

EFFECT OF TIP CLEARANCE ON FLOW FIELD OF A CENTRIFUGAL COMPRESSOR USING ANSYS-CFX

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ABSTRACT

The centrifugal compressor is widely used in process industries, turbochargers, small gas turbine engines, etc. The inherent advantages of centrifugal compressor are high pressure ratio per stage, compactness, light weight design, low mass flow applications, reasonable efficiency, large surge margin and low cost. The present work comprises of analysis of computational study of tip clearance effects in a low speed centrifugal compressor using structured multi block grid. The flow through the centrifugal compressor is modelled in Blade Gen and solved by a CFD solving software, CFX. Standard $k-\epsilon$ turbulence model is used for obtaining the solution. Centrifugal compressor impeller with four values of clearances i.e., 0 mm, 1 mm, 2 mm and 5 mm along blade height are examined. The effect of tip clearance on total pressure from inlet to outlet of the compressor is analyzed. The drop in total pressure with increase in tip clearance is found to be high at the tip of the blade due to high pressure fluid leakage at the tip of the blade. The reduction of blade loading near the tip with tip clearance increase is observed.

Keywords: centrifugal compressor, ANSYS, CFD solving software

1. INTRODUCTION

The flow field in the centrifugal impeller is influenced by the complex curvature of the impeller blades, the rotational forces, and clearance between the rotating impeller and stationary casing. Tip clearance studies are conducted to understand the flow behavior in order to minimise the effect of tip clearance. Hark-Jin Eum, et al. [8] investigated tip clearance effect on through-flow and performance of a centrifugal

compressor which has the same configuration of impeller with six different tip clearances. P. Usha Sri and N. Sitaram [5] 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., $\tau=0\%$, 1%, 2% and 5% 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 [2] 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 four tip clearances i.e., 0mm, 1mm, 2mm and 5mm is presented in this paper.

2. SOLUTION METHODOLOGY:

Tip clearance effects on flow field of a low speed centrifugal compressor are analysed computationally using structured multi block grid. Tip clearance in centrifugal compressor causes the leakage of high pressure fluid from pressure surface to suction surface of the impeller blade, making the flow field highly complex and

effecting the performance. Tip clearance analyses are conducted to understand the flow behaviour in order to minimize the effect 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:

- Inlet diameter D_1 = 120mm
- Outlet diameter D_2 = 250mm
- Outlet blade angle β_2 = 20^0
- Blade height, b_2 = 85 mm
- No. of blades of impeller, N_b = 15
- Thickness of the blade, t = 2 mm
- Rotor speed, N = 3000 rpm
- Mass flow rate = 0.15 kg/s

Centrifugal impeller with above specifications with 2mm thickness through out the blade is shown in Fig.1. A 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 Fig.2. Four tip clearances of 0mm, 1mm, 2mm and 5mm are considered for the analysis of the tip clearance flows.

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.

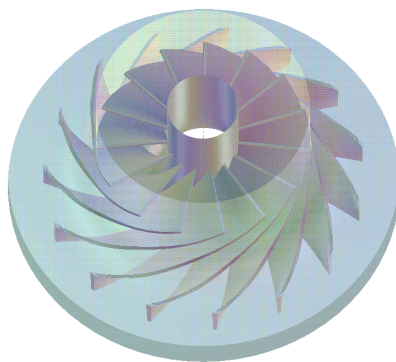


Figure 1. Shaded view of impeller blade

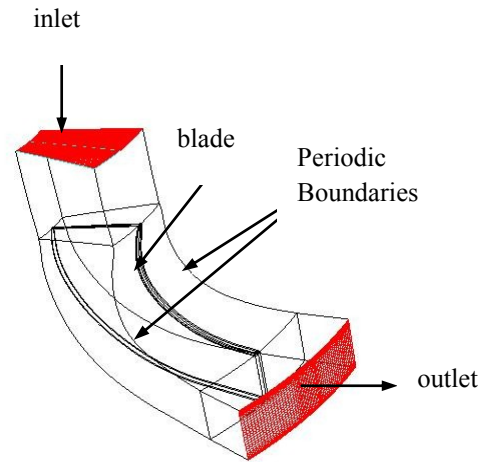


Figure 2. Computational domain of single passage

3. GRID INDEPENDENCY STUDIES:

Grid size plays an important role in both convergence and accuracy of the solution. A coarse mesh is initially used to quickly examine the solver settings and boundary conditions. Finer grids, in general, make the solution independent of the grid size and yield more accurate results but always require larger computational resources and time. Hence, a grid independence study was carried out to ensure that the numerical solutions are grid-independent. Results of grid independency are shown in Table1.

Table 1: Results of grid independency study

Sl.No.	Nodes	Massflow Average	% Deviation
1	2,18,589	1,02,122	-0.0058
2	2,54,863	1,02,128	-
3	3,19,539	1,02,133	0.0048

From the results, it is observed that the computed values for grid of 2,54,863 elements are close to the computed values

with grids of 2,18,589 and 3,19,539 elements. Grid of 2,54,863 elements is taken as the optimum grid. Hence all computations are done with the grid of 2,54,863 elements.

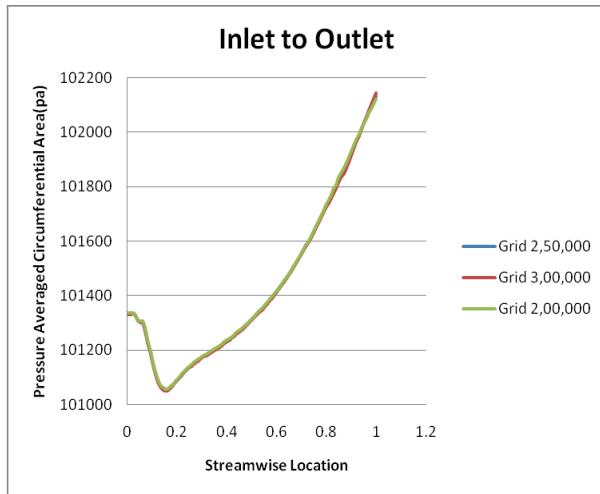


Figure 3. Grid independency variation from inlet to outlet

4. RESULTS AND DISCUSSION:

Centrifugal compressor flow analysis is analysed for four tip clearances for the impeller blade i.e. for 0mm, 1mm, 2mm and 5mm flow is analysed.

From Fig.4, it is observed that the static pressure contours show a continuous pressure rise from leading edge to trailing edge of the impeller due to the dynamic head developed by the rotating impeller. It is observed that pressure on pressure side of the blade is more than that of suction side at a given meridional section. The minimum value of the static pressure inside the impeller is located at the leading edge of the blades on the suction side.

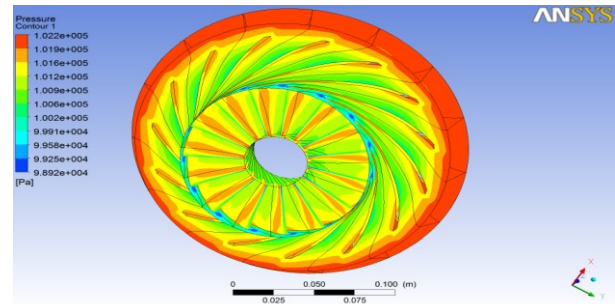


Figure 4. Pressure distribution for impeller for without tip clearance 0mm

From Fig. 5 to 7, it is observed that static pressure patterns are varying for various tip clearance of the impeller. Low pressures are observed near hub of the impeller. A low pressure and high velocity is observed near the leading edge on suction side of the blade because of the vane thickness. At trailing edge of the blade pressure loss is observed for all span wise locations due to the wake formation at trailing edge of the blade. With increase in tip clearance, pressures rise is decreasing because of tip clearance flow.

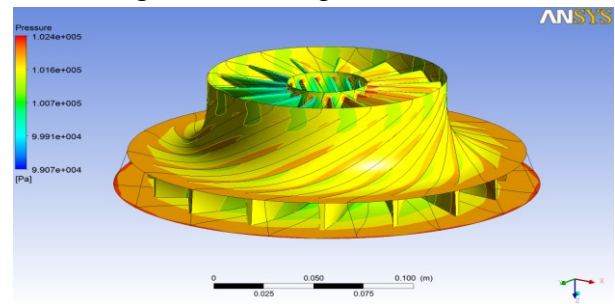


Figure 5: Pressure distribution for tip clearance of 1mm

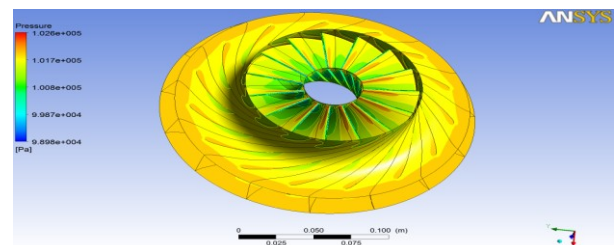


Figure 6. Pressure distribution for tip clearance of 2mm

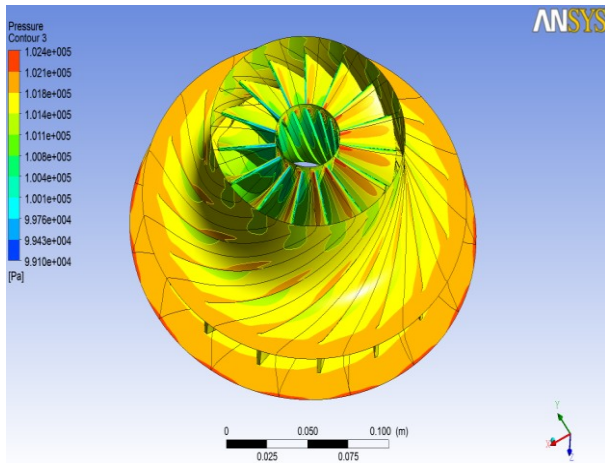


Figure 7. Pressure distribution for tip clearance of 5mm

The total pressure along stream wise direction for without tip clearance and with clearance from inlet to outlet chart of the compressor is shown in fig. 9. The 0mm tip clearance is a hypothesis compressor where the shroud is attached to the impeller blades and is stationary. For 0mm clearance model, the pressure is increasing from inlet to outlet along stream wise direction. For 1mm, 2mm, and 5mm clearance models, decrease in pressure rise is observed with increase in clearance. Gradual increase in total pressure from inlet to outlet is observed in all cases.

In stream wise direction up to 20% from the inlet, decrease in pressure is observed due to the flow in inlet duct is accelerating towards the impeller. From 20% stream wise location, the pressure is increasing due to the dynamic energy transfer from the rotating impeller to the fluid. For 1mm, 2mm and 5mm clearance the reduction in pressure rise is observed as compared to that of 0mm clearance.

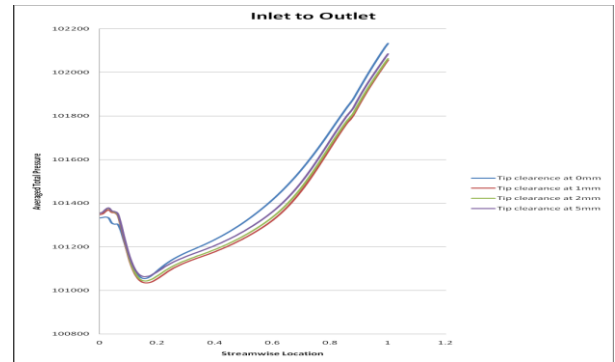


Fig.8: Stream wise variation of total pressure for different tip clearances 0mm, 1mm, 2mm, and 5mm

5. Blade loading charts

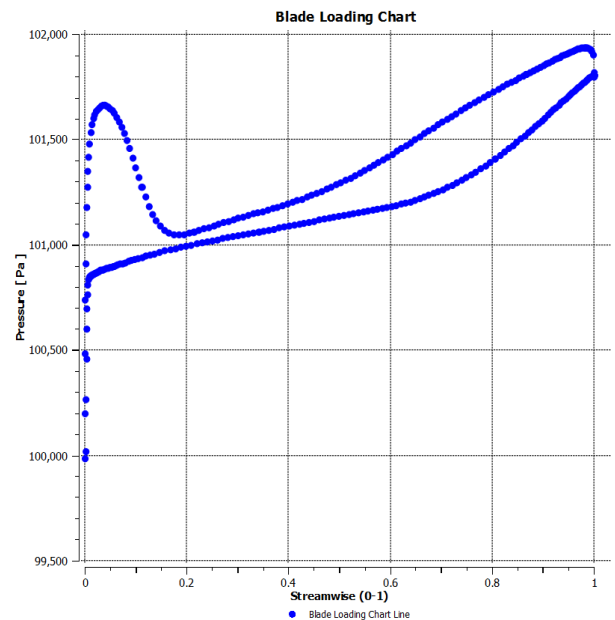


Figure 9. Blade loading chart for the impeller without tip clearance 0mm

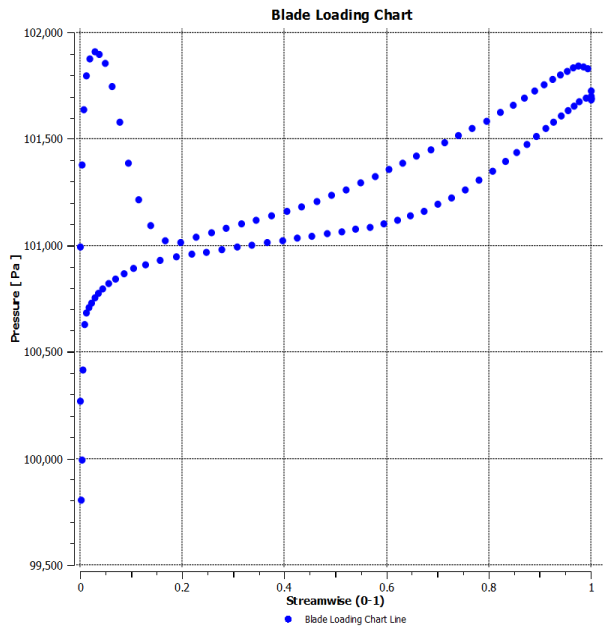


Figure 10. Blade loading chart for the impeller with tip clearance 1mm

Blade loading plot for the centrifugal impeller for different tip clearance values is shown in the blade loading graphs. Gradual increase of pressure is observed along stream wise direction. High pressures on pressure side of the blade and low pressures on suction side of the blade are observed.

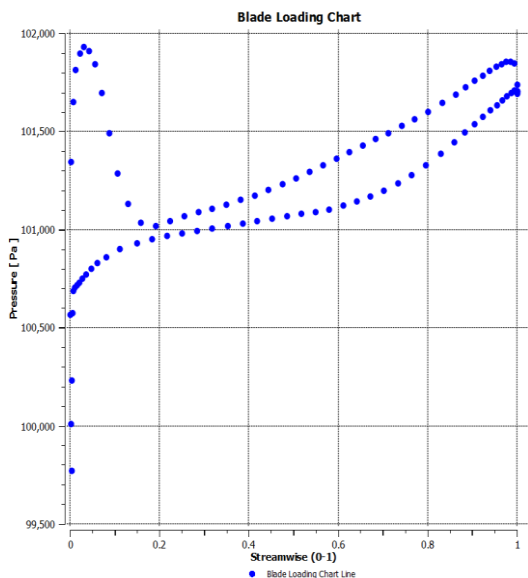


Figure 11. Blade loading chart for the impeller with tip clearance 2mm

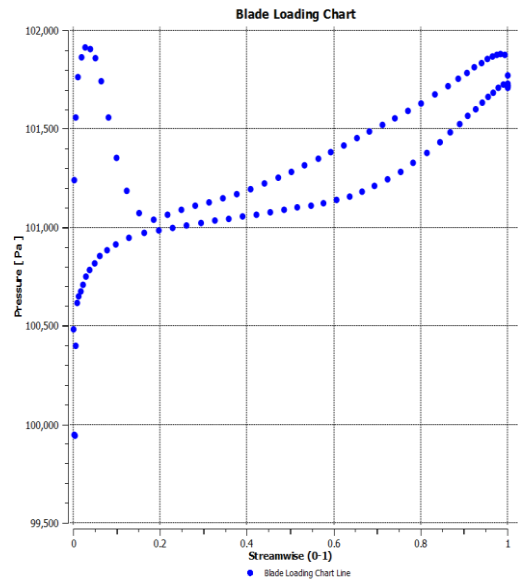


Figure 12. Blade loading chart for the impeller with tip clearance 5mm

6. CONCLUSION:

The analysis of centrifugal impeller, with the help of computational fluid dynamics (CFD) is presented. In this study, analysis of the compressor impeller for different tip clearances i.e. 0mm, 1mm, 2mm and 5mm is presented.

The following are the conclusions drawn from the Computational Flow Analysis in centrifugal compressor

- It is observed that with increase in tip clearance (i.e., for 1mm, 2mm, 5mm) there is reduction in pressure rise in centrifugal compressor impeller.
- The pressure contours show a continuous pressure rise from leading edge to trailing edge of the impeller due to the dynamic head developed by the rotating pump impeller.
- It is observed that the pressure on pressure side of the blade is more than

that of suction side at a given meridional section.

- It is observed that at inlet up to 20% stream wise location, the pressure is decreasing due to the flow in inlet duct accelerating towards the impeller.

7. REFERENCES:

[1] Hark-Jin Eum, Young-Seok Kang and Shin-Hyoung Kang, "Tip clearance effect on through-flow and performance of a centrifugal compressor", *KSME International Journal*, Vol 18, Issue 6, pp 979-989, June 2004.

[2] P. Usha Sri and N. Sitaram, "Tip Clearance Effects on Flow Field of a Centrifugal Compressor", *Thermal Turbo machines Laboratory, Department of Mechanical Engineering, IIT Madras, Chennai India*, 2012.

[3] Yohan Jung, Minsuk Choi, Seonghwan Oh and Jehyun Baek, "Effects of a Nonuniform Tip Clearance Profile on the Performance and Flow Field in a Centrifugal Compressor", *International Journal of Rotating Machinery*, Vol. 2012 (2012), 1-11 pages.

[4] Wei Xu, Tong Wang, Chuangang Gu, and Liang Ding, "Numerical Investigation of a Centrifugal Compressor With Holed Casing Treatment", *Key Laboratory for Power Machinery and Engineering of Ministry of Education, Shanghai Jiao Tong University, Shanghai, China, J. Eng. Gas Turbines Power* 134, 044502 (2012).

[5] Fayez M. Wassef, Ahmed S. Hassan, Hany A. Mohamed, and Mohamed A. Zaki, "Stability and performance of a low speed compressor with modified casing", *Mechanical Engineering Department, Assiut, University, Assiut, Egypt*.

[6] P. Usha Sri and N. Sitaram, "Computational Investigation of Flow in a Centrifugal Impeller with Chamfered Blade Tips: Effect of Tip Clearance", *Thermal Turbo machines Laboratory, Department of Mechanical Engineering, IIT Madras, Chennai India*, 2012.

[7] Chi-Yong Park, Young-Seok Choi, Kyoung-Yong Lee and Joon-Yong Yoon, "Numerical study on the range enhancement of a centrifugal compressor with a ring groove system", *Journal of Mechanical Science and Technology*, Vol 26, Issue 5, pp 1371-1378, May 2012.

[8] P. Subramanian and N. Sitaram, "Effect of Tip Clearance on the Periodic Static Pressure on the

Casing over the Impeller of a Centrifugal Compressor", *Thermal Turbomachines Laboratory, Department of Mechanical Engineering, Indian Institute of Technology Madras, Proceedings of the 13th Asian Congress of Fluid Mechanics 17-21 Dec., 2010*.

[9] S. Senthil and N. Krishna Mohan, "Experimental investigation on a centrifugal compressor by means of rectangular, elliptical and sloping squealer tips", *Indian Journal of Science and Technology*, Vol.2, No. 7, (July, 2009).

[10] P.Usha Sri and N.Sitaram, "Computational Study of Tip Clearance Effects in a Centrifugal Compressor", *Thermal Turbo machines Laboratory, Department of Mechanical Engineering, IIT Madras, Chennai India*, 2012.