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Modification in Design of Typical Electric Submersible Pump

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***Abstract* -Submersible pump is required to extract ground water which mainly consists of electric motor and impellers. The head available at the discharge depends upon number of impellers used in the pump. In order to increase head of the pump, outlet velocity must be increased. The cross-sectional design of impeller gives required outlet velocity. By modifying the dimensions of vanes of different impellers gives high head using same rated power electric motor. Electric motor is equipped with a water-cooling system. But when the level of coolant water reduces, the top portion of windings gets burnt and it increases maintenance cost. However, we can provide some arrangement to maintain the level of water around the windings and it automatically increases working life of electric motor.**

1. INTRODUCTION

A submersible pump is a pump that can be placed underwater and still carry out its intended purpose. Some pumps may be designed to work while being fully submerged, and others may be submerged or placed in a dry place. It is necessary to know the type of pump which you are dealing with in order that no damage is incurred when it used.

The pump consists of a rotating element (impeller) sealed in a casing. The rotating element is connected to a drive unit (motor) which supplies the energy to spin the rotating element. As the impeller spins inside the casing, an area of low pressure allows the atmosphere pressure on the liquid in the supply tank to force the liquid up to the impeller. Since the pump will not operate if there is no low pressure zone created at the centre of the impeller, it is important that the casing be sealed to prevent air from entering the casing. To insure the casing is air-tight, the pump will include some type of mechanical seal assembly at the point where the shaft enters the casing. This seal will also include some type of lubrication (water) to prevent excessive wear.

2. DETAILED PROBLEM DESCRIPTION

The typical electric submersible pump is capable to discharge water from certain depth below the ground surface. In order to increase the head, numbers of stages of pump are increased or higher power motors are used.

2.1 Need of Increasing Head

The radial flow type impellers are our main concern due to their high heads. The number of stages of a submersible pump indicates number of assemblies of impellers and diffusers together. The suction is at the lowest portion of this pump assembly, which becomes inlet for first impeller. The water or fluid enters axially at the centre and then flows radially outside the impeller due to centrifugal force. Now, diffuser attached above directs the water to next impeller and further this process is repeated. Each impeller is capable of delivering a certain head and finally all the impellers give the total head.
Due to depleting water sources below the ground surface there is a strong need of increasing the overall head of the submersible pump. In order to increase the head/suction lift, many attempts are made by modifying the conventional centrifugal pump components by bringing about changes in design values of parameters relating to impeller and diffuser that determine suction/delivery capacity of submersible pumps.

2.2 Loss At Cross Section Expansion

Velocity energy is transformed to static pressure energy at cross-section expansions in the pump, according to energy equation. The conversion is associated with a mixing loss. The reason is that velocity differences occur when the cross-section expands, see figure. The figure shows a diffuser with a sudden expansion because all water particles no longer move at the same speed, friction occurs between the molecules in the fluid which results in a discharge head loss. Even though the velocity profile after the cross-section expansion gradually is evened out, a part of the velocity energy is turned into heat energy instead of static pressure energy.

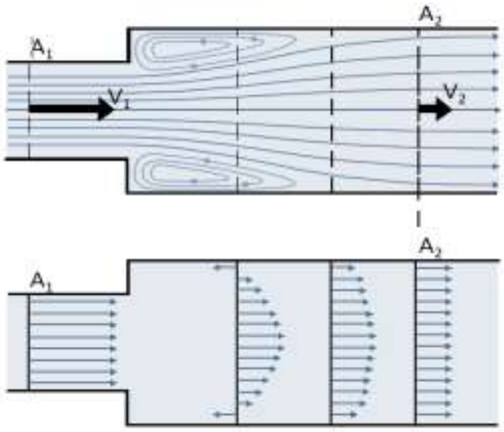


Fig. Velocity Loss at sudden Expansion

Mixing loss occurs at different places in the pump: At the outlet of the impeller where the fluid flows into the volute casing or return channel as well as in the diffuser. When designing the hydraulic components, it is important to create small and smooth cross-section expansions as possible.

2.3 Loss at cross-section contraction

Head loss at cross-section contraction occurs as a consequence of eddies being created in the flow when it comes close to the geometry edges, see figure 5.8. It is said that the flow separates. The reason for this is that the flow because of the local pressure gradients no longer adheres in parallel to the surface but instead will follow curved streamlines. This means that the effective cross-section area which the flow experiences is reduced.

The contraction accelerates the flow and it must therefore subsequently decelerate again to fill the cross-section. A mixing loss occurs in this process. Head loss as a consequence of cross-section contraction occurs typically at inlet to a pipe and at the impeller eye.

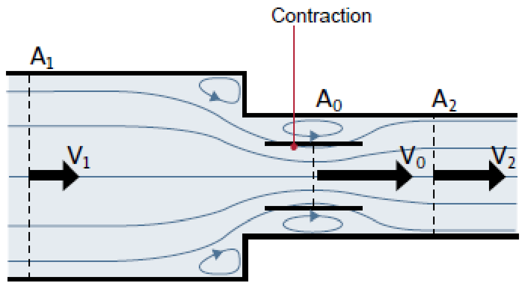


Fig. Velocity Loss at sudden Contraction

The magnitude of the loss can be considerably reduced by rounding the inlet edges and thereby suppress separation. If the inlet is adequately rounded off, the loss is insignificant. Losses related to cross-section contraction are typically of minor importance.

3. MATERIAL OF CONSTRUCTION

Sr. No.	Name of the Part	Material
1	Impeller	Glass filled polyphenylene oxide, glass filled polycarbonate
2	Diffuser	Polyphenylene oxide, polycarbonate, polyacetal or polypropylene
3	Wearing ring	PTFE, ABS or Nylon 66
4	Shaft Sleeve	Polyethylene, Nylon 66, PTFE, polypropylene

Advanced Materials of pump components

4. INCREASING HEAD OF PUMP

We know that total dynamic head of the submersible pump depends on dimensions of impeller and diffuser. Total dynamic head of a water system must be considered when determining the size of pumping equipment to be installed. It determines various head losses that the pump must overcome.

Total dynamic head = elevation head + friction head loss + pressure head.

(a)Elevation head - is the vertical distance which the water must be pumped. It is the elevation difference in feet between the pumping level in the well and the pressure tank.

(b)Friction head loss is the loss of pressure due to the flow of water through pipe and fittings.

(c) Pressure head - is the maximum operating pressure of the water system converted from pressure to feet of head.

4.1 Inlet Velocity Triangle

Usually it is assumed that the flow at the impeller inlet is non-rotational. This means that α_1=90°. The triangle is drawn as shown in figure 5.3, and C_{1m} is calculated from the flow and the ring area in the inlet. The ring area can be calculated in different ways depending on impeller type (radial impeller or semi-axial impeller), but in order to increase head, only radial impeller is considered. For a radial impeller, area is:

$A_1 = 2\,\pi\, r_1\, b_1$ ...eq. (4.1)

Where

r_1 = radial position of the impeller's inlet edge [m]

b_1 = blade's width at the inlet [m]

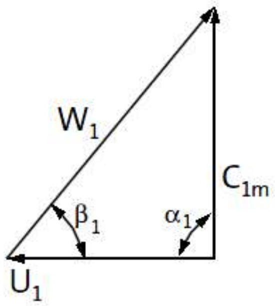


Fig. Inlet Velocity Triangle

The entire flow must pass through this ring area. C_{1m} is then calculated from:

$C_{1m} = Q_{impeller}/A_1$ ...eq. (4.2)

Where

C_{1m}=velocity of water at inlet

The tangential velocity U_1 equals the product of radius and angular frequency:

$U_1 = 2\pi r_{1*}(n/60)$
$= r.\omega$ ...eq. (4.3)

Where

ω = Angular frequency

n = Rotational speed

U_1= tangential velocity at inlet of impeller

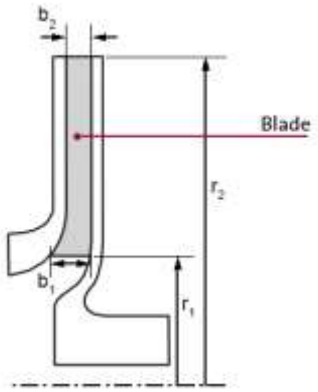


Fig. Radial Impeller

When the velocity triangle has been drawn, see figure 5.3, based on α_1, C_{1m} and U_1, the relative flow angle β_1 can be calculated. Without inlet rotation ($C_{1u} = C_{1m}$) this becomes:

$\tan\beta_1 = C_{1m}/U_1$ ...eq. (4.4)

4.2 Outlet Velocity Triangle:

As with the inlet, the velocity triangle at the outlet is drawn as shown in
figure 5.5. For a radial impeller, outlet area is calculated as:

$A_2 = 2\pi r_2.b_2$ ...eq. (4.5)

Where
r_2 = radial position of the impeller's outlet edge
b_2 = blade's width at the outlet

C_{2m} is calculated in the same way as for the inlet:

$C_{2m} = Q_{impeller}/A_2$ ...eq. (4.6)

Where
C_{2m}=velocity of water at outlet

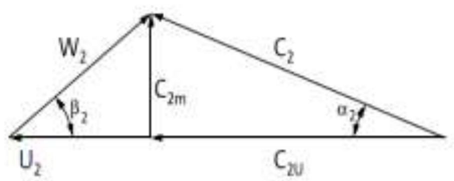


Fig. Outlet velocity triangle

The tangential velocity U is calculated from the following:

$U_2 = 2\pi r_2 (n/60)$
$= r_2.\omega$ ...eq. (4.7)

Where
ω = Angular frequency
n = Rotational speed
U_2= tangential velocity at outlet of impeller

In the beginning of the design phase, β2 is assumed to have the same value
as the blade angle. The relative velocity can then be calculated from:

$W_2 = C_{2m}/\sin\beta_2$ ...eq. (4.8)

And C_{2u} as:

$C_{2u} = U_2 - W_2$
$= U_2 - (C_{2m}/\sin\beta_2)$

4.3 Euler's pump equation

Euler's pump equation is the most important equation in connection with pump design. The equation can be derived in many different ways. The method described here includes a control volume which limits the impeller, the moment of momentum equation which describes flow forces and velocity triangles at inlet and outlet.

A control volume is an imaginary limited volume which is used for setting up equilibrium equations. The equilibrium equation can be set up for torques, energy and other flow quantities which are of interest. The moment of momentum equation is one such equilibrium equation, linking mass flow and velocities with impeller diameter. A control volume between 1 and 2, as shown in figure, is often used for an impeller.

The balance which we are interested in is a torque balance. The torque (T) from the drive shaft corresponds to the torque originating from the fluid's flow through the impeller with mass flow m = ρQ:

$T = m (r_2.C_{2u} - r_1.C_{1u})$ ...eq. (4.10)

By multiplying the torque by the angular velocity, an expression for the shaft power (P_2) is found. At the same time, radius multiplied by the angular velocity equals the tangential velocity, $r_2\omega = U_2$. This results in:

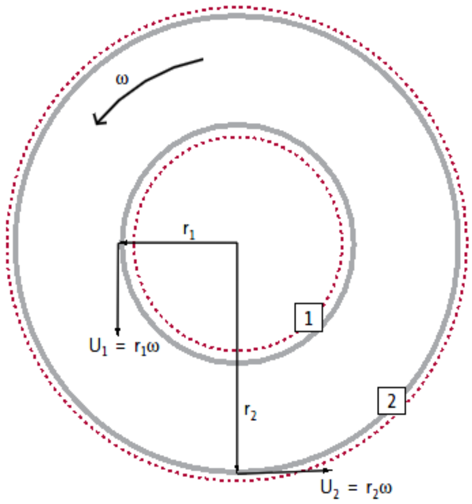


Fig. Control volume of impeller

$P_2 = T.\omega$

$= m\,(r_2.C_{2u} - r_1.C_{1u}).\ \omega$
$= m\,(r_2.C_{2u}.\ \omega - r_1.C_{1u}.\ \omega)$
$= m\,(U_2C_{2u} - U_1C_{1u})$
$= \rho.Q(U_2C_{2u} - U_1C_{1u})$ ...eq. (4.11)

According to energy equation, the hydraulic power added to the fluid can be written as the increase in Δp_{tot} across the impeller multiplied by the flow Q:

$P_{hyd} = \Delta p_{tot}.Q$ ...eq. (4.12)

The head is defined as:

$H = \Delta p_{tot} /\rho.g$ ...eq. (4.13)

The expression for hydraulic power can be derived to:

$P_{hyd} = Q.H.\rho.g$
$= m.H.g$ ...eq. (4.14)

If the flow is assumed to be loss free, then the hydraulic and mechanical power can be equated:

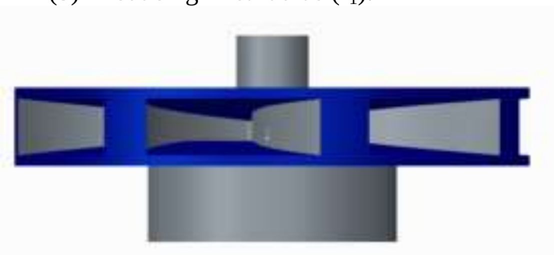
$P_{hyd} = P_2$
$\rightarrow m.H.g = m\,(U_2C_{2u} - U_1C_{1u})$
$\rightarrow H = (U_2C_{2u} - U_1C_{1u})/g$ ...eq. (4.15)

This is the equation known as Euler's equation, and it expresses the impeller's head at tangential and absolute velocities in inlet and outlet

5. CONCLUSION

From above stated three alternatives for increasing head gives below mentioned effect on submersible pump after performing it by calculation:

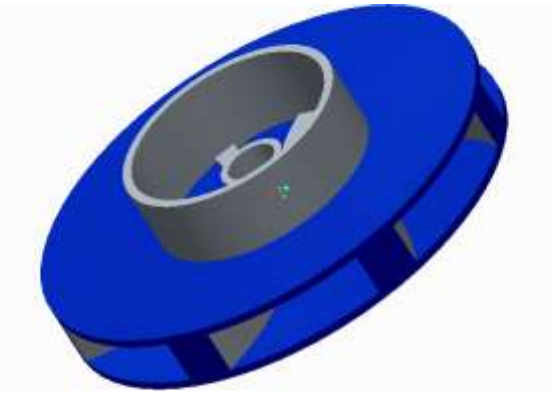
(1) Outlet radius (r_2) should be increased.
(2) Increasing the width (b_2) at impeller outlet.
(3) Reducing inlet radius (r_1).



In first case, when r_2 is increased then the size of impeller increases, which results in more space required for submersible pump to be installed. So, this is not feasible decision to be made and it increases the cost of installation.

In second case, b_2 gives nominal effect on the size of impeller and submersible pump. So, after implementing we found that progressive increment from b1 to b2, we have increased the Head (H) and the overall efficiency (η_o) of the electric submersible pump. From the calculation,

Increase in Head = Head after modification – Head before modification
= 81.23 – 78.32
= 2.94 m ~ 3 m at every stage



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