

Design And Fabrication of Vortex Pump

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ABSTRACT: Basically pumps are turbo machines that consume work and impart energy to the fluid. It is used various applications such as pumping water from wells, pond filtering and aeration, in the car industry for water-cooling and fuel injection, in the energy industry for pumping oil and natural gas or for operating cooling towers. Especially centrifugal pumps which belongs to the category of non positive displacement [output fluctuates with the speed of rotation of impeller] are used to transport fluids by the conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow. The rotational energy typically comes from an engine or electric motor. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits. They are used in various applications such as water, petroleum, sewage.

As mechanical engineers, we aim to solve the few of the above problems whilst preserving the advantages of a centrifugal pump simply because of the simple and efficient working principle involved, keeping in mind on cutting down on the manufacturing cost as well as simplifying the design of the volute casing. In order to meet the above specified requirements, a bladeless pump which works on the theory that real fluids have viscosity which exerts a drag force on the disc causing the fluid to exit in a direction perpendicular to axis of rotation after gaining kinetic energy and thus achieving the objective of transporting high viscous fluids efficiently, when compared to a centrifugal pump.

The scope of this pump can be further extended to a bladeless rugged turbine with high efficiency. The turbine can work on the same principle as the pump, only difference is that a working fluid (compressed air) drives the blade which in turn drives the shaft and can be used to generate electricity when coupled with an electric motor

KEYWORDS: Boundary layer effect, Centrifugal Force, Viscosity, Skin Friction Drag.

I. INTRODUCTION

A fluid is defined as a material which will continue to deform with the application of shear force however small the force may be. If the density of a fluid varies significantly due to moderate changes in pressure or temperature, then the fluid is called compressible fluid. If the change in density of a fluid is small due to changes in temperature and or pressure, then the fluid is called incompressible fluid.

Viscosity as a necessary evil

Viscosity is that property of a real fluid by virtue of which it offers resistance to shear force. Newton's law of viscosity states that the shear force to be applied for a deformation rate of (du/dy) over an area A is given by,

The positive displacement pump operates by alternating of filling a cavity and then displacing a given volume of liquid. The positive displacement pump delivers a constant volume of liquid for each cycle against varying discharge pressure or head.

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The positive displacement pump can be classified as:

1. Reciprocating pumps - piston, plunger and diaphragm
2. Power pumps
3. Steam pumps
4. Rotary pumps - gear, lobe, screw, vane, regenerative (peripheral) and progressive cavity

Rotodynamic Pumps

A rotodynamic pump is a device where mechanical energy is transferred from the rotor to the fluid by the principle of fluid motion through it. The energy of the fluid can be sensed from the pressure and velocity of the fluid at the delivery end of the pump. Therefore, it is essentially a turbine in reverse. Like turbines, pumps are classified according to the main direction of fluid path through them like radial flow or centrifugal, axial flow and mixed flow types.

The centrifugal or roto-dynamic pump produce a head and a flow by increasing the velocity of the liquid through the machine with the help of a rotating vane impeller. Centrifugal pumps include radial, axial and mixed flow units.

Centrifugal pumps can further be classified as

1. End suction pumps
2. In-line pumps
3. Double suction pumps
4. Vertical multistage pumps
5. Horizontal multistage pumps
6. Submersible pumps
7. Self-priming pumps
8. Axial-flow pumps
9. Regenerative pumps

Selecting between Centrifugal or Positive Displacement Pumps Based on Flow Rate and Pressure Head

The two types of pumps behave very differently regarding pressure head and flow rate:

1. The Centrifugal Pump has varying flow depending on the system pressure or head

2. The Positive Displacement Pump has more or less a constant flow regardless of the system pressure or head. Positive Displacement pumps generally gives more pressure than Centrifugal Pumps.

Based on Capacity and Viscosity

Another major difference between the pump types is the effect of viscosity on the capacity:

1. In the Centrifugal Pump the flow is reduced when the viscosity is increased
2. In the Positive Displacement Pump the flow is increased when viscosity is increased

Liquids with high viscosity fill the clearances of a Positive Displacement Pump causing a higher volumetric efficiency and a Positive Displacement Pump is better suited for high viscosity applications. A Centrifugal Pump becomes very inefficient at even modest viscosity.

Mechanical Efficiency

The pumps behave different considering mechanical efficiency as well.

1. Changing the system pressure or head has little or no effect on the flow rate in the Positive Displacement Pump
2. Changing the system pressure or head has a dramatic effect on the flow rate in the Centrifugal Pump

Net Positive Suction Head – NPSH

Another consideration is the Net Positive Suction Head NPSH.

1. In a Centrifugal Pump, NPSH varies as a function of flow determined by pressure
2. In a Positive Displacement Pump, NPSH varies as a function of flow determined by speed. Reducing the speed of the Positive Displacement Pump, reduces the NPSH

II. THEORY OF OPERATION

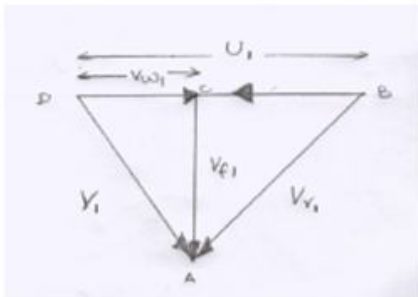
Every real fluid has viscosity, which causes the fluid to resist the relative motion of immersed objects through them as well as to the motion of layers with differing velocities within them. This property of real fluids causes a phenomenon called drag. Drag is generally of two types – Skin friction drag and pressure drag. The fluid adheres to the surface causing skin friction drag. Applying this principle across a design similar to that of a centrifugal pump, which is simpler but at the same time more efficient for pumping high viscous fluids. The design now is a series of stage wise bladeless rotors or discs which are driven by a motor, which take part in the pumping action. As flow enters the pump, the fluid interacts with the surface of the disks through the boundary layer effect and adhesion to enable a shearing stress on the surface of the disks. Adhesion is the tendency of dissimilar molecules to cling together due to attractive forces. The thin layer of fluid that interacts with the disk surface in this way is called the boundary layer, and the interaction of the fluid with the solid surface is called the boundary layer effect. As a result of this effect, the propelling fluid follows a rapidly accelerated spiral path along the disk faces until it reaches a suitable exit. Because the fluid moves in natural paths of least resistance, free from the constraints and disruptive forces caused by vanes or blades, it experiences gradual changes in velocity and direction. This in turn helps in transporting the liquid. So, this pumping principle involves the principle of skin friction drag and the fluid enters near the centre gains centrifugal force and is thrown out radially perpendicular to axis of rotation.

Assumptions

1. Incompressible Flow
2. Inviscid Flow with regards to the Vortex model
3. Blasius Flow as opposed to Couette or Poiseuille flow
4. Multiple disk gaps have an effect on flow
5. Tangential speed of the disks is equal to the inlet speed of the air

VELOCITY TRIANGLE

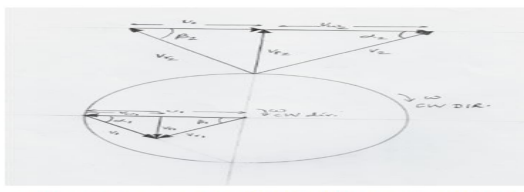
INLET VELOCITY TRIANGLE



AD = V_1 , AB = V_{r1} , AC = V_{t1}
BD (←) = U_1 , CD (→) = V_{w1}

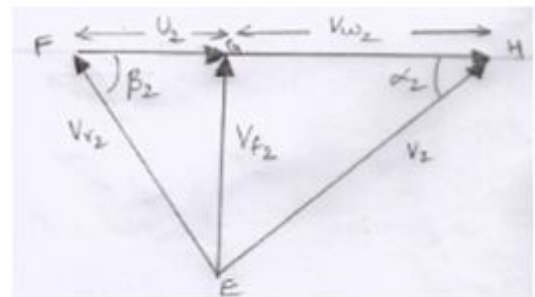
Figure 1

Figure 2



VELOCITY TRIANGLES AT INLET AND OUTLET OF THE PUMP

OUTLET VELOCITY TRIANGLE



EH = V_2 , EF = V_{r2} , EG = V_{t2}
FG (→) = U_2 , GH (→) = V_{w2}

Figure 3

III DESIGN OF PARTS

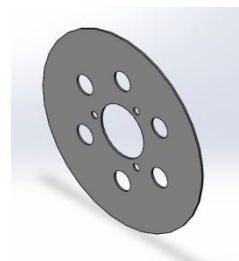


Figure 4 – RUNNER PLATE

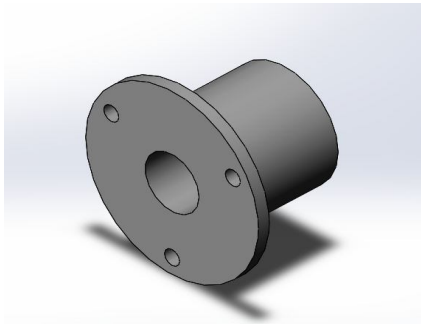


Figure 5 – TOP HAT



Figure 6 - SHAFT

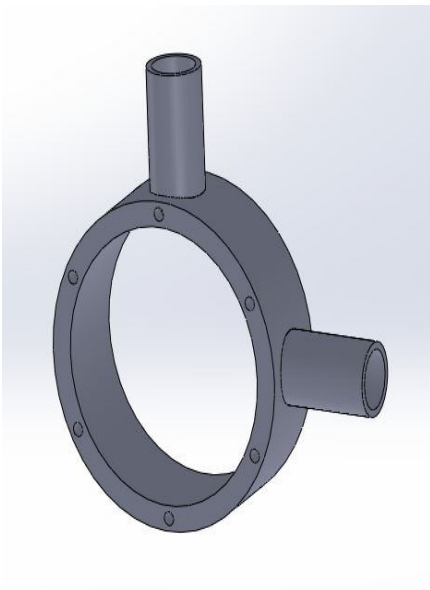


Figure 7 - PLATE HOUSING

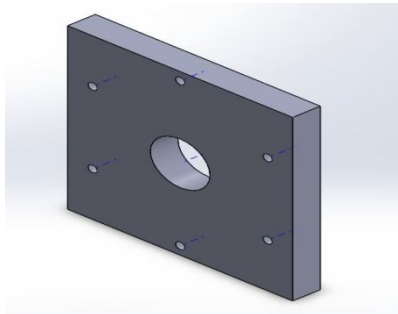


Figure 8 - HOUSING

Figure 9- ROTOR ASSEMBLY ON SHAFT SHAFT

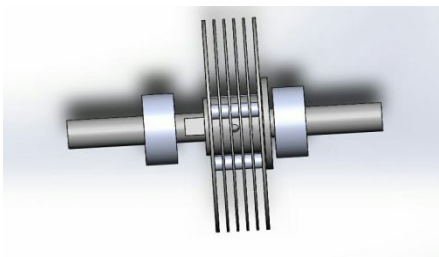


Figure 10- ROTOR ASSEMBLY ON



Figure 11 – FINAL ASSEMBLY

IV CALCULATION

For the calculation, following idealizations were adopted:

1. India Then the actual discharge can be estimated as , $Q_{actual} = (0.5 \text{ litres}) / (16.34s)$
So, $Q_{actual} = 0.03059 \text{ litres/sec} = 3.059 * 10^{-5} \text{ metre}^3 / \text{sec}$
The internal diameter of the discharge pipe is, 2 cm
The cross sectional area of the discharge pipe = $(\pi/4) * (2 * 10^{-2})^2$
 $= 3.14159 * 10^{-4} \text{ metre}^2$

Discharge, $Q_{actual} = \text{Exit Velocity} * \text{Exit cross sectional area of discharge pipe}$

Then, exit velocity, $V_{EXIT} = Q_{actual} / \text{Exit cross sectional area}$

$$V_{EXIT} = (3.059 * 10^{-5} \text{ metre}^3 / \text{sec}) / (3.14159 * 10^{-4} \text{ metre}^2)$$

$$V_{EXIT} = 0.0974 \text{ m /sec}$$

Theoretical Discharge,

$$Q_{theoretical} = 3.8721 * 10^{-5} \text{ metre}^3 / \text{sec}$$

For theoretical Torque,

$$\text{Torque}_{THEORETICAL} = I * \alpha \text{ Nm}$$

I = Moment of inertia of disc, in kg-m^2

α = Angular Acceleration , rad/sec^2

$$I \text{ for thin disc} = m * r^2 / 2$$

$$\text{mass of disc, } m = 1.5 \text{ kg [} 0.5 \text{ kg } * 3 \text{ discs]}$$

$$\text{Radius of disc , } r = 97.5 * 10^{-3} \text{ metres}$$

$$I = 1.5 * (97.5 * 10^{-3})^2 / 2$$

$$= 7.12968 * 10^{-3} \text{ kg-metre}^2$$

$$\alpha = \text{rate of change of angular velocity} = 2 * \pi * (N - 0) / 60 \text{ rad/sec}^2 = 150.796 \text{ rad/sec}^2$$

$$\text{Torque}_{\text{THEORETICAL}} = 7.12968 * 10^{-3} * 150.796$$

$$= 1.075 \text{ Nm}$$

$$\text{Volumetric Efficiency, } \eta_{\text{VOLUMETRIC}} = Q_{\text{actual}} / Q_{\text{theoretical}} * 100$$

$$\eta_{\text{VOLUMETRIC}} = ((3.058 * 10^{-5}) / (3.8721 * 10^{-5})) * 100 = 78.97 \%$$

$$\text{Mechanical Efficiency, } \eta_{\text{MECHANICAL}} = \text{Theoretical Torque} / \text{Actual Torque} * 100$$

$$\eta_{\text{MECHANICAL}} = (1.075 / 1.472) * 100 = 73.029 \%$$

$$\text{Overall Efficiency, } \eta_{\text{OVERALL}} = \eta_{\text{VOLUMETRIC}} * \eta_{\text{MECHANICAL}} = (78.97 * 73.029) / 100$$

$$\eta_{\text{OVERALL}} = 57.67 \%$$

1. Net head developed , $H = (V_{w2} U_2 - V_{w1} U_1) / g$

V_{w2} , V_{w1} - Tangential Velocity at outlet and inlet respectively in metre per second

U_1 , U_2 - Linear velocity of rotor at outlet and inlet respectively in metre per second

We know that the radius at which fluid enters and exits are the same. So for a given RPM, the linear velocity of rotor is constant. $U_1 = U_2 = U$

$$= \pi * D * N / 60$$

where D = diameter of disc

It can be assumed that the tangential velocity component of fluid at entrance is negligible when compared to tangential component of fluid at exit.

so, V_{w1} approximately is zero.

$$\text{Then, Net head developed } H = (U * V_{w2}) / g$$

The flow velocity at exit has already been found out i.e.

$$V_{\text{EXIT}} = 0.0974 \text{ m/s} = V_{w2} \text{ [ASSUMPTION]}$$

Then net head developed ,

$$H = (\pi * D * N / 60) * V_{w2} / g$$

$$H = ((\pi * 0.195 * 1440) / 60) * 0.0974 / 9.81$$

$$\text{Net Pressure head developed , } H = 0.1459 \text{ metres}$$

2. Reynold's number , $Re = V_{\text{EXIT}} * t / \nu$

Where V - Velocity of fluid flowing over thin disc

t - Thickness of thin disc

ν - Kinematic viscosity of fluid/water

At temperature of 30° C, the kinematic viscosity of water is $0.801 * 10^{-6} \text{ metre}^2/\text{sec}$

$$\text{Then optimized , } Re = (4/3) * (V_{\text{EXIT}} * t / \nu)$$

$$Re = ((4/3) * (0.0974 * (3 * 10^{-3})) / (0.801 * 10^{-6}))$$

$$Re = 486.39$$

For laminar flow consideration

$$Re < 2300$$

The flow obtained happens to be purely laminar although transitional boundary layer formations are also evident in practical simulation.

3. Boundary layer Thickness, $\delta_{lam} = 5 * \sqrt{(v/V)}$

Where, V - Velocity of fluid flowing over thin disc

v - Kinematic viscosity of fluid

At temperature of 30° C, the kinematic viscosity of water is $0.801 * 10^{-6}$ metre²/sec

$$\delta_{lam} = 5 * \sqrt{(0.801 * 10^{-6}) / 0.0974}$$

$$\delta_{lam} = 0.0143 \text{ metres}$$

4. Theoretically,

Disc Spacing, $s = \pi * \sqrt{(v/\omega)}$ meters

$$s = \pi * \sqrt{(0.801 * 10^{-6}) / (2 * \pi * N) / 60}$$
 meters

$$s = 0.0002289 \text{ metres}$$

It is difficult to achieve a disc spacing of 0.0002289 metres practically.

For this reason the spacing between discs is assumed to be as same as the boundary layer thickness formed

V. CONCLUSION

Our missions in this research were to

1. Design a simple pump compared to the conventional ones being used
2. Handle high viscous fluids
3. Better efficiency
4. Easy to fabricate at low cost.

The potential advantages of **VORTEX PUMP** over **CENTRIFUGAL PUMPS** are as follows

1. Reduced turbulent flow stresses compared to a bladed impeller.
2. Elimination of blade to blade leakage flow.
3. Absence of cavitation conditions.
4. Gentler fluid handling due to slow momentum change in the fluid.
5. More uniform forces due to the absence of blades.
6. Significantly reduced cost due to simplicity of manufacturing and assembly.
7. The design and robustness, which is extremely important for survivability in harsh environments

The pump rely on viscous drag or the boundary layer of the fluid to transfer energy to the fluid and as a result can pump fluids over a wide range of viscosity, which can be very beneficial if the fluid being pumped becomes viscous in low temperatures

The flow over thin disc model can be safely assumed as a model of laminar flow for best results. Transitional as well turbulent boundary layer model tend to happen practically but can be neglected because their effect on the flow model is not as influential as laminar boundary and also its beyond the scope of this research of the project which aims at applying basic engineering principle to achieve max results.

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VII. FUTURE SCOPE

Sewage pumping: the conventional pumps with blades tend to clog easily when pumping highly viscous fluids, we can overcome this difficulty by replacing it with the futuristic bladeless pumps which rely on boundary layer effect and hence achieve effective pumping at low cost.

Rankine cycle - Using a vortex pump reduces the back work ratio and energy destruction thus leading to an increase in the 1st law efficiency also increase in effectiveness is found which improves 2nd law efficiency.

Turbocharging - Vortex Turbine can be used because it has relatively lower inertia, thus enabling easy spooling of the turbine causing an increase in the boost pressures.

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