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Numerical simulation and optimizing multistage pump performance

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Abstract - *The increasing demand for high-head fluid supply in today's industrial revolution and fast-paced world makes multistage pumps an essential component in various applications. Their growing popularity stems from their ability to efficiently handle high-head requirements. Performance analysis and head loss evaluation of these pumps are crucial not only for economic reasons but also for energy conservation, given that multistage pumps account for approximately 22 percent of global energy consumption.*

This study aims to analyze head losses in different components of multistage pumps and investigate how the number of vanes in the diffuser affects these losses under various operating conditions. A numerical simulation analysis of a two-stage centrifugal pump was conducted to achieve this objective. The results focus on the head loss and performance parameters of the two-stage centrifugal pump, providing valuable insights into optimizing pump design and operation for better efficiency and reduced energy consumption.

Key Words: Multistage pump, Impellers, Diffuser, Return Channels

1. INTRODUCTION

1.2 CENTRIFUGAL PUMPS

A rot dynamic type of pump is a centrifugal pump. It operates on the forced vortex theory. A centrifugal pump uses centrifugal force to carry out pumping operations. The impeller, which has several mounted vanes, rotates about an axis and causes liquid to be thrown outward by centrifugal force, resulting in the creation of two distinct pressure zones along the impeller's radial direction. Liquid flow is made possible by the impeller's center having lower pressure than its outer edges, which have higher pressure.

The inlet pipe, impeller, diffuser or volute casing, and outflow pipe are a centrifugal pump's primary parts. Industrial, home, and other uses for centrifugal pumps include power plants, among others. These work within a specific range of discharge and are designed in accordance with the application. Radial flow pumps, axial flow pumps, mixed flow pumps, single stage pumps, multistage pumps, etc. are some of the subtypes of centrifugal pumps.

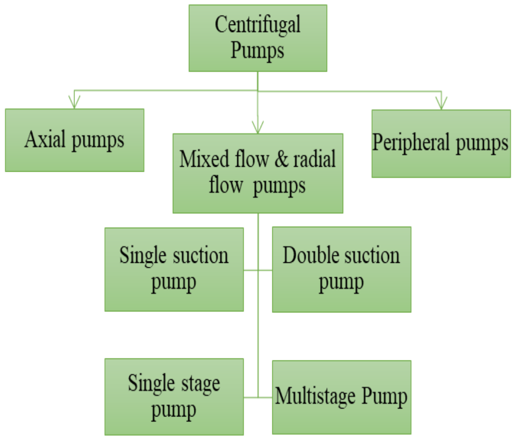

Figure 1.4: Classification of centrifugal.

Centrifugal pumps represent a dynamic class of machinery employed to facilitate the conveyance and displacement of fluids in a myriad of industrial, commercial, and residential contexts. Relying on the centrifugal force principle, these pumps harness rotational energy to endow the fluid with kinetic energy, subsequently translated into pressure energy. Their optimal performance is particularly notable in scenarios characterized by elevated flow rates and moderate-to-high head demands.

Salient attributes and characteristics of centrifugal pumps encompass:

Impeller Mechanism: Central to centrifugal pumps is the impeller—a core rotating element. The impeller's rotation within the pump housing engenders centrifugal force, propelling the fluid outward radially from the impeller's nucleus.

Energy Transformation: The outward propulsion of the fluid by the impeller augments its velocity, resulting in the conversion of mechanical energy into kinetic energy.

Pressure Generation: Subsequent to the kinetic energy infusion, the fluid's energy metamorphoses into pressure energy upon interaction with stationary pump casing components like the volute or diffuser.

Suction and Ejection: Fluid ingress occurs through an inlet, often designated as the suction port. The pressurized fluid is then expelled through an outlet or discharge port.

Single Stage and Multistage: Centrifugal pumps are available in both single-stage and multistage configurations. Single-stage pumps incorporate a single impeller and are well-suited for tasks requiring lower head requirements. In contrast, multistage pumps feature multiple impellers to cater to applications with elevated head demands.

Versatile Applications: Centrifugal pumps exhibit broad utility across domains encompassing water supply, sewage systems, industrial operations, HVAC (heating, ventilation, and air conditioning), irrigation, and petroleum refining, among others.

Efficiency and Performance: Factors such as impeller design, pump speed, and fluid attributes influence pump efficiency. Manufacturers furnish performance curves illustrating the nexus between flow rate, head, and efficiency specific to a given pump model.

Cavitations Vulnerability: A susceptibility to cavitations exists in centrifugal pumps—a phenomenon arising when pump pressure drops below the fluid's vapor pressure. Vapor bubble formation occurs, and these bubbles collapse upon encountering higher-pressure regions, potentially causing damage to pump components.

In summary, the functioning of centrifugal pumps pivots on the conversion of mechanical energy into kinetic and pressure energy through impeller rotation. Their adaptability, efficacy, and capability to accommodate diverse flow rates and head needs establish them as fundamental constituents in the realm of fluid conveyance, spanning a gamut of industries.

PUMP MULTISTAGE

The term "multistage pump" refers to a particular kind of centrifugal pump that consists of several impellers installed on a single shaft and linked in series, as seen in figure 1.5. This setup is primarily used to achieve higher head than a single stage pump. Each stage of a multistage pump is made up of an impeller, a diffuser, and a return channel.

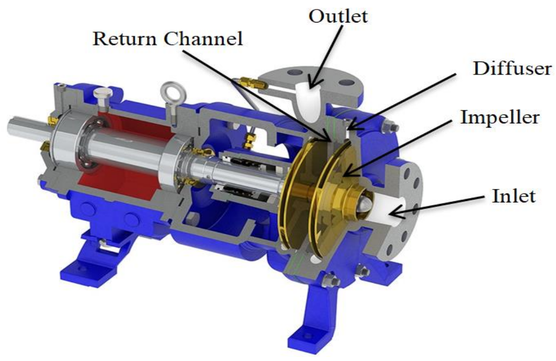

Figure 1.5: Multistage pump. [6]

Number of stage: One impeller, one diffuser, and one return channel make up a stage of a multistage pump. A multistage pump's head generation is boosted by coupling two or more stages in a series connection. The prime mover is connected to a single shaft on which the impellers of each stage are installed.

CURRENT WORK'S OBJECTIVE:

- Assess the multistage pump's design and optimization.
- Run a numerical simulation of a two-stage multistage pump by varying the number of diffuser vanes at different discharges.
- Run a numerical simulation of a two-stage multistage pump by varying the number of diffuser vanes at different discharges.

The work's scope:

- Gather design information (i.e. pump sizing, boundary conditions etc.).
- Creating a 3D model of the multistage pump in the Creo parametric software, and meshing all of its parts in ICEM-CFD.
- The preliminary processing and simulation of a two-stage pump with various diffuser vanes and discharges.
- Results of the head loss and performance metrics of the multistage pump were evaluated and analysed.

LAYOUT:

Chapter 1 Provides an introduction to pumps, centrifugal and multistage pumps, classification of pumps, and multistage pump components, followed by the thesis' structure.

Chapter 2 includes a survey of the literature on the numerical analysis of the multistage pump and centrifugal pump component designs.

Chapter 3 explains the multistage pump theory and the theory underlying the numerical simulation.

Chapter 4 contains the multistage pump's geometric modelling and numerical simulation procedure, both of which were completed for this thesis.

LITERATURE REVIEW

2.1 LITERATURE REVIEW

Up until the 1980s, the only means to evaluate the performance of such complex fluid machines was through physical model testing. As computational processing capacity increased, computational fluid dynamics (CFD) emerged as a reliable and practical method. (Shah et al.2012)[16]. numerous researchers numerically and experimentally examined various flow parameters inside multistage pumps to increase performance.

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- **Nagahara et al. (2005)[11]** Large eddy simulation (LES) was utilized to investigate the flow field in a multistage pump and compare the findings with experimental and CFD results. The interaction between the impeller and the stator was considered through LES calculations, enabling the study of the flow field in the input region of each component. Throughout the experimental investigation, velocity distributions and pressure changes were captured using a scaled model pump. The ratio of total head to experimental head was 1.03 in the LES approach and 1.04 in the RANS method, both of which deviated by only 4% from the true head.

- **Roclawski et al (2006)[14]** A CFD simulation was run, followed by an experimental test to confirm the CFD findings, in order to modify the diffuser to reduce the radial dimension of a multistage pump. They have modified the stator in order to reduce radial dimensions. Verification of the results is done using measurements of characteristic curves and information from hot wires. At its peak efficiency, the new stator concept's pump performance was around 7% less efficient than the one it replaced.

- **Yang et al. (2009)[23]**analysed multistage centrifugal pumps using integral modelling, compared the findings to experimental data, and found only small variations. A flow channel for a multistage pump was built from the ground up. The impact of the grid number was examined through comparison of the simulation results. Data were utilised to evaluate thedistributions of pressure and speed in the impellers, guiding vanes, and other parts. Because the projected values agree with the observed values, it proved that integral modelling can be used to numerically simulate flow in a multistage centrifugal pump. Less than 10%, or within acceptable limits, was discovered to be the inaccuracy in the integral modelling.

- **Tverdokhleb et al. (2012)[20]**Using computer modelling, we have attempted to reduce the radial dimension on multistage pumps by lowering the ratio of guide vane external diameter to impeller external diameter. Increasing the number of vanes utilised in the impellor with a two-row vane arrangement allows for the decrease of D2. While keeping the other performance factors same, they decreased the radial dimension by 4%.

- **Streamline patterns for 7 diffuser vanes**

- Figure 5.21 (a) and (b) show the velocity streamlines for seven diffuser vanes in the radial and axial planes, respectively. As we can see, the kinetic energy of the rotating impeller causes the fluid velocity in the impeller to be greater. In the diffuser, velocity is lowered by 4.42 m/s. In pump flow channels, a smooth flow is achieved.

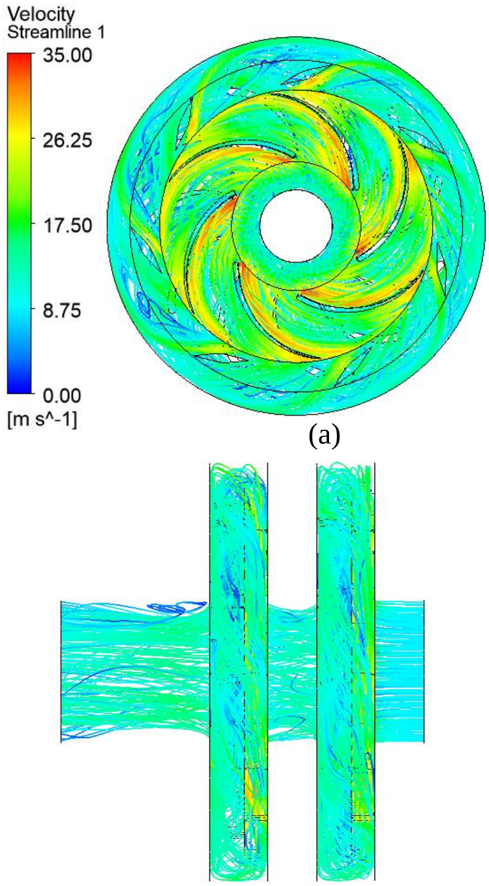

Figure 5.21: Stream lines for 7 diffuser vanes (a) Radial, (b) Axial.

- **5.7.2 Streamline patterns for 8 diffuser vanes**

Figure 5.22 (a) and (b) show the velocity streamlines for eight diffuser vanes in the radial and axial planes, respectively. As we can see, the kinetic energy of the rotating impeller causes the fluid velocity in the impeller to be greater. In the diffuser, velocity is lowered by 4.39 m/s. In pump flow channels, a smooth flow is achieved.

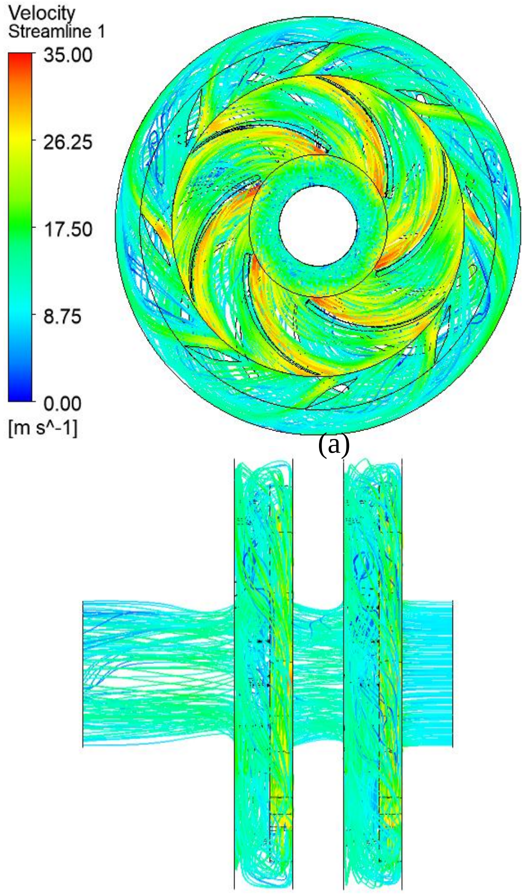

Figure 5.22: Stream lines for 8 diffuser vanes (a) Radial, (b) Axial.

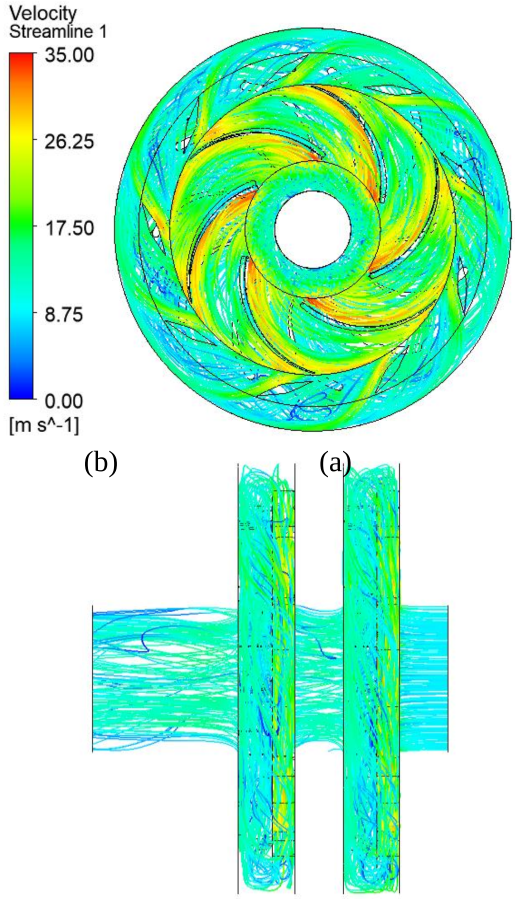

Figure 5.23: Stream lines for 9 diffuser vanes (a) Radial, (b) Axial.

5.7.3 Streamline patterns for 9 diffuser vanes

- Figure 5.23 (a) and (b) show velocity streamlines for nine diffuser vanes in the radial and axial planes, respectively. As we can see, the kinetic energy of the rotating impeller causes the fluid velocity in the impeller to be greater. In the diffuser, velocity is lowered by 4.52 m/s. In pump flow channels, a smooth flow is achieved.

- **5.7.4 Streamline patterns for 10 diffuser vanes**

- Figure 5.24 (a) and (b) show the velocity streamlines for 10 diffuser vanes in the radial and axial planes, respectively. As we can see, the kinetic energy of the rotating impeller causes the fluid velocity in the impeller to be greater. In the diffuser, velocity is lowered by 4.51 m/s. In pump flow channels, a smooth flow is achieved.

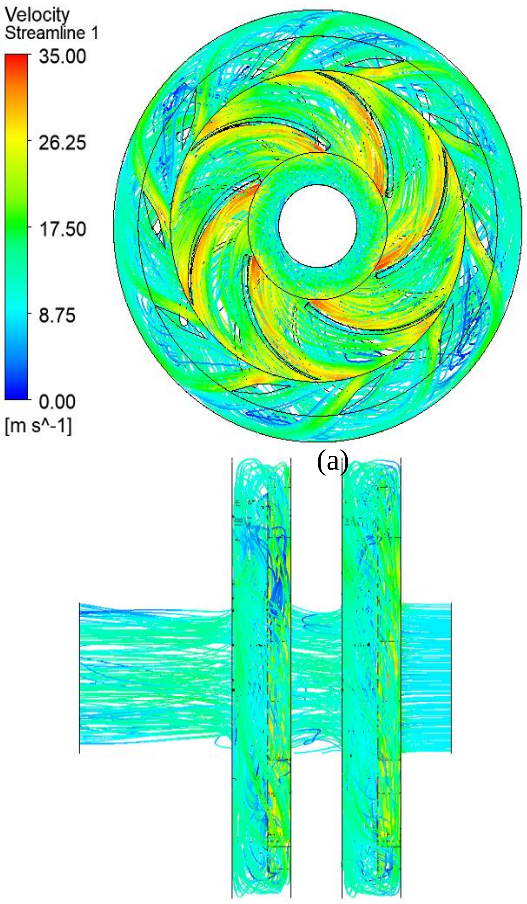

Figure 5.24: Stream lines for 10 diffuser vanes (a) Radial, (b) Axial.

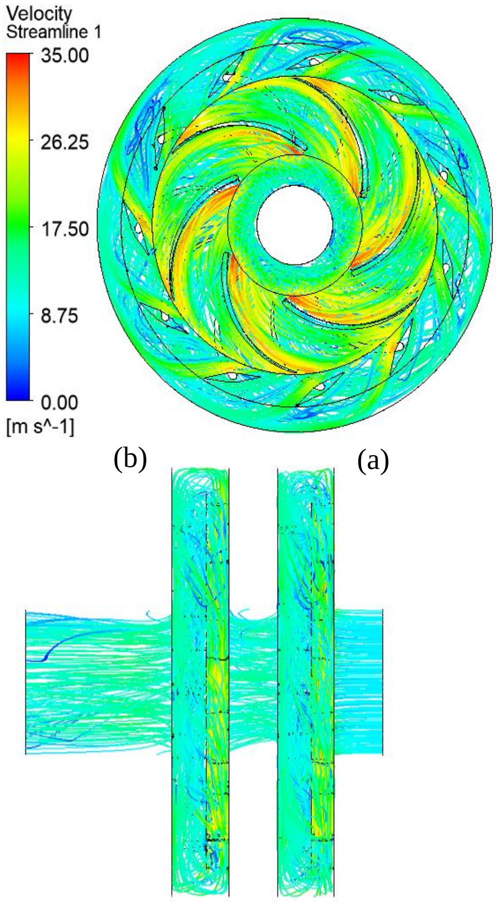

Figure 5.25: Stream lines for 11 diffuser vanes (a) Radial,(b) Axial.

5.7.5 Streamline patterns for 11 diffuser vanes

- Figure 5.25 (a) & (b) show the velocity streamlines for 11 diffuser vanes in the radial and axial planes, respectively. As we can see, the kinetic energy of the rotating impeller causes the fluid velocity in the impeller to be greater. In the diffuser, velocity is lowered by 4.60 m/s. In pump flow channels, a smooth flow is achieved.

Based on the simulation results, several key conclusions can be drawn:

1. Efficiency at Different Diffuser Vane Numbers: At 1900 rpm with six different discharge rates, the diffuser with seven vanes exhibited both the highest and lowest efficiency at a discharge of 630 m^3/h. This suggests a significant sensitivity of efficiency to both the vane number and discharge rate.

2. Impact of Vane Number (Odd vs. Even): Diffusers with an odd number of vanes generally performed better compared to those with an even number of vanes. This may be attributed to the relative angular positioning between the diffuser vanes and the impeller vanes, which likely reduces adverse interactions.

3. Head Consistency Across Discharges: For all tested vane configurations, the head values at discharges of 580, 630, and 700 m^3/h were nearly identical. This indicates that the number of vanes in the diffuser has a minimal impact on the head at higher discharge rates.

4. Influence of Diffuser Channel Size: The size of the diffuser channel has a substantial effect on the performance of the multistage pump. Even small reductions in channel size can significantly impact overall performance, highlighting the importance of optimizing this parameter.

These findings can help guide the design and optimization of diffuser vanes in multistage pumps, balancing efficiency, head consistency, and overall performance.

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