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The Effect of tip clearance on the flow field of a Centrifugal Compressor can be analyzed by using ANSYS-CFX

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ABSTRACT

The main goal of this investigation is to explore the potential for enhancing performance, achieving uniform exit flow, and reducing the impact of tip clearance on a low-speed centrifugal compressor. For achieve this, conducted computational simulations using a commercial CFD software.In this study examined six different configurations of blade tips to simulate the flow through the centrifugal compressor, used Blade Gen for modeling and CFX as the CFD solving software. Centrifugal compressor finds extensive applications in various industries, including process industries, turbochargers, and small gas turbine engines. They offer several inherent advantages such as high pressure ratio per stage, compact and lightweight design, suitability for low mass flow applications, reasonable efficiency, large surge margin, and cost-effectiveness. In this study, focused on analyzing the effects of tip clearance in a low-speed centrifugal compressor using a structured multi-block grid. Specifically examined a centrifugal compressor impeller with four different values of tip clearances, ranging from 0% to 8% along the blade height. By conducting this computational study, aimed to gain insights into how varying tip clearances impact the performance and flow characteristics of the compressor. Centrifugal compressor impeller with four values of clearances i.e., τ=0% to 8% of blade height at trailing edge are examined at five flow coefficients 0.2 Centrifugal compressor impeller with four values of clearances i.e., τ=0% to 8% of blade height at trailing edge are examined at five flow coefficients 0.28, 0.34, 0.42, 0.48 and 0.52. Yohan Jung, et.al [6] presented a numerical investigation of the effects of a non-uniform tip clearance profile on the performance and flow field in a centrifugal compressor with a vane less diffuser.Pressure from the inlet to the outlet of the compressor is indeed crucial. In this study, it was found that as the tip clearance increases, there is a significant drop in total pressure, particularly at the tip of the blade. This drop in pressure is primarily attributed to the leakage of high-pressure fluid at the tip of the blade. Additionally, an interesting observation was made regarding the reduction of blade loading near the tip as the tip clearance increases. This finding suggests that the presence of tip clearance affects the aerodynamic performance and loading distribution along the blade.

Keywords: centrifugal compressor, ANSYS, CFD solving software

1. INTRODUCTION

The flow field within a centrifugal impeller is indeed influenced by various factors. The complex curvature of the impeller blades plays a significant role in directing the flow and generating the desired pressure rise. The rotational forces imparted by the impeller's rotation also affect the flow pattern. Additionally, the clearance between the rotating impeller and the stationary casing can impact the efficiency and performance of the impeller. These factors collectively contribute to the overall flow behavior within a centrifugal impeller. Tip clearance studies are indeed crucial in understanding the flow behavior and its impact on the overall performance of a compressor. Researchers conduct these studies to gain insights into the adverse effects of tip clearance, such as pressure drop and efficiency reduction. By analyzing the flow patterns and characteristics near the impeller tip, they can develop strategies to minimize these negative effects and optimize the compressor's performance. These studies help in improving the design and efficiency of compressors, leading to more effective and reliable systems.

The findings from such studies can help in optimizing the design and operation of centrifugal compressors to improve their performance and minimize the impact of tip clearance.Hark-JinEum, Young-Seok Kang and Shin-Hyoung Kang [1], "Tip clearance effect on through-flow and performance of a centrifugal compressor".P. Usha Sri and N. Sitaram [2] studied tip clearance effects on flow field of a low speed centrifugal compressor and analysed computationally using structured multi block grid with fine grid in the tip clearance region. Centrifugal compressor impeller with four values of clearances i.e., τ=0% to8% of blade height at trailing edge are examined at five flow coefficients 0.28, 0.34, 0.42, 0.48 and 0.52. Yohan Jung, et.al [6] presented a numerical investigation of the effects of a non-uniform tip clearance profile on the performance and flow field in a centrifugal compressor with a vane less diffuser. Six impellers with different tip clearance profiles were tested in the flow simulations. The effect of tip clearance in centrifugal compressor using structured multi block grid in the tip clearance region for different tip clearances i.e., 0% to8% presented in thispaper.

2. SOLUTION METHODOLOGY:

Tip clearance in a centrifugal compressor can lead to the leakage of high-pressure fluid from the pressure surface to the suction surface of the impeller blade. This leakage can significantly impact the flow field, making it more complex and affecting the overall performance of the compressor.By using a structured multi-block grid, computational analysis can be performed to study these effects in detail. This approach allows for a more accurate representation of the flow field and enables the investigation of various parameters related to tip clearance.Tip clearance analyses are conducted to understand the flow behaviour in order to minimize theeffect of tip clearance.Effect of tip clearance and flow behaviour in a low speed centrifugal impeller with tip clearance is presented in this paper. The design details of the impeller used in the present investigation are given below:

The design details of the impeller which is used in the investigations are given below:

Inducer hub diameter, d_{1h}= 160 mm
Impeller tip diameter, d_2= 500 mm
No. of blades of impeller, N_b = 16
Blade angle at inducer tip, β_{1t} = 35^o
Thickness of the blade, t = 3 mm
Inducer tip diameter, d_{1t} = 300 mm
Blade height at the exit, b_2= 34.7 mm
Blade angle at inducer hub, β_{1h}= 53^o
Blade angle at exit, β_2 = 90^o
Rotor speed, N_b= 2000rpm
Massflowrate = 0.15 kg/s

All angles are with respect to the tangential direction specifications with 2mm thickness throughout the blade anda single passage of the impeller with inlet at 50mm ahead of the impeller and outlet at a distance of 35mm downstream of impeller is shown in figure. It appears that you are studying the tip clearance flows in a centrifugal compressor with different tip clearances ranging from 0% to 8%. The blade model has a height of 85mm, an inlet diameter of 120mm, and an outlet diameter of 250mm.To simulate the rotational periodicity have considered a single blade with half the pitch on either side of the blade for analysis. This approach allows for a simplified representation of the flow field while still capturing the essential characteristics of the tip clearance flows.Fig.1. shows for different tip clearances of 0% to8% are considered for the analysis of the tip clearanceflows.Blade is modelled with a height of 85mm, with inlet diameter of 120mm and out let diameter of 250mm. Assuming rotational periodicity, a single blade with half the pitch on either side of the blade is considered for analysis.

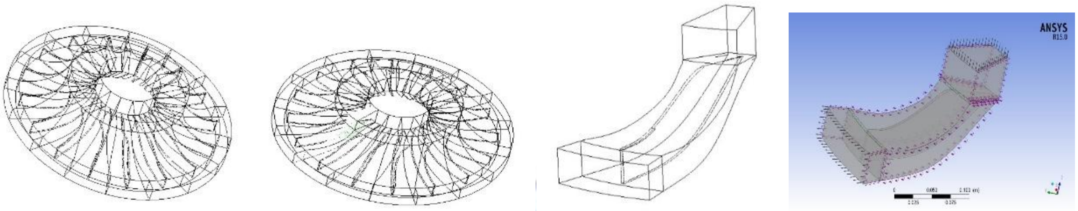


Figure 1. Impeller blade and Computational domain of single passage

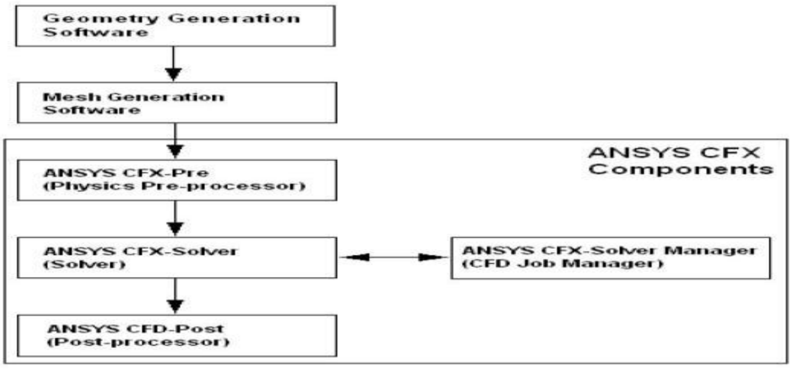
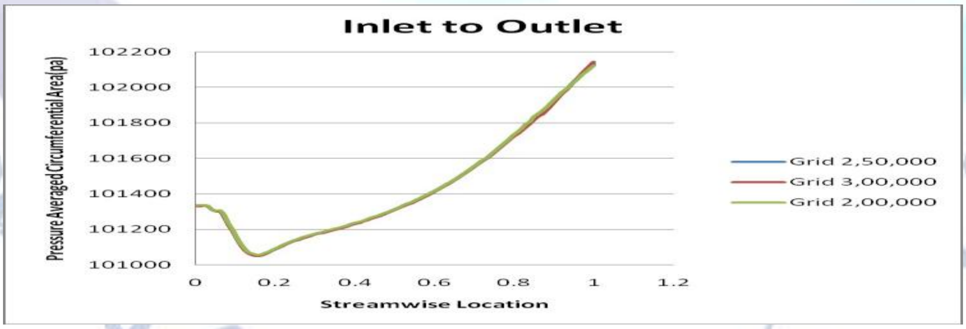


Figure 2: Working of CFD

3. GRID INDEPENDENCY STUDIES:

Table 1 must provide valuable insights into the relationship between grid size, convergence, and solution accuracy.A grid independence study is crucial in determining the appropriate grid resolution for simulation. It helps identify the point at which further refinement of the grid does not significantly affect the results, ensuring that are using computational resources efficiently.By comparing the results obtained from different grid sizes can assess whether the solution is converging and if the accuracy is consistent across various grid resolutions. This information is essential for making informed decisions about the appropriate grid size to use for simulations.



Statistics	
Nodes	445604
Elements	2310116
Mesh Metric	Skewness
Min	7.666276246443E-05
Max	0.797751114670892
Average	0.233106168038319
Standard Deviation	0.12186113343001

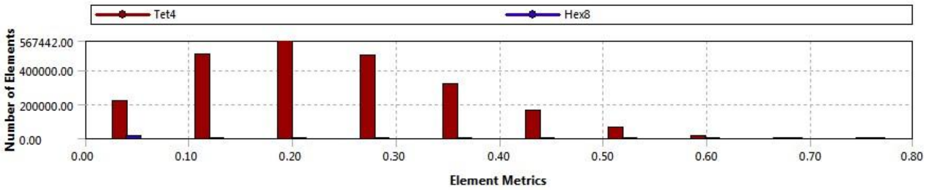


Fig.3 Frequency of distribution of skewness

4.RESULTS AND DISCUSSION:

It seems that the inclusion of a partial shroud in the compressor design has resulted in higher efficiency compared to a compressor without a partial shroud. This improvement in efficiency can be attributed to the reduction in tip leakage flows at a tip clearance value of 2.2%.Both experimental and simulation results have shown that the presence of a partial shroud has a positive impact on the performance of the compressor. This suggests that incorporating a partial shroud can be highly beneficial in terms of improving the overall efficiency of the compressor

Table 1. The centrifugal compressor performance is maximum at tip clearance ranges

Range of tip clearance	Best Range	Maximum Efficiency (With PS)	Maximum Efficiency (Without PS)
0 – 5%	2.2%	49.8	47.1
5.1 – 7%	5.1%	49.4	45.4
7.1 – 8%	7.9%	48.6	45.2

The analysis of the centrifugal compressor flow and the observations from Figure 4. It's interesting to note that the static pressure contours show a continuous pressure rise from the leading edge to the trailing edge of the impeller. This pressure rise is a result of the dynamic head generated by the rotating impeller.Additionally, it's observed that the pressure on the pressure side of the blade is higher than that on the suction side at a given meridional section. This difference in pressure between the two sides of the blade is likely due to the aerodynamic forces acting on the impeller.Furthermore, the minimum value of the static pressure inside the impeller is located at the leading edge of the blades on the suction side. This can be attributed to the flow acceleration and the resulting decrease in static pressure at that particular location

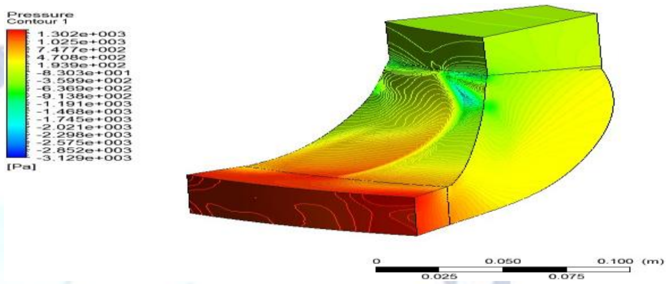


Figure 4. Pressure distribution for impeller for without tip clearance 0%.

It is observed that variations in static pressure patterns for different tip clearances of the impeller. Low pressures are noticed near the hub of the impeller, while a combination of low pressure and high velocity is observed near the leading edge on the suction side of the blade due to vane thickness. Additionally, pressure loss is observed at the trailing edge of the blade for all span wise locations, which can be attributed to wake formation. It's interesting to note that as the tip clearance increases, the rise in pressures is decreasing due to tip clearance flow.

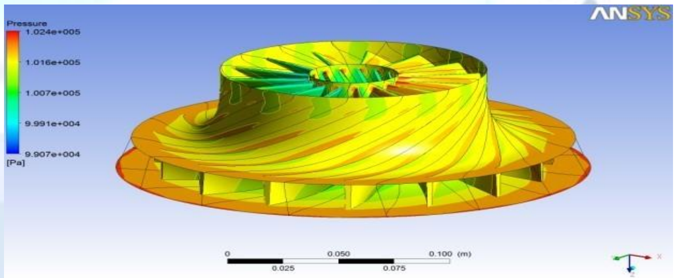


Figure 5: Pressure distribution fortip clearance of1%

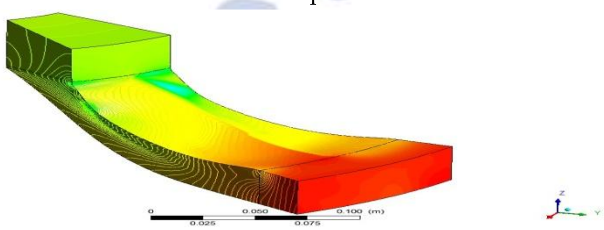


Figure 6. Pressure distribution fortip clearance of2%

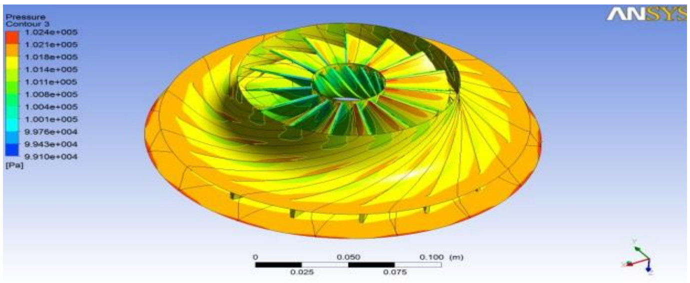


Figure 7. Pressure distribution for tip clearance of 5%

The total pressure along the stream wise direction varies for different models with and without tip clearance in the compressor. In the case of the 0% tip clearance model, where the shroud is attached to the impeller blades and is stationary, the pressure increases from the inlet to the outlet along the stream wise direction. However, for models with tip clearance ranging from 0% to 8%, a decrease in pressure rise is observed as the clearance increases. Despite this decrease, there is still a gradual increase in total pressure from the inlet to the outlet in all cases.

It seems that in the stream wisedirection up to 25% from the inlet, there is a decrease in pressure. This can be attributed to the flow in the inlet duct accelerating towards the impeller. However, from the 25% stream wise location onwards, the pressure starts to increase. This increase is due to the dynamic energy transfer from the rotating impeller to the fluid.Furthermore, when comparing models with tip clearance ranging from 0% to 8%, there is a reduction in pressure rise compared to the 0% clearance model. This suggests that as the tip clearance increases, the pressure rise decreases.

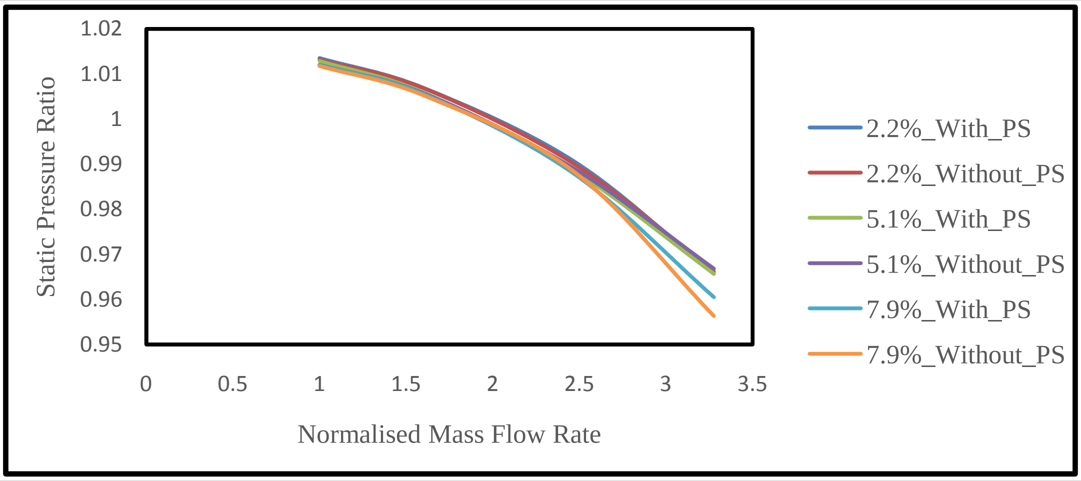


Fig.8: Static pressure ratio vs. Normalised mass flow rate (ϕ/ ϕd)

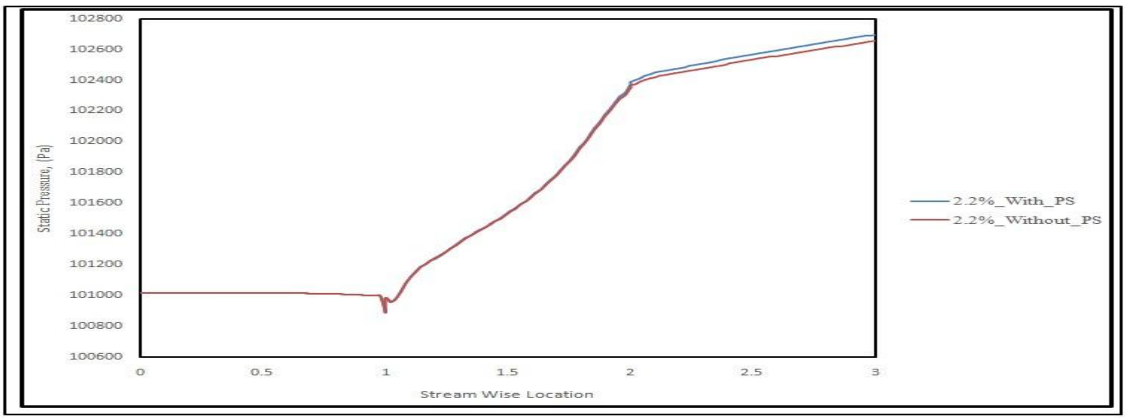
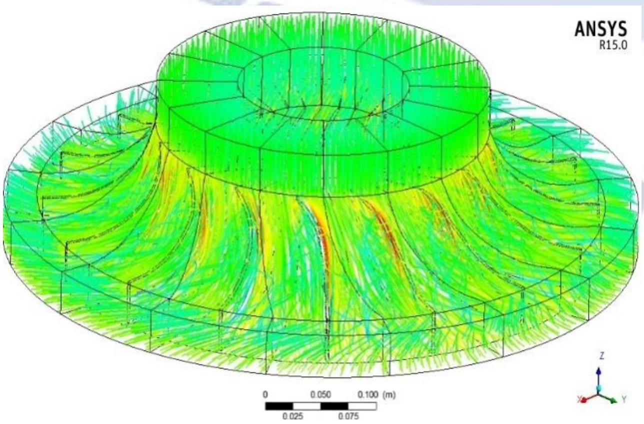


Fig.9: Stream wise variation of total pressure for different tip clearances 2.2%

the velocity streamlines inside the impeller with and without partial shroud for different tip clearances and flow coefficient. It appears that the presence of tip leakage flow affects the flow patterns within the impeller.

The tip leakage flow interacts with the low momentum fluid on the suction surface side, causing it to roll down and move towards the exit. As the fluid reaches the rotor exit, the flow pushes the low momentum fluid back into the impeller passage from the pressure surface side to the suction surface side.These observations suggest that the tip leakage flow and its interaction with the surrounding fluid play a significant role in the flow behavior within the impeller. The effects of the tip leakage flow on the flow deceleration and the wake region at the exit of the impeller blade.It appears that the presence of the tip leakage flow leads to further deceleration of the flow on the suction side. Additionally, the strength and location of the wake region at the exit of the impeller blade are heavily influenced by the tip leakage flow.When the vanes of the diffuser are closer to the impeller, the reverse flow enhances the tip leakage flow near the impeller exit. This observation is supported by the observed streamlines pattern.These observations the tip leakage flow has a significant impact on the flow behavior and characteristics within the impeller, as well as at the exit region.

Velocity streamlines inside impeller with and without partial shroud for different tip clearances and flow coefficient at 0.34 is shown in figures 10. The tip leakage flow interacts with the low momentum fluid on the suction surface side causing the roll down and move towards the exit. At the rotor exit fluid flow pushes the low momentum fluid back in to the impeller passage from the pressure surface side to suction surface side. This causes further deceleration of the flow from suction side. The strength and location of the wake region at the exit of impeller blade is heavily depended upon the tip leakage flow. When the vanes of diffuser are closer to the impeller the reverse flow enhances the tip leakage flow near the impeller exit. This is clearly observed from the streamlines pattern.



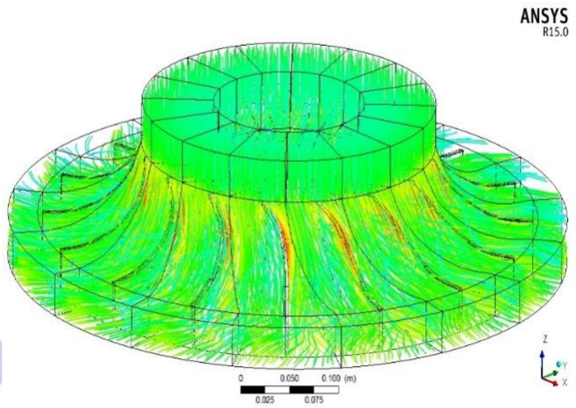


Fig.10 Velocity streamlines inside impeller at 2.2% tip clearance for without and with partial shroud at 0.34 flow coefficients.

5.BLADE LOADING CHARTS:

The blade loading plot for the centrifugal impeller with different tip clearance values. It's interesting to note that there is a gradual increase in pressure along the stream wise direction.The high pressures on the pressure side of the blade and low pressures on the suction side are commonly observed in centrifugal impellers. This pressure distribution is a result of the impeller's design and the flow characteristics.The pressure difference between the pressure and suction sides of the blade is essential for generating the desired fluid flow and achieving the impeller's intended purpose. It helps in converting the kinetic energy of the fluid into pressure energy.

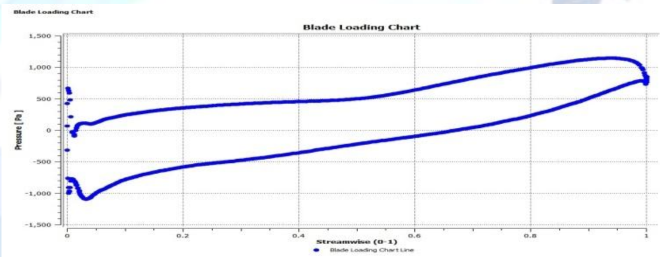


Figure 11. Blade loading chart for the impeller without tip clearance 0%

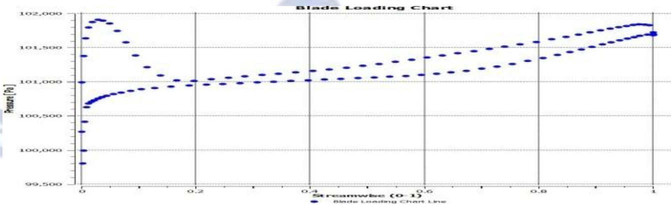


Figure 12. Blade loading chart for the impeller with tip clearance 1%

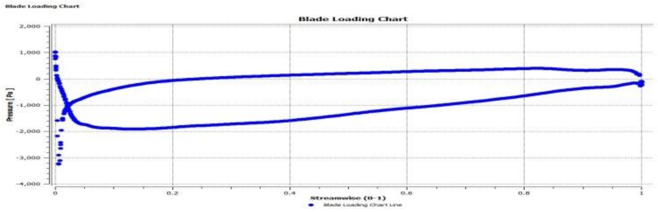


Figure 13. Blade loading chart for the impeller with tip clearance2%

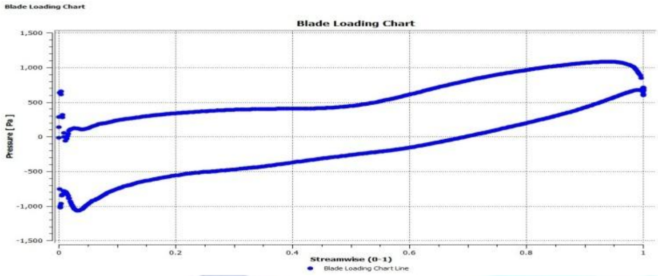


Figure 14. Blade loading chart for the impeller with tip clearance5%

6. CONCLUSION

The analysis of centrifugal impellers using computational fluid dynamics (CFD) is different tip clearances were considered in the analysis, ranging from 0% to 8%.Based on the Computational Flow Analysis in the centrifugal compressor, the conclusions are drawn from the study.The conclusions from the computational investigation on centrifugal compressor impellers is that an increase in tip clearance leads to a reduction in pressure rise within the impeller. The continuous pressure rise from the leading edge to the trailing edge of the impeller is attributed to the dynamic head developed by the rotating pump impeller.The computational investigation highlights that the inclusion of a partial shroud on the tip of the blade has resulted in an increase in compressor efficiency. Specifically, the efficiency has improved to 51.38% from 49.8% at a 2.2% tip clearance, when compared with experimental efficiency.

It is observed that the pressure on the pressure side of the blade is higher than that on the suction side at a given meridional section. Additionally, the pressure decreases at the inlet up to 25% stream wise location due to the flow accelerating towards the impeller in the inlet duct. In this computational analysis, reducing tip leakage flows through partial shrouds has more beneficial effects, especially at higher values of tip clearance. Furthermore, as the tip clearance increases, the static pressure and total pressure distribution along the stream wise direction of the compressor decrease.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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