modification thereof). A fluid to be pumped is supplied to the clearance at a

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point or zone at a relatively substantial distance upstream from each blade, considered with respect to the direction of rotation of the rotor, and the fluid entrained by the surface of the rotor and stopped by the interposition of the blade is withdrawn under pressure from a point or zone upstream from, and relatively close to, each blade; such supply and delivery points are indicated diagrammatically at S and D, respectively.

In the form shown in Fig. 1 the blade 2 is substantially rectangular in cross section and has a close sliding fit in the slot 1, which is deep enough so that an appreciable space 1' is left between the back surface of the blade and the back wall 1'' of the slot. The working surface 3 of the blade is so disposed that the upstream edge 3' lies farthest from the surface of the rotor while the downstream edge 3'' approaches closest to said surface. The clearance at 3' is designated b_1 , and that at 3'' is designated b_2 . It is evident that rotation of the rotor in the direction indicated will cause the formation of a "wedge" of fluid under pressure in the zone between the working surface 3 of the blade and the adjacent surface of the rotor. One or more passages 4 traverse the blade from a point shown as being approximately midway between the edges 3' and 3'' to the back surface of the blade, thus connecting the zone of the fluid wedge with the space in the slot behind the blade.

Fig. 1a represents graphically a normal pressure pattern in the zone just referred to, L being the length of the wedge path, P being the wedge pressure at any point x distance from edge 3' and P max. being maximum pressure.

A floating blade of the type shown will maintain b_2 sensibly constant over the complete range of speeds and viscosities normally encountered. By locating the passages 4 at a point x at which P equals P average, so that they are somewhat upstream from the point $X_{P \text{ max.}}$, at which P max. occurs, it will be found that, as the blade tends to lift, P max. moves toward the edge 3' thus forcing fluid at higher than average pressure through the passages 4 to the space in the back of the slot 1 where it acts to force the blade downward again and to reestablish the normal or optimum clearance at b_2 . If the blade should move to contact the rotor, the hydraulic restoring mechanism functions in an opposite manner. That is, P max. moves downstream causing P at rotor end of passage 4 to be less than P average, thus forcing fluid from space in back of slot 1 to surface 3 where it acts to equalize pressures and cause blade to lift.

The location of P max. is defined by the following equation:

$$X_{P \text{ max.}} = \frac{b_1 L}{b_1 + b_2} \quad I$$

When the blade moves away from the rotor the denominator increases faster than the numerator and X decreases, as previously explained, thus automatically restoring the most desirable condition. Since the passages through the blade are small (e. g., .020" in a small pump) relative to the fluid displaced by the turning of the rotor or other motion, damping will be effective to preclude the possibility of any vibration.

Further mathematical confirmation of the foregoing may be visualized as follows:

Total lifting force per unit width =

$$F = \frac{6uVL^2}{b_2^2 \left(\frac{b_1}{b_2} - 1 \right)^2} \left[\ln \frac{b_1}{b_2} - 2 \left(\frac{\frac{b_1}{b_2} - 1}{\frac{b_1}{b_2} + 1} \right) \right] \quad II$$

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$$\text{Average pressure} = \bar{P} = \frac{F}{L} \quad \text{III}$$

Combining Equations II and III:

$$\text{Average pressure} = \bar{P} = \frac{6uVL}{b_2^2 \left(\frac{b_1}{b_2} - 1 \right)^2} \left[\ln \frac{b_1}{b_2} - 2 \left(\frac{\frac{b_1}{b_2} - 1}{\frac{b_1}{b_2} + 1} \right) \right] \quad \text{IV}$$

Pressure at any $x = P$

$$P = \frac{6uVx \left[b_1 - \frac{x(b_1 - b_2)}{L} - b_2 \right]}{\left[b_1 - \frac{x(b_1 - b_2)}{L} \right]^2 [b_1 + b_2]} \quad \text{V}$$

Wherein,

 b_1 = clearance at 3' b_2 = clearance at 3'' L = length of wedge path V = velocity x = any distance from edge 3' toward 3'' u = absolute viscosity

When the Formulae IV and V are equated $6uV$ cancels showing that x is independent of speed and viscosity.

In Figs. 2 and 3 there is shown a blade 5 similar to that of Fig. 1 but having its working surface 6 formed as a concave surface substantially concentric with the surface of the rotor when spaced for optimum operation. The blade is provided with passages 7 extending from the midpoint of surface 6 to the enclosed space at the back of the blade, as before. In this case the fluid entrained by the rotor reaches its highest pressure at the upstream edge 6' of the blade; from that point some of it may inadvertently leak along the blade to the space at the back while some passes between the blade and the rotor, losing pressure in a straight line gradient from edge 6' to edge 6'' where it is necessarily at inlet pressure.

Although leakage can occur along the upstream side of the blade, bleeding P max. pressure into the space behind the blade, the pressure in this space will be automatically maintained at pressures averaging $\frac{1}{2} P$ max. because the passages 7 are properly sized and located in a $\frac{1}{2} P$ max. pressure zone at surface 6, and the projected area of surface 6 is equal to the projected area of the back of the blade. If the passages 7 are so small as to prevent prompt stabilization of the fluid back of the blade at approximately $\frac{1}{2} P$ max., the blade will tend to be temporarily urged into closer relation with the rotor.

If the blade lifts, P average on the working surface 6 will fall but P at passage 7 will be greater than new P average by virtue of the addition of a pressure pattern caused by an incremental fluid wedge formed by the downstream edge 6'' of the blade creating a smaller clearance than at the upstream edge 6'. This results from the upstream edge 6' being in line radially with the center of the rotor and the downstream edge 6'' off-center. Thus the fluid behind the blade attains a pressure in excess of P average on the working surface 6 and so forces the blade toward the rotor.

If the blade moves into contact with the rotor, the clearance at upstream edge 6' becomes zero while the clearance at the downstream edge 6'' is still a significant value radially, thus forming a low pressure zone between working surface 6 and the rotor; the pressure pattern decreases from 6'' to 6'. Hence, fluid will flow from the space at the back of the blade to low pressure zone and equalize at pressure value existing at passage 7 opening on working surface 6. Since P average on the working surface is greater than the pressure at the passage opening, an unbalanced force will exist to lift the blade back to its normal operating position.

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The blade 8 shown in Fig. 4 is approximately square in cross-section and is disposed in a slot 9 of corresponding size and shape in which there is incorporated a biasing spring 9' which acts radially. The working surface 10 of the blade is recessed longitudinally as shown at 10' and the side surfaces 11 and 12 are likewise recessed to leave only narrow lands in position to form a close sliding fit with the side walls of the slot 9. A plurality of small passages 13 connect the recess 10' to the recess 12 on the downstream side. In operation, the pressure in recess 10' under such a blade 8 is higher than at other points along the working surface 10, due to the wedge effect; as the fluid at high pressure is conducted by the passages 13 to the downstream face 12 of the blade it is effective to equalize (or even exceed) the force on the opposite face 11. The form of blade shown in Fig. 6 differs from that in Figs. 4 and 5 only by having an additional recess 14 in the top face. The function of this recess is to provide an effective pressure area even though the back surface of the blade may contact the end of the slot under some extreme condition. Both forms exhibit the same operating characteristics and the letters applied to Fig. 6 represent the same factors as are involved in Fig. 4; a is the height of the blade, c is the distance from its upstream face to its point of "contact" with the rotor, d is its width, e is the height of each land bounding the lateral recesses, P is the fluid pressure at the upstream edge of the blade, and ΔP is the incremental pressure in the recess 10'. For elimination of sticking or jamming, per unit length of blade,

$$(P + \Delta P)(a - 2e) \geq Pa \text{ ----}$$

For vertical balance, if the blade should move to contact the rotor (and since the fluid necessarily leaks past the blade into the closed upper part of the slot), where F is the force of the biasing spring 9',

$$\left(P + \frac{\Delta P}{2} \right) c > Pd + F$$

Thus with proper design, average pressure on the working surface of the blade becomes greater than the total force on the back surface of the blade and so restores the blade to proper clearance with the rotor. If the blade lifts, average pressure on the working surface is only slightly greater than that on the back surface of the blade and so is overcome by the force of biasing spring 9' which increases with lifting motion of the blade, thus again restoring the blade to proper clearance with the rotor.

Referring to the parts as shown in the drawing, it will be understood that fluid pumps, fluid motors, journal bearings, or the like in which such blades are used may employ a plurality of blades disposed symmetrically (or otherwise) and mounted in any position whatever with respect to the earth's surface—upside down, sideways, on end, etc. As an order of magnitude, the blades presently contemplated are conceived as having a height of about one inch or less, a length of a few inches and being adapted for use in connection with a viscous fluid such as oil in a clearance space measured in thousandths or hundredths of an inch. (In the drawings, certain clearances and dimensions have been exaggerated for purposes of illustration.) Referring to blade 8 of Figs. 4, 5 and 6, in a small blade, one inch square or less, the total clearance between the lateral lands and the walls of the slot may be no greater than .005", and the width (height) c of each land may be no greater than $0.05a$.

The wording "close sliding fit" used herein shall be construed to mean a fit that:

- (a) imposes little or no binding restriction to blade motion and that
- (b) limits leakages to or from the chamber above the blade to such negligible values that the desired pressure relations will not be significantly affected.

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It will be evident that blades made in accordance with the principles set forth herein embody self-contained and self-actuating means for balancing the hydraulic forces to which they are exposed in such a manner that binding, sticking and jamming of the blades in their slots cannot occur. It will be understood, further, that various changes may be made in the form, construction and arrangement of the parts shown, without departing from the spirit and scope of the invention.

What I claim is:

1. In a fluid pump, a fluid motor, journal bearing or the like comprising a rotor of circular cross-section and a stator separated by a substantially uniform clearance space of constant volume to which fluid is supplied and from which it is delivered under pressure, a doctor blade construction which includes, a slot formed in the stator and opening only into said clearance space, and a doctor blade of substantially rectangular cross-sectional outline located and movable in said slot with a close sliding fit, said blade having its bottom surface disposed adjacent to the surface of the rotor without contacting said surface, and being provided with at least one fluid passage opening at one end to said bottom surface intermediate between the upstream and downstream edges thereof, considered with respect to the direction of movement of the rotor surface while operating as a pump, and at the other end to a point on another surface of the blade within said slot.

2. A blade construction according to claim 1 in which the said other surface of the blade is the upper surface thereof.

3. A blade construction according to claim 1 in which the said other surface of the blade is the downstream side thereof.

4. A blade construction according to claim 1 in which said bottom surface lies farthest from said rotor surface

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at a point adjacent the upstream side of the blade and lies closest to said rotor surface at a point adjacent the downstream side of the blade.

5. A blade construction according to claim 4 in which the said other surface of the blade is the upper surface thereof.

6. A blade construction according to claim 4 in which the said other surface of the blade is the downstream side thereof.

7. A blade construction according to claim 1 in which said bottom surface is shaped to be concentric with the rotor surface and so disposed for optimum operation as to lie at all points substantially equidistant from said rotor surface.

8. A blade construction according to claim 1 in which the said bottom surface is provided with a groove extending lengthwise of the blade and in which the first-named end of said passage opens to said groove.

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