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The Effect of Trimming the Diameter of a Radial Type Submersible Pump Impeller

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Abstract: *Impeller trimming is the process of decreasing the diameter of an impeller by machining to decrease the energy added to the system fluid. Impeller trimming provides a useful correction to pumps that are oversized for their application. Trimming an impeller is an alternative to designing, manufacturing or purchasing a smaller impeller. Oftentimes, the next smaller size impeller is too small for the pump load. Moreover, smaller impellers may not be available and impeller trimming is the only practical solution without replacing the entire pump/motor assembly. Nowadays this process is very much popular among many Submersible Pump manufacturers. This is like a competitive tool in meeting the client's need without development of a special size impeller and thus slowly becoming a standard Industry practice. This paper investigates and discusses the step by step procedure with CFD analysis conducted on ANSYS CFX 14.0 used by the Industry.*

1. Introduction

Submersible pumps are manufactured and assembled in single or multistage depending upon the desired head and discharge. Impeller trimming reduces tip speed, which in turn directly lowers the amount of energy imparted to the system fluid and lowers both the flow and pressure generated by the pump[1-9]. However, trimming an impeller changes its operating efficiency, and impeller diameters are rarely reduced below 70 percent of their original size. Excessive trimming can even result in a mismatched impeller and casing, resulting in internal fluid recirculation and reduced efficiency[10]. Furthermore, for some pumps, impeller trimming increases the pump's required net positive suction head (NPSHR). To reduce the risk of cavitations, the effect of impeller trimming on NPSHR should be evaluated using manufacturer-provided data over the full range of operation conditions[11]. We have approached various leading and reputed submersible pump manufacturers in Gujarat and Maharashtra, India to collect the different information about the type of impellers they are using in their regular pump models. The product which was best suited for this experimentation was vertical open well submersible pump as shown in Figure 1.

Figure 1. Vertical open well submersible pump (Courtesy VIRA Pumps, Kolhapur, INDIA)

Such type of pump is immensely popular in India for agricultural use. Such types of pumps are installed in rivers, lakes, ponds, etc. The discharge range of such pump is from 0.00016m3/s to 0.025m3/s and head ranging from 5m to 75m. The pump sets are manufactured in the ratings of 2.2 kW, 3 kW, 3.7 kW, 4.5 kW, 5.6 kW, 7.5 kW, etc. Depending upon the head required, the pump may be manufactured in single as well as multistage. Below is the list of available impellers used by the pump manufacturers depending up on the customer requirements in Table 1

Table 1. List of impellers with ratings

Sr. No.	Power (P) in kW	Head (H) at duty point in m	Discharge (Q) in m^3/s at duty point
1	3	15	0.00899
2	3.7	13.9	0.012

By using the relation of power[8]

$$\text{Power P(kW)} = \frac{wQH}{1000 \times \eta_o} \quad (1)$$

Where P : power (kW), w: specific weight of water (N/m^3), Q : discharge (m^3/s), H : head (m), η_o : overall efficiency and by considering overall efficiency (ηo) as 44% [12] and w is specific weight of water in N/m3, Table 1 is formed. Using only these two impellers, the manufacturer produces the array of pumps given in Table 2. This table is formed by collecting data from different reputed pump manufacturers derived from the technical specifications published by them.

Table 2. Different models of pumps produced using 3 kW and 3.7 kW impeller

Sr. No.	HP	kW	No. of Stages	Head Range in m	Impeller used	No. of impellers used
1	4	3	1	15-20	3	1
2	7.5	5.6	2	30-40	3	2
3	5	3.7	1	15-20	3.7	1
4	10	7.5	2	30-40	3.7	2
5	12.5	9.3	3	45-55	3	3
6	15	11.1	3	45-55	3.7	3
7	15	11.1	4	60-70	3	4

After observing this table carefully, it will be clear that, there are some pump models which customers may demands but which will not be possible using these two impellers. Unfortunately such types of impellers are not available in the market nor such designs are developed by the manufacturers as a result of this, the customer may be forced to buy an oversized pump or sometimes undersized pump only due to the fact that exact specification can be mate using the present impeller. Consider a situation where a customer may require a pump of head (H) 14m and discharge (Q)of 0.0108 m^3/s (650 LPM). To fulfill this requirement suppose we use 3.7 kW impeller then, this will result

$$\text{Power P(kW)} = \frac{wQH}{1000 \times \eta_o}$$

$$\text{Discharge Q} = \frac{P \times 1000 \times \eta_o}{w \times H} \quad (2)$$

$$Q = \frac{3.7 \times 1000 \times 0.44}{9810 \times 14}$$

$=0.0118 m^3/s$ (711 LPM)

From result it can be observed that, discharge is more than expected. Now the recommended power rating is between 3 kW to 4 kW only so again, if we select 3 kW impeller, the situation will be as follows.

$$\text{Power P(kW)} = \frac{wQH}{1000 \times \eta_o}$$

$$\text{Discharge Q} = \frac{P \times 1000 \times \eta_o}{w \times H}$$

$$Q = \frac{3 \times 1000 \times 0.44}{9810 \times 14}$$

$=0.0096 m^3/s$ (576 LPM)

Again this will be an underperforming pump which will not be acceptable to the customer, so there is a need of such impeller design which will perform in between 3.7 kW to 3 kW. Unfortunately such impeller design is not available in the market so, trimming an impeller is an alternative to designing, manufacturing or purchasing a small impeller. Oftentimes the next smaller size impeller is the only practical solution without development of a special size impeller. In this paper we have selected very popular 3.7 kW impeller design to change its performance by trimming diameter of this impeller. The details of the impeller are given in Table 3.

Table 3. Specifications of the original 3.7 kW impeller

Sr. No.	Description	Values
1	Impeller inlet diameter (D1)	73 mm
2	Impeller outlet diameter (D2)	145 mm
3	Number of blades (Z)	5
4	Shaft diameter (Ds)	25 mm
5	Inlet Vane Angle (β1)	20^0
6	Outlet Vane Angle (β2)	28^0
7	Blade inlet height (B1)	17.80
8	Blade outlet height (B2)	15.11 mm
9	Mass flow rate (Q)	0.011 m^3/s
10	Head (H)	12.3 m
11	Rotation (N)	2750 RPM

2. Trimming of the impeller diameter

Figure 2. Typical radial type impeller

Figure 2 Shows a typical radial type impeller used in vertical open well submersible pump and Figure 3 shows side view of this radial type impeller.

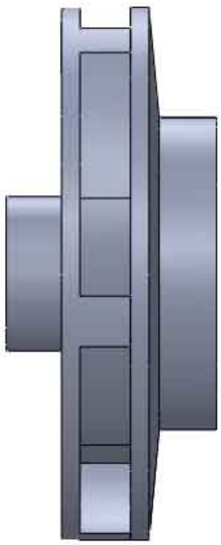

Figure 3. Side view of Radial type impeller

The diameter of the impeller has to be increased or decreased according as head or capacity is to be increased or decreased. To reduce the capacity, the pressure side diameter i.e., left side of impeller, needs to be trimmed by producing a draft of 8^0 to 10^0 as shown in Figure 4.

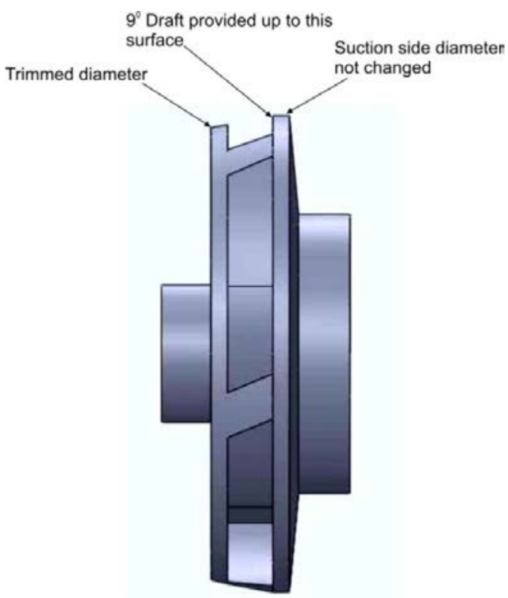

Figure 4. Trimmed impeller with 9^0 draft

By doing this, area of passage changes and therefore at constant speed (N)

Area (a) of passage α D (3)

But $Q = a \times B$ (4)

Therefore, $Q \; \alpha \; D^2$

Where a : area (mm^2), D: diameter (mm), B : width (mm).

Since Head (H) depends upon velocity (u^2), width (B), etc. which are proportional to diameter (D)[9], we may write that,

$H \; \alpha \; D^2$ (5)

Now, power, $P \; \alpha \; Q \times H$ (6)

Therefore, $P \; \alpha \; D^4$ (7)

By summing up,

We get ,

$$\frac{Q_1}{Q_2} = \left[\frac{D_1}{D_2}\right]^2 \quad (8)$$

Where Q_1 : discharge of original impeller (m^3/s), Q_2 : discharge of trimmed impeller (m^3/s), D_1 : diameter of pressure side of original impeller (mm), D_2 : diameter of pressure side of trimmed impeller (mm).

$$\frac{H_1}{H_2} = \left[\frac{D_1}{D_2}\right]^2 \quad (9)$$

Where H_1 : head of original impeller (m), H_2 : head of trimmed impeller (m) and

$$\frac{P_1}{P_2} = \left[\frac{D_1}{D_2}\right]^4 \quad (10)$$

Where P_1 : power of original impeller (kW), P_2 : power of trimmed impeller (kW). In our case, we have found the power of trimmed impeller (P_2).

As we know, power of original impeller P_1 = 3.7 kW and

$$\frac{P_1}{P_2} = \left[\frac{D_1}{D_2}\right]^4$$

Therefore,

$$\frac{3.7}{P_2} = \left[\frac{145}{137.32}\right]^4$$

$P_2 = 2.97$ kW

i.e., 3.7 kW impeller will have power of 2.97 ≈ 3 kW impeller after trimming.

3. CFD analysis of the impeller

Now as the details of 3.7 kW impeller are already been provided by the manufacturer so, to conduct the CFD analysis 3D model have to be constructed. The CFD analysis of this untrimmed original impeller with the trimmed impeller is done to verify and substantiate the fact that how the capacity of the impeller can be decreased by trimming the pressure side of the impeller. It is interesting to know that, CFD only complements the testing and experimentation and cannot replace these approaches. It only reduces the total efforts required in laboratory, so there is always a need for testing and experimentation.

4. CFD analysis of original 3.7 kW impeller

The performance of 3.7kW impeller has been observed while performing CFD analysis. CFD analysis of this impeller has been performed using ANSYS CFX 14.0 software. ANSYS CFX 14.0 software uses only fluid region of the impeller for analysis purpose[13-17].Solid Works 2014 software is used to construct the fluid model which can be seen in Figure 5

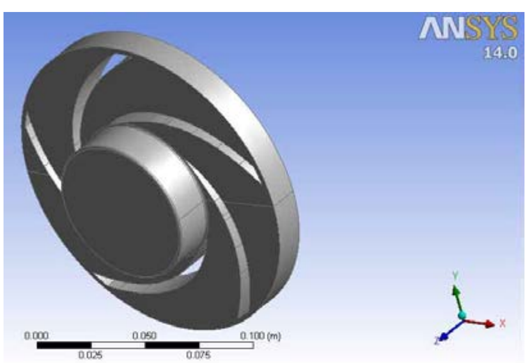

Figure 5. Fluid model of the 3.7 kW impeller

The final mesh of fluid model of the impeller generated consists of total 105388 nodes and 561797 elements. The working fluid through the pump is water at 25^0 C. k-ε turbulence model with turbulence intensity of 5% is considered. Three dimensional incompressible Navier Stokes equation are solved with ANSYS CFX 14.0 Solver. After mesh generation the initial boundary conditions are to be given such as fluid domain has been selected as rotating frame of reference with the rotational speed of -2750 rpm (Anti-Clockwise) and the static pressure of 101325 Pa at inlet and the flow rate at outlet (discharge at outlet) havebeen set as given in Table 4. These values are the inputs for the CFD analysis i.e., for CFX-pre setup. After setting the boundary conditions, ANSYS CFX 14.0 solver has been set for 300 iterations for accurate results. Various results have been observed after the CFD analysis i.e., CFX-post. The various results observed for head and discharge are given in the Table 4. Pressure contours of original impeller can be observed in the Figure 6.

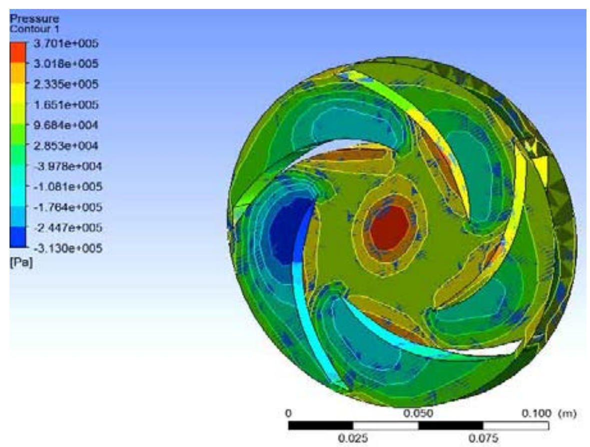

Figure 6.Pressure contours

Table.4 Discharge and pressure head observed at outlet of original impeller

Sr. No.	Static pressure at inlet in Pa	Discharge at outlet in m^3/sec	Pressure observed at outlet. in Pa	Pressure observed at outlet. in Meter
1	101325	0.0015	262551	26.78
2	101325	0.0041	235296	24
3	101325	0.0067	208138	21.23
4	101325	0.0093	164903	16.82
5	101325	0.0107	152942	15.6
6	101325	0.012	136275	13.9
7	101325	0.0155	120295	12.27

5. CFD analysis of trimmed impeller

The effect of trimming the original impeller has been analyzed by performing CFD analysis. The 3D model of original impeller is trimmed by producing the draft of 9^0 as shown in the Figure 4. Figure 7 shows 3D model of fluid region of trimmed impeller which has been used for the CFD analysis purpose The final mesh of fluid model of the impeller generated consists of total 104692 nodes and 558091elements. The impeller domain is considered as rotating frame of reference with rotational speed of -2750 rpm (Anti-Clockwise). The working fluid through the pump is water at 250 C. k-ε turbulence model with turbulence intensi ty of 5% is considered. Three dimensional incompressible Navier Stokes equations are solved with ANSYS CFX 14.0 Solver.

Sr. No.	Static pressure at inlet in Pa	Discharge at outlet in m^3/sec	Pressure observed at outlet. in Pa	Pressure observed at outlet. in Meter
1	101325	0.001	262551	26.78
2	101325	0.0035	235296	24
3	101325	0.0057	208138	21.23
4	101325	0.0089	164903	16.82
5	101325	0.0096	152942	15.6
6	101325	0.0109	136275	13.9
7	101325	0.012	120295	12.27

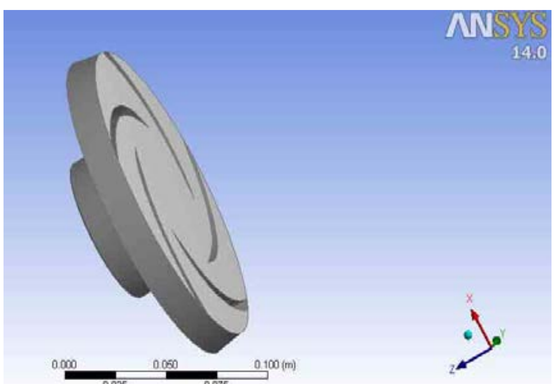

Figure 7. Fluid model of the trimmed impeller

5.1 Boundary conditions

After mesh generation the initial boundary conditions are to be given. These values as given below will work as the inputs for the CFD analysis i.e., for CFX-pre setup.

1. Fluid domain is to be selected as rotating with the rotational speed of -2750 rpm (Anti-Clockwise).
2. The static pressure of 101325 Pa is to be set at inlet.
3. The Outlet flow rate (discharge at outlet) is to be set as given in Table 5 which replicates the adjustment of the valve.

After setting the boundary conditions, ANSYS CFX 14.0 solver is to be set for 300 iterations for accurate results. Various results have to be observed after the CFD analysis i.e., CFX-post. The pressure head attained at the outlet of impeller is of prime importance and the results observed at the outlet will be utilized to compare with original impeller. During CFD analysis of fluid model various results for head and discharge have been observed. Table 5 shows the values of head and discharge. Pressure contours of trimmed impeller can be observed in the Figure 8

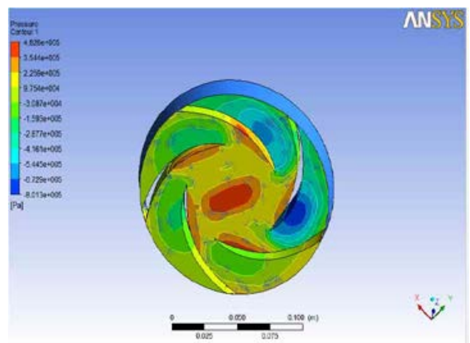

Figure 8. Pressure contours

Table 5. Discharge and pressure head observed at outlet of trimmed impeller

Now we will find out capacity of both the pumps at duty point i.e., at 13.9 m using the earlier relation.

$$P(kW) = \frac{wQH}{1000 * \eta_o}$$

For original impeller

$$P(kW) = \frac{9810 \times 0.012 \times 13.9}{1000 \times 0.44} = 3.71 \text{ kW}$$

And for trimmed impeller

$$P(kW) = \frac{9810 \times 0.0109 \times 13.9}{1000 \times 0.44} = 3.37 \text{ kW}$$

i.e., there is a reduction of about 10% in capacity of the pump.

6. Conclusion

This paper thus presents the effects of trimming the diameter of a radial type submersible pump impeller. This effect is studied by conducting CFD analysis on both original as well as trimmed impeller. It shows that the capacity of the original impeller changes from 3.71 kW to 3.34 kW, which is an approximately 10% reduction. We can thus see how this method can provide a useful correction to pumps that are oversized for their application thus eliminating the need of developing a completely new Impeller. In this paper a draft of 9^0 have been used and achieved the results satisfactorily. In industry this angle varies from 8^0 to 10^0. With a powerful tool like CFD, variation in the draft angle can be done from 8^0 to 10^0 and the angle can be optimized for the specific impeller.

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