Analysis of Single Stage Axial Flow Compressor by varying the Axial Gap

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Abstract— In axial flow compressors, spacing between the rotor and stator is an important parameter and plays a vital role in the performance characteristics. This parameter determines the compressor pressure ratio of the corresponding compressor. A study has been carried out to verify and explain the effect of axial spacing on the performance of 6.52 pressure ratio multi stage transonic compressor stage through CFD analysis using ANSYS FLUENT. Standard k-ε realizable turbulence model with standard wall function is used for analysis. Reynolds Averaged Navier-Stokes equations are discretized with finite volume approximations using hybrid grids. First the analysis was carried out for 31.5mm increase in axial gap and further the same amount was reduced and best operating conditions showed for the axial spacing +/- between the rotor and the stator. CFD values which were obtained were compared with the numerical values and validated. CFD analysis was carried out. This study showed good agreement with increase in axial spacing between the rotor and stator which increased the performance at the same time reducing the losses in the axial flow compressor.

Key words: Analysis of Single Stage Axial Flow Compressor, CFD analysis

I. INTRODUCTION

A. *Air Compressors*

An air compressor is a device that converts power (usually from an electric motor, a diesel engine or a gasoline engine) into potential energy by forcing air into a smaller volume and thus increasing its pressure. The energy in the compressed air can be stored while the air remains pressurized. The energy can be used for a variety of applications, usually by utilizing the kinetic energy of the air as it is depressurized.

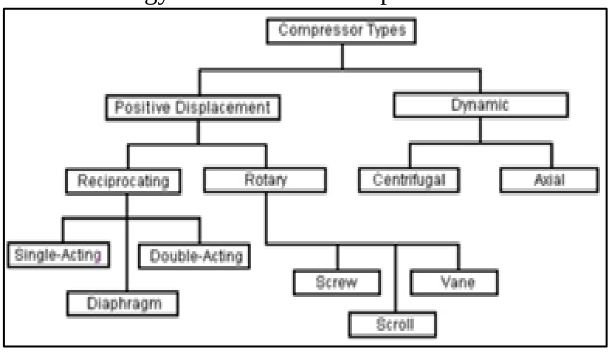

Fig. 1: Classification of compressor

1) *Types of Compressors*

a) Based on the pressure delivered

– Low-pressure air compressors (LPACs), which have a discharge pressure of 150 psi or less
– Medium-pressure compressors, which have a discharge pressure of 151 psi to 1,000 psi
– High-pressure air compressors (HPACs), which have a discharge pressure above 1,000 psi

b) Based on design and principle of operation

– Rotary screw compressor
– Turbo compressor
– Overall pressure ratio is the ratio of the stagnation pressure as measured at the front and rear of the compressor of a gas turbine engine. Generally speaking, a higher overall pressure ratio implies higher efficiency, but the engine will usually weigh more, so there is a compromise.

Typical Application	Type of flow	Pressure ratio per stage	Efficiency per stage
Industrial	Subsonic	1.05–1.2	88%–92%
Aerospace	Transonic	1.15–1.6	80%–85%
Research	Supersonic	1.8–2.2	75%–85%

Table 1: Typical Application

B. *Aim and Objective*

– To find the best performance for the Single stage axial flow compressor by varying the axial gap.
– To analyze and compare the results of varying the axial gap to a certain level increment and reducing it to the same.

C. *Schematic representation of an axial flow compressor*

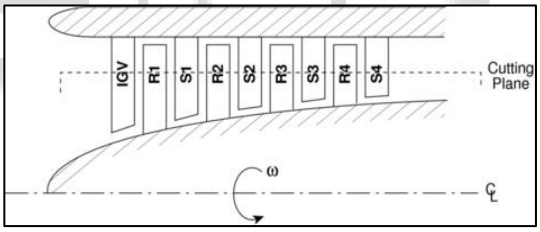

Fig. 2: Schematic representation of an axial flow compressor

D. *Computational Fluid Dynamics (CFD)*

Computational Fluid Dynamics (CFD), is one of the branch of Engineering, Finding numerical solutions of governing equations, using modern high speed digital computer. CFD uses numerical methods to solve the fundamental non-linear differential equations that describe fluid flow for predefined geometries and boundary conditions. It helps in prediction of flow velocity, temperature, pressure, density etc. for any region where flow occurs. The key advantage CFD is that it is a virtual modeling technique with powerful visualization capabilities and engineers can evaluate the performance of wide variety of turbo machines configurations by computers in short duration of time.

Computational Fluid Dynamics (CFD) provides a qualitative or quantitative prediction of fluid flows by means of:

– Mathematical modeling (partial differential equations)
– Numerical methods (discretization and solution techniques)
– Software Tools (pre- and postprocessor tools)

All CFD codes contain three main elements:

1) A Pre-Processor

It is used to input the problem geometry, generates the grid; define the flow parameter and the boundary conditions to the code.

2) A Flow Solver

Which is used to solve the governing equations of the flow subject to the conditions provided. There are three different methods used as a flow solver.

- Finite difference method
- Finite element method
- Finite volume method

E. Steps Involved

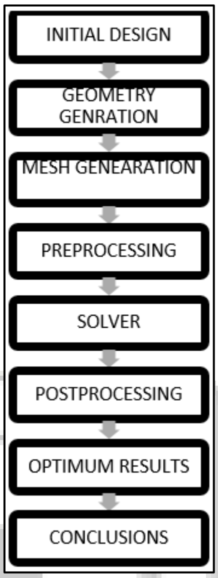

Fig. 3: Steps involved

II. LITERATURE SURVEY

A. Hanoca P and Shobhavathy M T

The axial spacing between the rotor and stator is an important parameter and has a strong influence on the performance of axial turbo machines. A study has been carried out to verify the effect of axial spacing on the performance of 1.35 pressure ratio single stage transonic compressor stage through CFD analysis using commercial code ANSYS FLUENT. Standard k-ε turbulence model with standard wall function is used for analysis. Reynolds Averaged Navier-Stokes equations are discretized with finite volume approximations using hybrid grids. First the analysis has been carried out for the baseline configuration of the compressor stage having an axial blade spacing of 75% of the rotor tip axial chord. The steady flow computations have been carried out for four speeds namely 43%, 60%, 80% and 90% of the compressor design speed and obtained the overall performance characteristics of the compressor stage. For validation, CFD values are compared with the experimental results. CFD results showed good agreement with the experiments and hence, the analysis has extended to four more axial spacing configurations such as 30%, 60%, 90% and 120% of the rotor tip axial chord. This study shows that for getting best operating conditions, the axial spacing for the referred compressor stage should lie in the range of 65 to 75% of rotor tip axial chord.

III. OVERVIEW OF THE COMPRESSOR

A. Axial Flow Compressor Description

Axial compressors consist of rotating and stationary components as shown in Fig.2:

- Rotor is the rotating part.
- Stator is the stationary part.

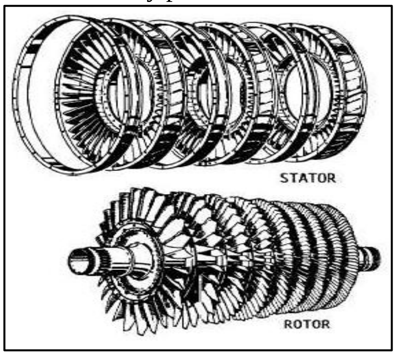

Fig. 4: Axial compressors

The rotating airfoils, also known as blades or rotors, accelerate the fluid. The stationary airfoils, also known as stators or vanes, convert the increased rotational kinetic energy into static pressure through diffusion and redirect the flow direction of the fluid, preparing it for the rotor blades of the next stage.

B. Current Design

A study has been carried out to verify the effect of axial spacing on the performance of 1.35 pressure ratio single stage transonic compressor stage through CFD analysis using commercial code ANSYS FLUENT. Standard k-ε turbulence model with standard wall function is used for analysis. Reynolds Averaged Navier-Stokes equations are discretized with finite volume approximations using hybrid grids. First the analysis has been carried out for the baseline configuration of the compressor stage having an axial blade spacing of 75% of the rotor tip axial chord. The steady flow computations have been carried out for four speeds namely 43%, 60%, 80% and 90% of the compressor design speed and obtained the overall performance characteristics of the compressor stage.

C. Our Design

Our Design focuses on to verifying the effect of axial spacing with increment to a certain level and decrement to the same level using a standard single stage transonic compressor through CFD analysis using commercial code ANSYS FLUENT.

1) Main specification of axial flow compressor

- Type of compressor: Multi Stage Transonic Axial Flow
- Corrected rotational speed : 15900 rpm
- Corrected mass flow rate : 24.189 kg/s
- Stage total pressure ratio : 1.16
- Stage adiabatic efficiency : 89%
- The axial blade spacing is :42%

IV. NUMERICAL ANALYSIS OF THE RESEARCH COMPRESSOR BASELINE CONFIGURATION

A steady state flow numerical analysis has been carried out using ANSYS FLUENT for different axial gaps of the compressor design speed and obtained the overall performance characteristics of the compressor stage. These values are compared with the experimental results for validating the CFD code.

A. Solid Modelling of the Flow Domain

The solid modeling of the rotor and stator were made with the help of CAD tools CATIA as shown in Figure 5. A single passage with one rotor blade and one stator blade instead of 360° model was considered for flow analysis to reduce the grid size. The flow field domain for the baseline configuration was divided into six sub volumes to have a choice of hybrid grid generation and fixing up the boundary conditions appropriately.

B. Flow Analysis

1) Numerical algorithm

3-D steady Navier-Stoke equations were solved using segregated pressure based implicit solver by ANSYS FLUENT. Standard k–ε turbulence viscosity model with simple pressure-velocity coupling and First-Order Upwind discretization scheme was used for the analysis.

2) Boundary conditions

A no-slip condition was specified for the flow at the wall boundaries of the blade, hub and casing for both rotor and stator fluid. A periodic condition was applied to the rotor and stator fluid. A static pressure at exit with radial equilibrium condition was specified as shown in the Figure 5. The interface between the rotor and the stator plane was set to a mixing plane, in which the flow data at the mixing plane interface are averaged in the circumferential direction both at rotor outlet and the stator inlet boundaries and are updated at each iteration.

V. RESULTS AND APPLICATIONS

A. Conclusion

A steady state CFD analysis has been carried out on a multi stage transonic axial flow compressor of 6.52 pressure ratio to obtain the overall performance of the compressor by varying the axial gap design conditions using commercial code ANSYS FLUENT. The predicted values had good agreement with the experimental data. CFD analysis was extended to two different configurations of the compressor with different axial spacing, to verify the influence of axial spacing on the performance of the referred compressor stage. After studying about this, it has been clearly brought out that, the best axial spacing for the referred compressor stage is

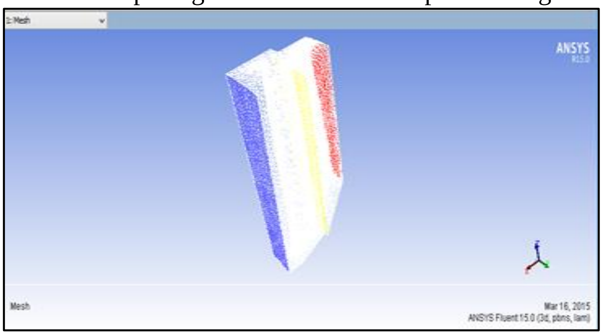

Fig. 5: Meshed flow domain

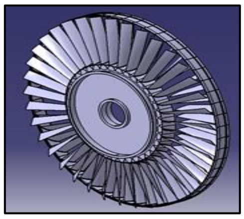

Fig. 6: Solid modeling of the rotor and stator combined

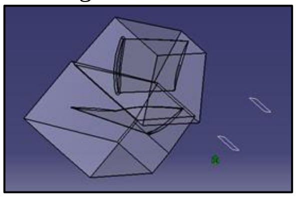

Fig. 7: Stator and rotor blade combined

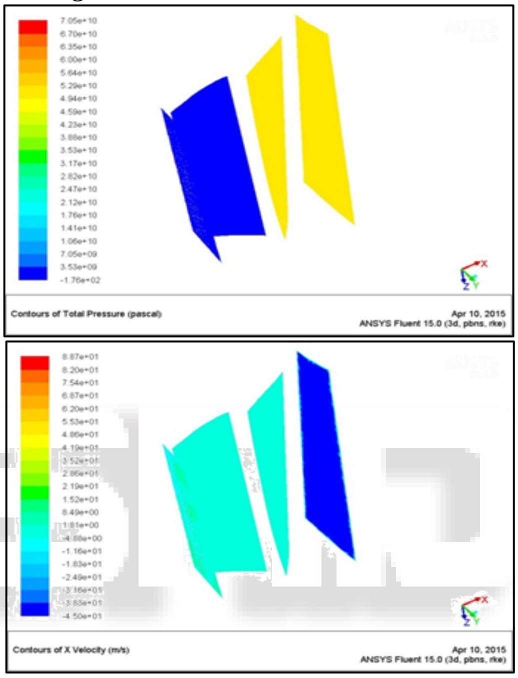

Fig. 8: Contours of total pressure and velocity

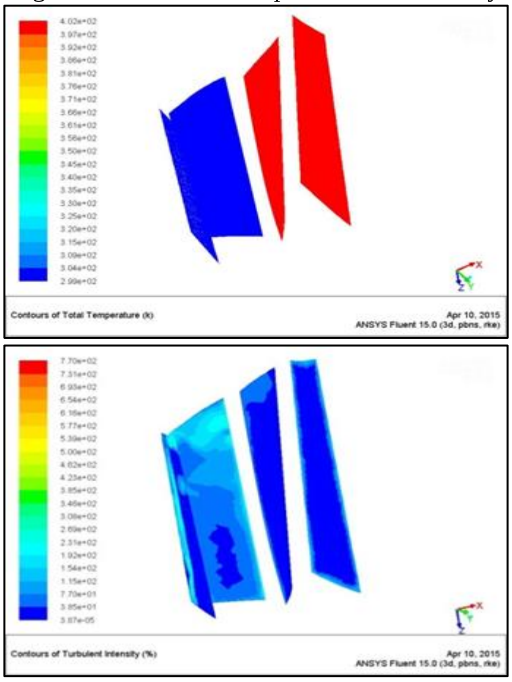

Fig. 9: Contours of total temperature and turbulent intensity

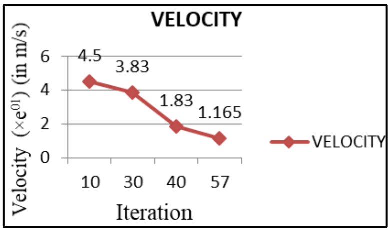

Fig. 10: Graph showing the variation of Velocity

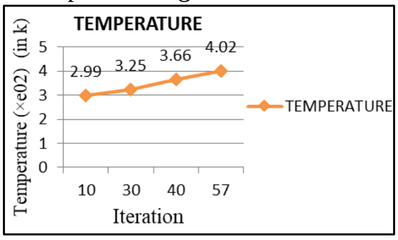

Fig. 11: Graph showing variation of Temperature

- Axial velocity is not uniform along the blade height.
- The end wall boundary layers are responsible for the nature of span wise axial velocity distribution.
- The axial velocity profile becomes more and peakier as the flow proceeds downstream and settles down in the fourth stage.
- There is no appreciable change in the axial velocity profile beyond fourth stage.

Axial velocity is not uniform along the temperature height. Temperature includes the static temperature and dynamic component related to the kinetic energy of the gas. Temperature measured with the sensor travelling at the same velocity as the fluid.

B. *Application*

- Portable air compressor for powering tools, such as jackhammers
- To supply high-pressure clean air to fill gas cylinders
- To supply moderate-pressure clean air to a submerged surface supplied diver
- To supply moderate-pressure clean air for driving some office and school building pneumatic HVAC control system valves
- To supply a large amount of moderate-pressure air to power pneumatic tools, such as jackhammers
- For filling tires
- To produce large volumes of moderate-pressure air for large-scale industrial processes (such as oxidation for petroleum coking or cement plant bag house purge systems).

Most air compressors either are reciprocating piston type, rotary vane or rotary screw. Centrifugal compressors are common in very large applications. There are two main types of air compressor's pumps: oil-lubed and oil-less. The oil-less system has more technical development, but is more expensive, louder and lasts for less time than oil-lubed pumps. The oil-less system also delivers air of better quality.

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