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DESIGN AND OPTIMIZATION OF IMPELLER BLADE THICKNESS FOR CENTRIFUGAL PUMP BY USING CFD

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ABSTRACT

The project aims to optimize impeller blade thickness for centrifugal pumps using Computational Fluid Dynamics (CFD) simulations. The impeller's geometry significantly impacts fluid flow characteristics, efficiency, and overall pump effectiveness. The research involves creating a parametric model to explore different blade thickness configurations and analyzing fluid flow under different operating conditions. Performance parameters like pressure distribution, velocity profiles, and efficiency are evaluated for each design iteration. The study aims to provide insights into the relationship between impeller blade thickness and pump performance, aiding pump designers in developing more efficient centrifugal pumps. Integrating CFD in design can be cost-effective and time-efficient.

Keywords:
Centrifugal pump, Impeller blade thickness, Computational Fluid Dynamics (CFD), Optimization, Hydraulic performance.

1. INTRODUCTION

Centrifugal pumps are essential in various industries for transferring fluids. They convert machinery energy into fluid pressure and kinetic energy through impellers. The efficiency and performance of these pumps are heavily influenced by the design of the impeller blades, with blade thickness being a critical parameter. Recently, optimization using mechanical concepts has been studied to create higher efficiency pumps with higher heads. The significant cost and time of trial and error in constructing and testing physical prototypes contribute to the profit margins of pump manufacturers. Therefore, computational fluid dynamics (CFD) analysis is being used in hydrodynamic design for various pump types, providing accurate information on fluid behavior and performance evolution.

2. LITERATURE REVIEW

Jin-Hyuk KIM et al. improved the performance of a centrifugal pump by optimizing impeller and volute design. They used computational fluid dynamics and the Response Surface Method to assess the impact of impeller parameters. The optimized impeller design achieved 98.2% efficiency and a 64.5m head. [1]

Chia-Nan Wang et al. developed a method to improve centrifugal pump performance by developing a numerical model and using an artificial intelligence algorithm for pre-experiment optimization. They adjusted parameters like casing section area, impeller interference, volute tongue length, and volute tongue angle, ensuring a complex multi-objective optimization process. [2]

Bo Qian et al. improved vibration performance in centrifugal impellers in pumps by optimizing blade thickness distribution. They compared an optimized impeller (OPT), a prototype impeller with splitter blades (PRT), and an ordinary impeller (ODN) using numerical and experimental methods, and examined the effects of thickness distribution optimization on vibration. [3]

Vijaypratap R. Singh et al. found that measuring pump performance parameters is crucial for efficient operation of centrifugal pumps. However, experimental studies are complex, time-consuming, and costly. Using a CFD prediction model can help speed up production by analyzing flow patterns and varying critical parameters. The adverse pressure gradient of pumps can be improved by studying these patterns. [4]

Kaviarasan et al. used Computational Fluid Dynamics software to study complex internal flows in centrifugal pump impellers. They modeled the impeller in Pro engineering software and used CFD analysis to predict pump performance. The study aimed to increase hydraulic efficiency by predicting velocity and pressure distributions, and analyzing results using 3-dimensional graphs. The study aimed to improve pump design and performance. [5]

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Sung Kim et al. conducted a study on design optimization of a mixed flow pump impeller to enhance efficiency and suction performance. They used optimization techniques to analyze trends of different shapes, resulting in an optimized shape that meets design specifications. The study confirmed the correlation between specific speed and mixed flow pump performance. [6]
S.R. Shah et al. reviewed the use of computational fluid dynamics (CFD) in analyzing centrifugal pumps, highlighting its potential for future improvements. The researchers applied CFD techniques for performance prediction, parameter study, diffuse pump analysis, and turbine mode performance. They found Reynolds average Navier stocks equations and two equation k-k turbulence models suitable for CFD analysis.[7]
Mr.Nilesh Patil et al. use software to study key components like the impeller in centrifugal pumps to find optimal conditions. They use literature review and computational CFD to explore methods to improve pump efficiency. They found that increasing outlet velocity improved flow characteristics for the impeller, allowing further experimentation. [8]

3. PROBLEM STATEMENT

Impeller blade is the important part of Centrifugal pump which enhance the efficiency and performance of the pump. Design and optimization of the impeller blade thickness will be done to get the pressure drop and velocity across the impeller outlet. Five simulations will be performed of the blade thickness from 5mm to 9mm thickness. Simulation will provide insights into the impact of blade thickness of pump performance. Simulation performed using CFD will be compared with experimental data from existing pump designs to validate the accuracy of the simulation. Using CFD by performing simulation the parameters of centrifugal pump such as efficiency, speed and water power are analyzed.

4. DESIGN CALCULATION

Calculations for velocity triangles of centrifugal pump: Actual centrifugal pump is certified for (standard):
Discharge is 11 liter/seconds
Head of the pump in range of 15.2 to 20.9 meter
Speed of pump is (N) 2600 revolution/minute
Total head of pump is 19 meters
Efficiency of the pump is 66%
Pump input is 3.70 kW
Suction pipe diameter is 80mm
Delivery pipe diameter is 65mm
From CAD Model,
Impeller outer diameter (D_2) is 144.5mm
Impeller inner diameter (D_1) is 72.25mm
Width of impeller (B_2) is 19mm

VELOCITY TRIANGLE

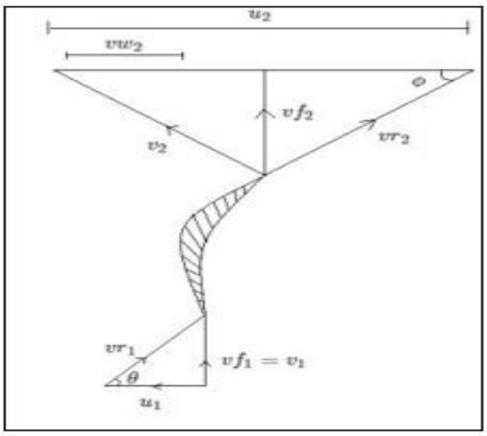

Figure 4.1.Velocity triangles of Centrifugal pump

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Now, outer velocity of impeller can be calculated as,

$U2 = \frac{\pi D_{2N}}{60} = 19.67$ m/s

$U1 = \frac{\pi D_{1N}}{60} = 9.83$ m/s

$Q = \pi \times D2 \times B2 \times Vf_2$

$Vf_2 = \frac{Q}{\pi \times D2 \times B2} = 1.27$ m/s

For the centrifugal pumps $Vf_2 = Vf_1$

Now,From inlet velocity triangle,

$\tan\theta = \frac{Vf1}{U_1}$ $\therefore$ $\theta = 7.36°$

$\sin\theta = \frac{Vf1}{Vr_1}$ $\therefore$ $Vr_1 = 9.92$ m/sec

Now,From outlet velocity triangle,

$\eta_{mano} = \frac{\rho Hm}{Vw2 \times u2}$ $\therefore$ $Vw2 = 11.15$ m/sec

$V2 = \sqrt{(Vf2)^2 + (Vw2)^2} = 11.22$ m/sec

$Vr2 = \sqrt{(Vf2)^2 + (U_2 - Vw2)^2} = 8.61$ m/sec

$\tan\beta = \frac{Vf2}{Vw2}$ $\therefore$ $\beta = 6.49°$

$\tan\emptyset = \frac{Vf2}{VU2 - Vw2}$ $\therefore$ $\emptyset = 8.470$

Now, Work done by the impeller on water per second,

$W.D. = \frac{w}{\rho} \times vw2 \times u2 = 2412.5255\ N - m/sec.$

Now, Water power = $\rho.\ g.\ Q.H = 2050.29 N - m/sec.$

Also, Overall Efficiency,

$\eta o = \frac{\text{water power}}{\text{shaft power}}$ $\therefore shaft\ power = 3106.5$

Also, Manometric Efficiency,

$\eta mano = \frac{g.Hm}{Vw2 \times u2} = 84\%$

Also, Torqe,

$S.P. = \frac{2\pi NT}{60} =$ $\therefore$ $T = 11.45 N$-m

Specific speed:

$N_s = \frac{N\sqrt{Q}}{H_m^{\frac{3}{4}}} = 29.965$

[Company → 2600rpm→ 2840 change parameter]

■ At 2600rpm [Head= 23m, Discharge= 11 lit/ sec]

1. Change shroud angle [Varying]
2. Change number of blades if required.

Go through CFD results

■ At 2840 rpm

1. Change or decrease diameter of impeller Which will require less power, Go through CFD result.

Sr. No.	Particulars	Details
1	Discharge	11 litre/seconds
2	Head of pump range	15.2 to 20.6 meter
3	Speed of pump	2600 rev/min
4	Total head of pump	19 meters
5	Efficiency of pump	66%
6	Pump input	3.70kW
7	Suction pipe diameter	80mm
8	Delivery pipe diameter	65mm
9	Impeller outer diameter	144.5
10	Impeller inner diameter	65mm

Table 4.1 Standard centrifugal pump's parameters

5. CAD DESIGN

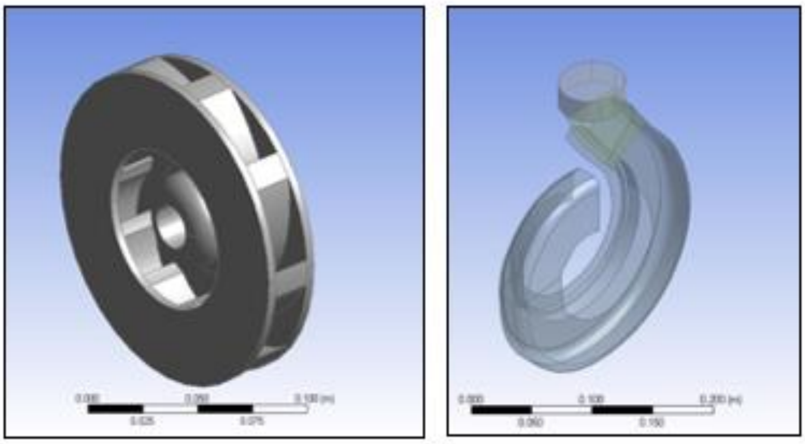

Figure 5.1 CAD design of impeller blade and pump casting

6. RESULTS

6.1 Pressure Drop:

The pressure drop across a pump is influenced by changes in impeller blade thickness. Thinner blades generally result in lower pressure drops, indicating efficient fluid transfer due to reduced frictional losses and improved fluid dynamics. However, as blade thickness increases, pressure drop increases due to increased resistance to flow and greater losses. This behavior is unusual, as thinner blades are typically associated with lower pressure drops due to reduced frictional losses and improved fluid dynamics.

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Simulation Cases	Blade Thickness	Pressure Drop ΔP (Pa)	M of H_2O
Base	5	204563.3	20.9
Rev_01	3	205475.3	21.0
Rev_02	4	195054.1	19.9
Rev_03	6	189921.4	19.4
Rev_04	7	185817.4	18.9

6.2 Velocity

Average Velocities at the impeller outlet are increased in Rev_02 (~13.5 m/s). Velocities at pump outlet are almost similar in all the cases except some small variations.

Table 6.2 Results of velocity drop

Average Velocity (m/s)		
Cases	Impeller Outlet (m/s)	Pump Outlet (m/s)
Base	13.5	4.6
Rev_01	13.3	5.0
Rev_02	13.5	4.8
Rev_03	13.3	4.6
Rev_04	13.2	4.3

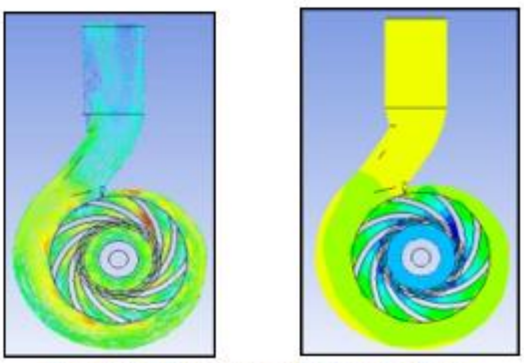

Figure 6.1 Pressure and Velocity drop

7. FUTURE DIRECTIONS

Future research should explore advanced optimization techniques like genetic algorithms, neural networks, or machine learning algorithms to improve impeller performance. Three-dimensional analysis can provide a more realistic representation of flow phenomena, while transient simulations can identify potential issues. Integrating multi-physics simulations, such as fluid-structure interaction, can provide a holistic understanding of pump performance. Experimental validation is crucial for ensuring the accuracy and reliability of simulation predictions. Future research should focus on optimizing centrifugal pump designs to minimize energy consumption, reduce carbon emissions, and improve environmental performance. Application-specific optimization strategies for centrifugal pumps in various industries can further improve performance and efficiency. These strategies can provide significant benefits to end-users across different sectors.

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8. CONCLUSION

The study explores the relationship between blade geometry and pump performance in a centrifugal pump. It found that increasing impeller blade thickness decreases pressure drop across the pump, with Rev_04 showing significant improvement over the base case. Velocities at the impeller outlet also increased in Rev_02, with average speeds at the pump outlet. The study also found that a 7mm blade thickness with Rev_04 significantly improved head and impeller velocity compared to the base case, suggesting potential for further research.

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