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Study of Blade Design of Centrifugal Pump Impeller

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ABSTRACT: The study of blade design for centrifugal pump impellers is a critical aspect of optimizing pump performance and efficiency in fluid handling systems. This research delves into the intricate details of impeller design, examining the hydraulic characteristics, blade geometry, and materials to enhance pump functionality. Utilizing a combination of computational simulations, theoretical analyses, and experimental testing, the study aims to provide insights into the factors influencing impeller performance. The ultimate goal is to contribute to the development of more efficient and reliable centrifugal pumps, addressing challenges in fluid dynamics, cavitation, and overall pump efficiency.

KEYWORDS: Blade, Centrifugal Pump, Impeller, Ansys.

I. INTRODUCTION

Centrifugal pumps stand as indispensable components in various industrial, commercial, and residential applications, serving to transport fluids across a spectrum of industries. At the heart of these pumps lies the impeller, a crucial element responsible for imparting energy to the fluid and facilitating its movement through the pump system. The efficiency and performance of a centrifugal pump are intricately linked to the design of its impeller blades.

The primary objective of this study is to conduct a comprehensive examination of the blade design of centrifugal pump impellers, considering various factors that influence the pump's hydraulic performance. The impeller, acting as the primary rotor in the pump, is responsible for converting mechanical energy into kinetic energy, driving the fluid from the pump inlet to its outlet. Achieving optimal impeller design is essential to ensure a smooth and efficient flow while minimizing energy losses.

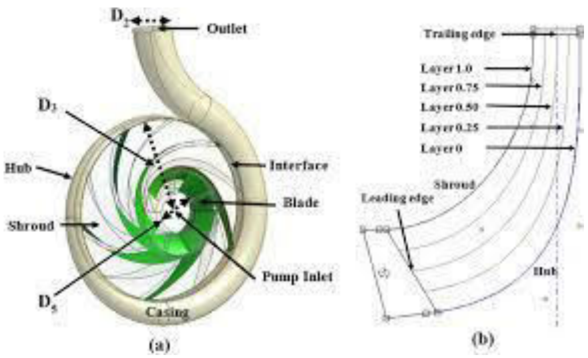

Figure 1: Sample image of blade design

Hydraulic characteristics, including flow patterns, pressure differentials, and velocity profiles, are key focal points in this study. The shape of the impeller blades, their angles, and the overall geometry play pivotal roles in determining the pump's efficiency. The interplay between these design elements is complex, requiring a multidimensional approach to achieve an optimal solution.

Blade loading, or the distribution of work among individual blades, is another critical aspect that influences the impeller's performance. Proper loading is essential for maintaining a balanced flow and preventing issues such as

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cavitation, which can compromise pump efficiency and reliability. To gain deeper insights, this study employs advanced techniques such as Computational Fluid Dynamics (CFD) simulations. These simulations provide a detailed analysis of fluid flow within the impeller, offering a virtual environment to assess the design's effectiveness before physical prototyping.

The research methodology extends beyond theoretical models and simulations, incorporating practical aspects through experimental testing. Prototypes of impellers with varying designs are subjected to controlled testing environments, allowing for the validation of theoretical models and simulations. Performance metrics such as pump efficiency, specific speed, and head-capacity curves are employed to evaluate and compare different impeller designs.

The study of blade design for centrifugal pump impellers combines theoretical analyses, computational simulations, and experimental validation to enhance our understanding of fluid dynamics within the pump system. The outcomes of this research endeavor aim to contribute to the development of more efficient and reliable centrifugal pumps, addressing challenges associated with fluid handling in diverse applications.

II. RELATED WORK

F. Elida et al.,[1] Centrifugal pump usage has increased over the past year due to its importance and efficiency. Its function is to transport liquid from one place to another using energy applied to the pump. This work revolves around the idea of design and analysis of centrifugal pump for performance enhancement within the pump specifications. Design and simulation were conducted using ANSYS CFX, using the Navier-Stokes equation. Shear Stress Transport (SST) was chosen for turbulence model for this project. From the simulation results, it can be observed that as the rotation speed of the impeller increases, the pressure within the impeller increases.

T. Qilong et al.,[2] The aero fuel pump is a significant accessory for aircraft fuel system. To enhance the anti-cavitation capability of the pump and reduce hydraulic loss, the work try to combine the inducer and impeller. Three centrifugal pump combination impellers were designed with different wrap angle. The impact of the wrap angle on the pump hydraulic performance was numerically performed and analyzed by using a computational fluid dynamics code based on the Realizable k-ε turbulence model, in which the influence of rotation and curvature are considered. The simulation results predicted indicate that the inducer and impeller combination can increase the hydraulic efficiency. In addition, this combination can reduce the inlet flow rate and increase the inlet pressure, enhance the anti-cavitation capability of the centrifugal pump.

Q. Zhang et al.,[3] The visual experimental system for the centrifugal pump was established. The mock centrifugal pump with six curving semi-open impellers was manufactured by polymethyl methacrylate. The flow characteristics inside the mock centrifugal pump was studied by the combination of laser induced fluorescence (LIF) and particle image velocimetry (PIV). The polyamide resin particles were dissolved into the fluid of the circulation for PIV analysis, and fluorescent dye rhodamine B was head-on injected to the impellers for LIF analysis. The front plane of the impellers was covered by Nd: YAG laser sheet, one CCD camera collected the reflected laser light from the particles. Synchronously, another camera collected the fluorescence of rhodamine.

P. Puentener et al.,[4] The importance of the main impeller design parameters in bearingless centrifugal pumps with respect to hemolysis for cardiopulmonary bypass (CPB) and extracorporeal membrane oxygenation (ECMO) applications are studied in this work. Methods: Impeller prototypes were designed based on theoretical principles. They were manufactured and their hydraulic and hemolytic performance were analyzed experimentally. The cell compatibility is benchmarked against commercially available centrifugal blood pumps BPX-80 (Medtronic) and FloPump 32 (International Biophysics Corporation). Results: The developed prototypes outperform the BPX-80 and FloPump 32 with regard to hemocompatibility by more than a factor of 4.5.

Z. Wang et al.,[5] For large flow rates, double-suction centrifugal pumps are widely used in agricultural irrigation. The effects of the flow rate and silt content on the vibration characteristics of these pumps have not been extensively investigated. This study conducted an experiment to obtain the vibration signals on a pump bearing housing. The flow rates ranged from 0% to 150% of the design flow rate (Qd), and the silt concentration ranged from 0 kg/m ^{3} to10 kg/m ^{3} . The vibrations in the axial direction were higher than those in the horizontal and vertical directions at each flow rate. At zero flow rate, the axial vibration increased by 190% compared with that at Q_d .

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M. Ali et al.,[6] This work aims to provide a numerical method approach to centrifugal pump manufacturers in Pakistan. Nowadays Computational fluid dynamics (CFD) is widely used to investigate the flow through turbomachines. In this research, centrifugal pump impeller of low specific speed (Nq=10.5) is numerically investigated to study the flow phenomena and achieve better hydraulic performance through parametric analysis. The shear stress transport (SST) turbulence model is employed to solve 3-D steady RANS equations using CFD solver CFX (ANSYS).

B. Bohn et al.,[7] A sensing concept for quantifying the performance of centrifugal pumps is proposed herein. The system uniquely combines three measurement approaches: thermodynamic efficiency monitoring, vibration monitoring, and dynamic fluid pressure analysis. The instrumentation comprises five conventional sensors; two pressure transducers, two temperature sensors, and an accelerometer. Pressure and temperature measurements are collected at the pump intake and discharge, and vibration data is collected on the axial face of the pump volute.

D. V. V Kallon et al.,[8] The The performance of the centrifugal pump drops because the suction of the pump does not allow a smooth flow of the fluid as the fluid enters the pump. The high pressure in the pump causes cavitation, and this is because the high pressure is not enough. This can result in the component of the pump breaking. The purpose of the project is to design a centrifugal pump and develop a model that can predict the amount of flow required at the suction to keep the centrifugal pump running efficiently. Suitable material was chosen based on application criteria. For most water and other noncorrosive services, grey cast iron material satisfies these criteria for the impeller and the casing of the pump. Design constraints and limitations were identified.

A. Daraz et al.,[9] The impeller is one of the main mechanical rotating components in a centrifugal pump which contains vanes at the middle between two faces often called as a closed impeller. Basically, the plain vane leads to the edge square to the back shroud. The impeller in the pump needs more attention as the mechanical wear can cause severe damage reducing the lifetime and efficiency of the pump significantly. In this work impeller wear of centrifugal pump is investigated based on the acoustic mechanism under different flow rates. A little wear that appears in the area of impeller inlet rapidly increases with the rise in peripheral velocity.

M. B. Hossain et al.,[10] Solar tracking system is a paramount component for utilizing the full potential of the solar system. Single axis and dual axis tracking system are available to be used with a solar panel. Both of them along with a fixed tilt system was implemented and evaluated based on their performance. The load was selected to be a DC submersible centrifugal fuel pump commonly used for fuel refilling purpose. The impeller of the fuel pump was modified for better results. For the fixed-tilt system, maximum power achieved at no load condition was 18.83 W and at full load it reached 12.9 W.

III. CHALLENGES

The study of blade design for centrifugal pump impellers involves various challenges that researchers and engineers must address to achieve optimal performance and efficiency. These challenges span theoretical, computational, and practical aspects, reflecting the complexity of fluid dynamics and pump operation. Some key challenges include:

1. **Hydraulic Complexity:**

   - The fluid flow within a centrifugal pump is inherently complex, involving interactions between impeller blades, volute, and diffuser. Understanding and predicting the intricate hydraulic behavior poses a significant challenge.

2. **Cavitation:**

   - Cavitation is a phenomenon where vapor bubbles form and collapse within the pump, leading to erosive damage and reduced efficiency. Designing impellers to mitigate or eliminate cavitation is a constant challenge, requiring a delicate balance between pressure, flow, and blade geometry.

3. **Optimization Trade-offs:**

   - Achieving optimal performance often involves trade-offs between conflicting design parameters. For instance, increasing blade curvature for higher efficiency might lead to higher loads and increased risk of cavitation.

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4. **Material Selection:**

   - Selecting appropriate materials for impeller blades is crucial to ensure durability, corrosion resistance, and fatigue strength. Finding materials that meet these requirements under various operating conditions can be challenging.

5. **Transient Effects:**

   - The dynamic nature of pump operation introduces transient effects, such as variations in flow rates and pressures. Designing impellers to handle these transient conditions while maintaining efficiency poses a challenge.

6. **Computational Simulation Accuracy:**

   - Computational Fluid Dynamics (CFD) simulations play a vital role in impeller design, but accurately capturing the complex fluid-structure interactions remains challenging. Calibration and validation of simulation models are critical to ensure accuracy.

IV. CONCLUSION

The study of blade design for centrifugal pump impellers is a multifaceted and challenging endeavor that requires a comprehensive understanding of fluid dynamics, material science, and mechanical engineering. The impeller, as a central component in centrifugal pumps, plays a critical role in converting mechanical energy into fluid flow, and optimizing its design is essential for achieving high efficiency and reliability in pump systems. Throughout this study, researchers grapple with the intricacies of hydraulic complexity, seeking to balance the trade-offs inherent in impeller design. Challenges such as cavitation pose a constant threat to pump performance, demanding innovative solutions to mitigate potential damage. The optimization of impeller geometry, materials, and loading must consider the interplay of these factors while addressing the transient effects and operational variability encountered in real-world applications.

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