Design of Propeller Pump (Impeller) for Fertilizer Industry

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Abstract: Pump technology is a proven technology in the world. The application and use of pumps today are universal. The rotodynamic pumps comprising axial flow, radial flow or centrifugal and axial flow pumps are all designed based on the same principle, i.e., mechanical energy is converted into fluid energy by rotational motion of an impeller. The axial flow pump is chosen because it can widely use in the field of municipal water works, drainage system, power plants, agriculture, irrigation work and many other utility services and industries. The purpose of this paper is to calculate the design calculation of axial flow pump (impeller) which can produce hydraulic energy by lifting action of the pump impeller blades. In this paper, the head and the flow rate of axial flow pump are 4.8 m and 0.75 m³/sec. The rotation speed is 720 rpm. The paper, especially involves the design calculation of propeller type impeller running in a casing of the pump. The result data of impeller are outlet diameter is 530 mm, the hub diameter is 265 mm, respectively. The number of blades is four. The clearance between impeller and pipe or casing is 0.00035 m. The designed axial flow pump can fulfill the requirements of agricultural process.

Keywords: Axial Flow Pump, Blade Design, Rotational Speed, Number Of Blades.

I. INTRODUCTION

In an axial flow pump, pressure is developed by flow of liquid over blades of airfoil section. It consists of a propeller-type of impeller running in a casing. The impeller is mounted on a shaft which is supported by bearings and driven through a flexible or rigid coupling by a driver. The pump casing includes suction and discharge portion, and has to be packed around the shaft to prevent external leakage. The advantage of an axial flow pump is its compact construction as well as its ability to run at extremely high speeds. The flow area is the same at inlet and outlet. Axial flow pump may consist of a single runner in a cylindrical casing, or it may consist of a runner with one or two sets of fixed guide vanes. Axial flow pumps belong to the category of rotodynamics or dynamic pressure pumps where in the pumping of liquids or generation of head is affected by rotary motion of the rotating wheel called the impeller. It has the highest specific speed, low head, low rpm and large capacities.

Normally, the absolute velocities of the fluid in an axial flow pump are quite low. Typical velocities for a pump described above as having a 13,300 specific speed are 12.7 feet per second for the axial velocity at both entrance and exit with a 6 feet per second tangential component at the periphery at exit and a vane peripheral speed of 68 feet per second. Under normal application conditions, the peripheral velocities generally do not exceed 5,000 feet per minute or 83 feet per second. The runner may be driven by a high speed electric motor, an internal combustion engine, or a gas turbine. Belt drives and direct connections are used. The discharge from the axial flow machine is relatively smooth and steady during normal operation. Axial flow pumps can be mounted either vertically, horizontally, or adapted to discharge at various angles. Axial flow pumps are available that can handle various liquids, mash, sewage liquids containing sands, gravel, and rocks of moderate size.

Figure 1. Impeller of axial flow pump

II. SPECIFICATION DATA

Axial Flow Pump with the following specifications has been installed on Fertilizer Industry at Salay Township, Magway Division, Myanmar.

Capacity, Q = 45 m³/min
Pump Head, H = 4.8 m
Rotational Speed, N = 720 rpm
Density of water, \( \rho = 1000 \text{ kg/m}^3 \)
Acceleration due to gravity, \( g = 9.81 \text{ m/s}^2 \)

### III. METHODOLOGY

In design procedure of axial pump impeller, the specific speed is expressed as follow:

\[
N_s = \frac{3.65 \times N \times \sqrt{Q}}{H^*}
\]  

(1)

The Impeller Hub - Ratio can be calculated by using following equation:

\[
D_d = 26.8 (N_s)^{0.603}
\]  

(2)

#### A. Power

Water Horse Power,

\[
\text{WHP} = \rho \times g \times Q \times H
\]

Bake Horse Power,

\[
\text{BHP} = \frac{\text{WHP}}{\eta_o}
\]  

(3)

#### B. Impeller Diameter

To determine the Diameter of impeller is as follow;

\[
D = (0.1 \pm 0.08)\sqrt{Q \times 60}
\]  

(4)

Checking by Optimum Diameter,

\[
D_{opt} = (4 \pm 4.6)\sqrt{\frac{1}{(1 - D_d^2)}} \times \sqrt[3]{\frac{Q}{N}}
\]  

(5)

Checking by Flow Velocity,

\[
V_z = (0.06 \pm 0.08) \times \sqrt[3]{Q \times N^2}
\]  

(6)

Knowing the capacity, the flow velocity and impeller-hub ratio, and the following equation can be used to determine the diameter of impeller;

\[
D = 2 \times \sqrt{\frac{Q}{\pi \times V_z \times (1 - D_d^2)}}
\]  

(7)

#### C. Blade Dimensions

Hub- Diameter,

\[
D_h = D_d \times D_o
\]  

(8)

The diameters at various sections,

- **Section I,**

\[
D_1 = D_h + (0.03 \text{ to } 0.05)D_o
\]  

(9)

- **Section II,**

\[
D_2 = D_1 + \left( \frac{D_3 - D_1}{2} \right)
\]  

(10)

- **Section III,**

\[
D_3 = \sqrt{\frac{D_o^2 + D_h^2}{2}}
\]  

(11)

- **Section IV,**

\[
D_4 = D_3 + \left( \frac{D_3 - D_1}{2} \right)
\]  

(12)

#### D. Flow Velocity and Angular Velocity

The flow velocity can be calculated with following equation;

\[
V_z = \frac{4Q}{\pi(D_o^2 - D_h^2)}
\]  

(13)

The angular velocity is

\[
\omega = \frac{2\pi \times N}{60}
\]  

(14)

#### E. Circulation Speed of Fluid Element

Total circulation,

\[
\Gamma = \frac{2 \times \pi \times g \times H}{\omega \times \eta_{hyd}}
\]  

(15)

Circulation speed per blade,

\[
\Gamma_n = \frac{\Gamma}{z}
\]  

(16)

#### F. Dimensionless Parameters

Flow Coefficient,

\[
K_Q = \frac{Q}{N \times D^3}
\]  

(17)

Head Coefficient,

\[
K_H = \frac{H}{N^2 \times D^2}
\]  

(18)

#### G. Vane Angles

Peripheral Velocity,

\[
u_1 = \frac{\pi \times D \times N}{60}
\]  

(19)

Inlet Vane Angle,

\[
\tan \beta_i = \frac{V_z}{u_1 - v_{u1}}
\]  

(20)

Tangential component of absolute velocity,

\[
v_{u2} = \frac{2 \times g \times H}{\omega \times \eta_{hyd} \times D}
\]  

(21)

Outlet Vane Angle,

\[
\tan \beta_2 = \frac{v_z}{u_2 - v_{u2}}
\]  

(22)

Vane Curvature,

\[
\Delta \beta = \beta_2 - \beta_1
\]  

(23)

Vane Spacing,

\[
t = \frac{\pi \times D}{z}
\]  

(24)

Chord Length,

\[
\frac{1}{t} = 5.95 \times K_H
\]  

(25)

### H. Average Value of Vane Angle and Relative Velocity

Average Value of Tangential Component of Relative Velocity,

\[
\text{Average Value of } V_z = \frac{1}{z} \sum (\beta_j)
\]

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\[ w_{u,ave} = u - \left( \frac{v_{u1} + v_{u2}}{2} \right) \]  
(28)

Average Value of Vane Angle,

\[ \tan \beta_{ave} = \frac{v_z}{w_{u,ave}} \]  
(29)

Average Value of Relative Velocity,

\[ w_{ave} = \frac{w_{u,ave}}{\cos \beta_{ave}} \]  
(30)

The angle between the vane chord and fluid flow direction can be calculated,

\[ \alpha = \alpha' + \Delta \alpha \]  
(31)

IV. VELOCITY TRIANGLE OF IMPELLER

Figure 2 shows inlet and outlet velocity triangle of axial flow pump impeller.

![Velocity triangle of impeller](image)

Figure 2. Inlet and outlet velocity of impeller.

V. RESULTS AND DISCUSSION

A. Theoretical Results

<table>
<thead>
<tr>
<th>No</th>
<th>Design Parameter</th>
<th>Symbol</th>
<th>Values</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific speed</td>
<td>( N_s )</td>
<td>701.8</td>
<td>rpm</td>
</tr>
<tr>
<td>2</td>
<td>Power</td>
<td>( P )</td>
<td>35.316</td>
<td>kW</td>
</tr>
<tr>
<td>3</td>
<td>Outside diameter</td>
<td>( D_o )</td>
<td>0.53</td>
<td>m</td>
</tr>
<tr>
<td>4</td>
<td>Inside diameter</td>
<td>( D_h )</td>
<td>0.265</td>
<td>m</td>
</tr>
<tr>
<td>5</td>
<td>Number of blades</td>
<td>( z )</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE II. RESULTS DATA OF IMPELLER PROFILE

<table>
<thead>
<tr>
<th>units</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>r m</td>
<td>0.145</td>
<td>0.17</td>
<td>0.21</td>
<td>0.238</td>
<td>0.26</td>
</tr>
<tr>
<td>( v_z ) m/s</td>
<td>4.532</td>
<td>4.532</td>
<td>4.532</td>
<td>4.532</td>
<td>4.532</td>
</tr>
<tr>
<td>( u ) m/s</td>
<td>10.93</td>
<td>12.81</td>
<td>15.83</td>
<td>17.90</td>
<td>19.22</td>
</tr>
<tr>
<td>( V_{u1} ) m/s</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>( V_{u2} ) m/s</td>
<td>5.094</td>
<td>4.344</td>
<td>3.517</td>
<td>3.11</td>
<td>2.896</td>
</tr>
<tr>
<td>( \beta_1 ) deg</td>
<td>22.52</td>
<td>19.47</td>
<td>15.97</td>
<td>14.2</td>
<td>13.26</td>
</tr>
<tr>
<td>( \beta_2 ) deg</td>
<td>37.82</td>
<td>28.14</td>
<td>20.20</td>
<td>17.03</td>
<td>15.51</td>
</tr>
<tr>
<td>( \Delta \beta ) deg</td>
<td>15.30</td>
<td>8.669</td>
<td>4.23</td>
<td>2.831</td>
<td>2.248</td>
</tr>
<tr>
<td>( t ) m</td>
<td>0.228</td>
<td>0.267</td>
<td>0.329</td>
<td>0.373</td>
<td>0.401</td>
</tr>
<tr>
<td>( l/t ) -</td>
<td>0.85</td>
<td>0.735</td>
<td>0.62</td>
<td>0.585</td>
<td>0.55</td>
</tr>
<tr>
<td>( l ) m</td>
<td>0.194</td>
<td>0.196</td>
<td>0.203</td>
<td>0.218</td>
<td>0.22</td>
</tr>
<tr>
<td>( \Gamma ) m³/s</td>
<td>4.641</td>
<td>4.641</td>
<td>4.641</td>
<td>4.641</td>
<td>4.641</td>
</tr>
<tr>
<td>( \beta_{ave} ) deg</td>
<td>28.41</td>
<td>23.07</td>
<td>17.85</td>
<td>15.49</td>
<td>14.3</td>
</tr>
<tr>
<td>( w_{ave} ) m/s</td>
<td>9.533</td>
<td>11.57</td>
<td>14.78</td>
<td>16.96</td>
<td>18.34</td>
</tr>
<tr>
<td>( \Delta \alpha ) deg</td>
<td>1.3</td>
<td>0.23</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>( \alpha ) deg</td>
<td>29.71</td>
<td>23.3</td>
<td>18.05</td>
<td>15.59</td>
<td>14.4</td>
</tr>
</tbody>
</table>

The design of impeller in this paper is calculated inlet and outlet diameters and number of blades. The designed data of impeller in this research are the hub diameter \( D_h \) is 0.265m and Impeller outlet diameter \( D_o \) is 0.53m. All of the calculated data are slightly smaller than the actual data. The number of impeller blade is same at these two data.

B. Numerical Results

![Velocity distribution of axial flow pump impeller](image)

Figure 3. Velocity distribution of axial flow pump impeller (flow trajectories).
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Figure shows the velocity distribution of axial flow pump impeller by using SolidWorks software. Flow rate and rotation speed are input data for these flow simulation. The theoretical calculated value of flow velocity is nearly the same with numerical research value.

VI. CONCLUSIONS
Axial flow pump from ‘Salay Fertilizer Industry’ is designed in this paper. This paper is attempted to design a axial flow pump from ‘Salay Fertilizer Industry’. The design of impeller in this paper is inlet and outlet diameters, vane angles for various sections and number of blades. To obtain all diameters all blade entrance and discharges angles, the blade is divided into five segments from the base of the hub to the outside diameter of the blade. The results of various vane entrance and discharge angles and vane curvatures, blade dimensions at various sections of profile are described. This paper describes the inlet and outlet velocity triangle. And this research shows the velocity distribution by using SolidWorks software. Axial flow pumps are used in the field of municipal water works, drainage system, power plants, agriculture and many other services and industries. In this paper, the axial flow pump is designed with data from ‘Salay Fertilizer Industry’. The axial flow pump is used an auxiliary component. This paper can also be improved to gain a better understanding of the relationship between velocities and blade shape by using suitable theory. Moreover, the design procedure is described in detail. And this can support the production of axial flow pump impeller.

VII. ACKNOWLEDGMENT
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VIII. NOMENCLATURE

\[ v_1 \]: Absolute velocity of fluid at entrance
\[ v_2 \]: Absolute velocity of fluid at discharge
\[ v_{a1} \]: Absolute tangential velocity at entrance
\[ v_{a2} \]: Absolute tangential velocity at discharge
\[ w_{a1} \]: Relative tangential velocity at entrance
\[ w_{a2} \]: Relative tangential velocity at discharge
\[ z \]: Number of blades
\[ \omega \]: Angular velocity
\[ \rho \]: Density of water
\[ \eta_{hyd} \]: Hydraulic efficiency

IX. REFERENCES