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Design and Analysis of Axial Flow Compressor Blade Using Different Aspect Ratios with Different Materials

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Abstract:-- **An axial flow compressor is a pressure developing machine. It is a rotating, airfoil-based compressor in which the working fluid principally flows parallel to the axis of rotation. This is in contrast with other rotating compressors such as centrifugal compressors, axial flow centrifugal compressors and mixed-flow compressors where the air may enter axially but will have a significant radial component on exit. The energy level of air or gas flowing through it is increased by the action of the rotor blades which exert a torque on the fluid which is supplied by an electric motor or a steam or a gas turbine. In this work, an axial flow compressor is designed by varying aspect ratios (ratio of blade height to axial chord length) where blade height is kept constant and 3D models are modeled using Pro/E. The present material used is Chromium Steel it is replaced with Titanium alloy and Nickel alloy.**

CFD analysis is done to verify the flow characteristics of fluid under turbulent conditions by applying the mass flow rate and inlet pressure, outlet pressure, velocity and mass flow rates. Structural analysis is done on the compressor models to verify the strength of the compressor for all the materials chromium steel, titanium alloy and nickel alloy by applying pressure which is output from CFD analysis. The analysis is done in Ansys.

Index Terms - Axial flow compressor, Aspect ratios and CFD analysis.

1. INTRODUCTION

An axial compressor is an important part of any efficient gas turbine. Axial flow compressors are the fluid pumping machinery where the fluid enters and exits axially to the rotor axis. The unique features like high mass flow rate for a small frontal area and high efficiency ratio with higher mass flow rate makes multistage axial flow compressors a perfect choice for gas turbines used in jet engines. The performance and reliability of a gas turbine heavily relies on its axial compressor module. An axial flow compressor is a machine that can continuously pressurize gases. It is a rotating, airfoil-based compressor in which the gas or working fluid principally flows parallel to the axis of rotation. This differs from other rotating compressors such as centrifugal compressors, axial flow centrifugal compressors and mixed-flow compressors where the fluid flow will include a "radial component" through the compressor. The energy level of the fluid increases as it flows through the compressor due to the action of the rotor blades which exert a torque on the fluid. [1]The stationary blades slow the fluid, converting the circumferential component of flow into pressure. Compressors are typically driven by an electric motor or a steam or a gas turbine. Axial flow compressors produce a continuous flow of compressed gas, and have the benefits of high efficiency and large mass flow rate, particularly in relation to their size and cross-section. [2]They do, however, require several rows of airfoils to achieve a large pressure rise, making them complex and expensive relative to other designs (e.g. centrifugal compressors). This paper describes the effect of aspect ratio by using ansys to investigate the influence of aspect ratio on a single stage subsonic axial flow compressor. [3]The design method then provides the blade shape that would accomplish this loading by imposing the appropriate pressure jump across the blades and the flow tangency condition. [4]The axial flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase. The fluid is accelerated by a row of rotating airfoils(blades) stationary blades(stator).the diffusion in the stator converts the velocity increasing gained in the rotor to a pressure increase[6] The objective of the paper is to design a axial flow compressor blade by using two different aspect ratios to get better efficiency by optimizing the results we going to design axial flow compressor blade with AR1:550:550 and then CFD analysis is done similarly with AR2:550:275 and then CFD analysis is done. Need to optimize the better AR from the results of AR1 & AR2 Then need to perform structural analysis on the compressor blade for three materials chromium steel, titanium alloy and nickel alloy by observing the results we can optimize the best material to be used for manufacturing axial flow compressor blade

II. ASPECT RATIO

The performance of axial flow compressors is known to be affected by the choice of aspect ratio. An increase in aspect ratio has been observed to have an adverse effect on the performance of single-stage axial flow compressors. In experimental, numerical and theoretical investigations have been performed in the past, studying the effects of aspect ratio on compressor performance, but yielded mixed results [5], [7], [8], [9], observed a Effects of Aspect Ratio on blade loading, blade excitation, and the pre-twist blade angles. At high aspect ratios the blades had to be designed with mid span shrouds, and tip shrouds. This decreases the efficiency of the stage; however, without the shrouds the pre-twist blade angle had to be increased and the blade excitation resulted in blade failure. [10] Results of their studies do not indicate any basic limit on aspect ratio other than possible supersonic velocities for acceptable design point performance. They note that off-design performance and mechanical design problems may limit the maximum usable aspect ratio. The high axial pressure gradients associated with higher aspect ratio blade could require refinements in the profile loss correlation that was used in order to predict performance accurately. The results of injection with different injected mass flow rates show that for the special type of injector adopted in the paper the effect of injection on tip clearance flow may be different according to the relative strength between these two streams of flow [10]. For a fixed injected mass flow rate, reducing the injector area to increase injection velocity can improve the effect of injection on tip clearance flow and thus the compressor stability. Results show that a good estimation of the mean flow features is obtained with the numerical model, even if some discrepancies are also observed, especially when regarding the transport of information along the axial distance[11]. This paper deals with the numerical simulation of technologies to increase the compressor performances. The objective is to extend the stable operating range of an axial compressor stage thanks to passive control devices located in the tip region.

III. AXIAL FLOW COMPRESSOR MODEL

In this work we have taken two aspect ratios AR1 and AR2 for analysis. The blade details diagram shown in fig.1 & fig.2 For two different aspect ratio the blade structure is indicated in the diagram itself. For AR1 Blade height – 550mm, Chord length – 550mm is taken. And for AR2 Blade height – 550mm, Chord length – 275mm is taken for our analysis.
Pro-e modeling uses parameters to define model examples for parameters are: dimensions used to create model features, material density, formulas to describe swept features, imported data (that describes a reference surface, for example). the parameter may be modified later, and the model will update to reflect the modification. Typically there is a relationship between parts, assemblies, and drawings. A part consists of multiple features, and an assembly consists of multiple parts drawings can be made from either parts or assemblies. Related to parameters, but slightly different are constraints. Constraints are relationships between entities that make up a particular shape.

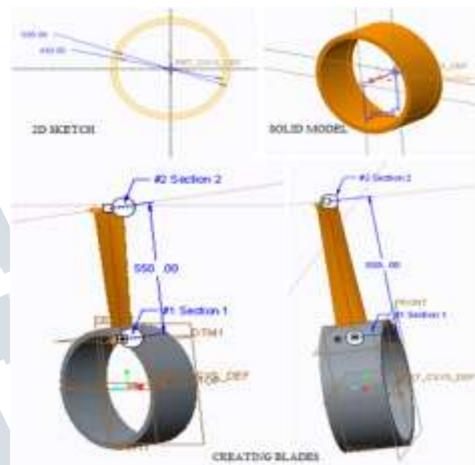
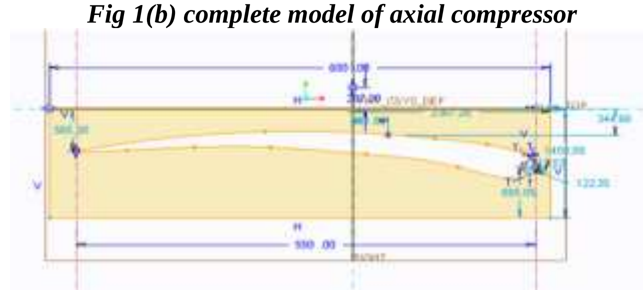


Fig 1(a) creating a model of axial compressor

Fig 1(b) complete model of axial compressor



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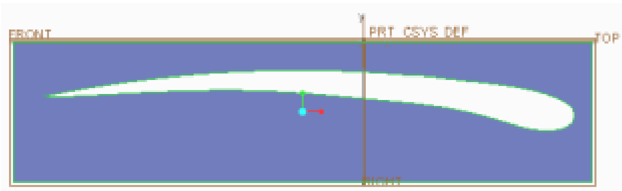

Fig.2. 2D sketch and surface model of the blade as per the aspect ratio 1

The above figure shows the sketch of the axial flow compressor blade with AR1 which has created in pro-e design software using sketcher module, and the surface model of the blade which has generated through surface module.

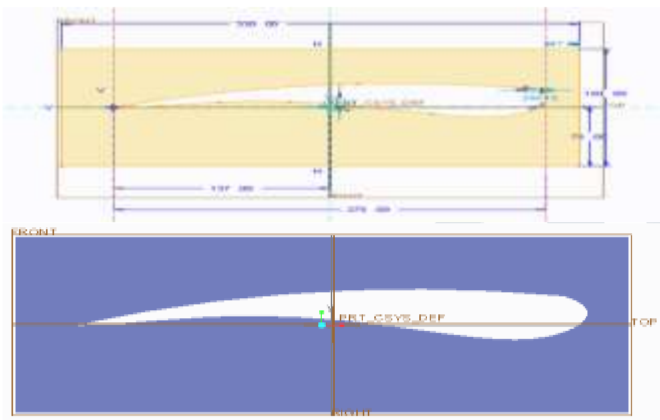

Fig.3. 2D sketch and surface model of the blade as per the aspect ratio 2

The above figure shows the sketch of the axial flow compressor blade with AR2 which has created in pro-e design software using sketcher module, and the surface model of the blade which has generated through surface module.

IV. CFD ANALYSIS

Table 1: Experimental Result

	Static Pressure(Pascal)	Velocity Magnitude (m/s)	Mass Flow Rate (kg/s)
Aspect ratio 2	3.55×10^{7}	2.59×10^{4}	58.008289
Aspect ratio 1	2.49×10^{8}	2.55×10^{4}	48.348129

The above table 1 represents the result comparison of CFD analysis done in Ansys software with pressure inlet and outlet on axial flow compressor blades which are designed with AR1 and AR2

It seems that static pressure and velocity magnitude are less for AR1 compared with AR2

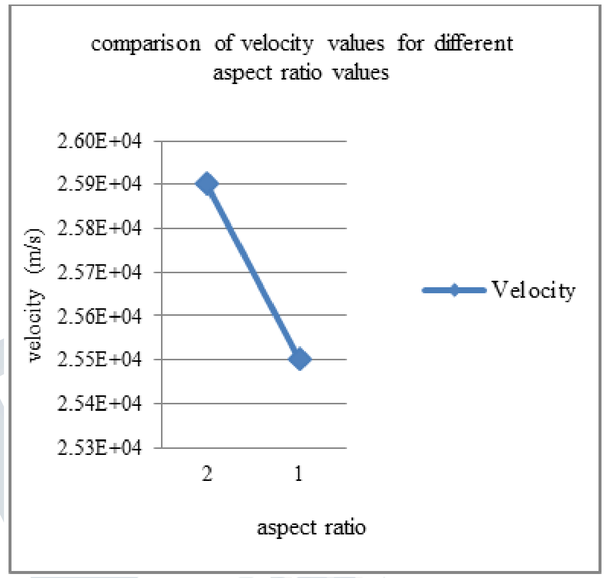

Fig.4 Comparison of Velocity Values At Different Aspect Ratio Values

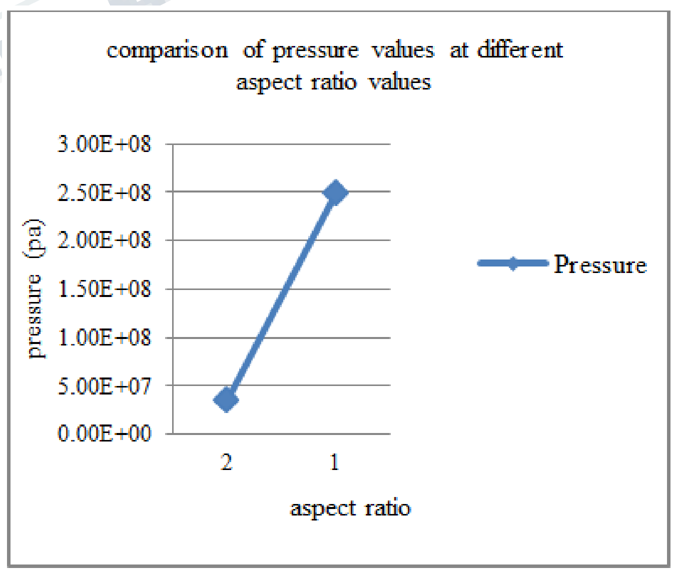

Fig.5 Comparision of Pressure Values At Different Aspect Ratio Values

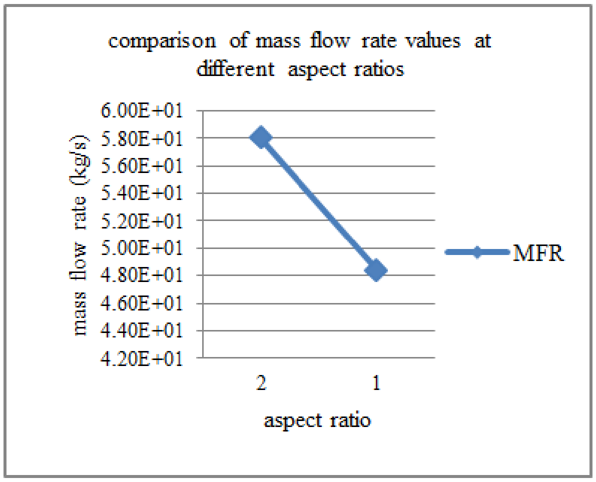

Fig.6 Comparision of Mass Flow Rate Values At Different Aspect Ratios

V . STRUCTURAL ANALYSIS

Table 2: Properties of Materials

Material	Density	young's modulus	poisson's ratio
titanium alloy	4700kg/m^3	110000 Mpa	0.3
nickel alloy	13.4 g/cc	235000 Mpa	0.382
chromium steel	7.70 g/cc	200000 Mpa	0.32

The above table 2 represents the density, young's modulus and poisson's ratio for the three materials titanium alloy , nickel alloy and chromium steel it shows that the material titanium alloy has better properties when compared.

STRUCTURAL ANALYSIS

Table 3: Deformation, Stress &Strain results for AR2

Materials	Total deformation(mm)	Stress (MPa)	Strain
Titanium alloy	17244	4.8943 x10^5	5.372
Nickel alloy	10551	1.2028 x10^6	5.3764
Chromium steel	10041	7.5846 x10^5	3.9866

The above table 3 represents the result comparision of structural analysis done in ansys software on axial flow compressor blades of different materials , it shows that the total deformation, stress and strain are maximum for titanium alloy for AR2

Table 4: Deformation, Stress &Strain results for AR1

Materials	Total deformation (mm)	Stress (MPa)	Strain
Titanium alloy	30561	3.8692 x10^6	40.322
Nickel alloy	12415	3.8527 x10^6	16.402
Chromium steel	14841	3.908 x10^6	19.548

The above table represents the result comparision of structural analysis done in ansys software on axial flow compressor blades of different materials , it shows that the total deformation, stress and strain are maximum for titanium alloy for AR1

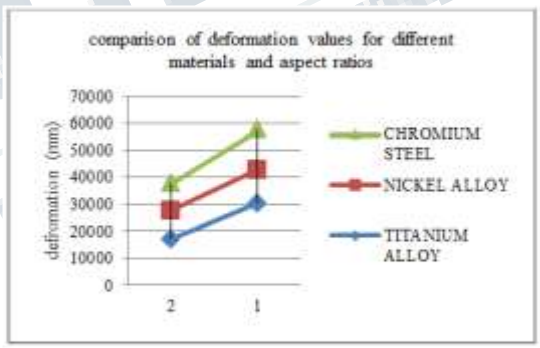

Fig.7 Comparision of Deformation Values for Different Materials and Aspect Ratios

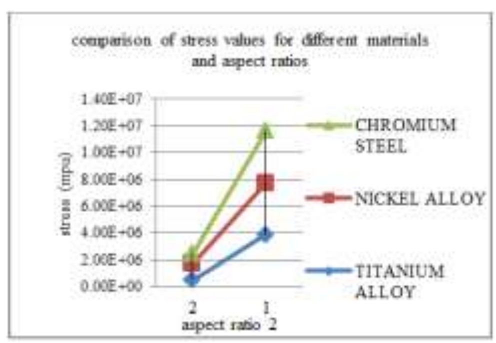

Fig.8 Comparision of Stress Values for Different Materials and Aspect Ratios

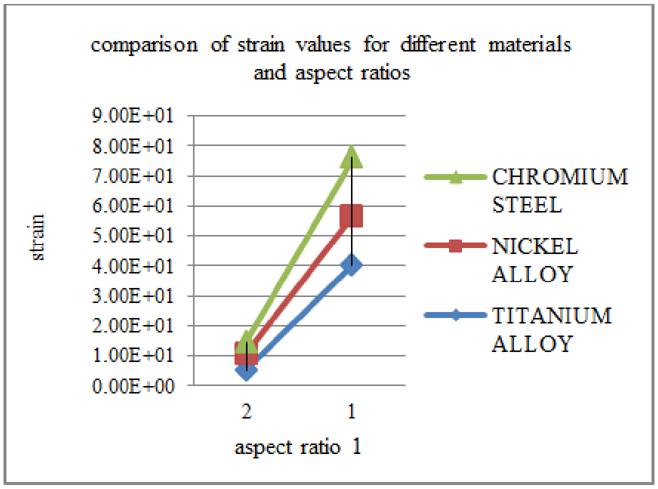

Fig.9 Comparision of Strain Values for Different Materials and Aspect Ratios.

VI. RESULT AND DISCUSSION

Fig.4 represents the comparision of velocity values for axial flow compressor blades which are designed with AR1 and AR2, and it shows that the velocity is less for AR1 compared with AR2
Fig.5 represents the comparision of pressure values for axial flow compressor blades which are designed with AR1 and AR2 and it shows that the pressure value is less for AR1 compared with AR2
Fig.6 represents the comparision of mass flow rate values for axial flow compressor blades which are designed with AR1 and AR2 and it shows that the mass flow rate value is less for AR1 compared with AR2
Fig.7 represents the result of total deformation on axial flow compressor blades of different materials by structural analysis done in ansys software it shows that the total deformation is minimum for titanium alloy for both AR1and AR2
Fig.8 represents the result of stress on axial flow compressor blades of different materials by structural analysis done in ansys software it shows that the stress is minimum for titanium alloy for both AR1and AR2
Fig.9 represents the result of strain on axial flow compressor blades of different materials by structural analysis done in ansys software it shows that the strain is minimum for titanium alloy for both AR1and AR2

CONCLUSION

CFD and Structural analysis is performed on the axial flow compressor by varying aspect ratios where blade height is kept constant. 3D modeling is done in Pro/Engineer. The present used material is Chromium Steel, it is replaced with Titanium alloy and Nickel alloy. By observing CFD analysis results, the pressure rise is more for aspect ratio 1 than aspect ratio 2, the velocity and mass flow rates at outlet are increasing with increase of aspect ratio from 1 to 2.By observing structural analysis results, the deformation and stresses are decreasing with increase of aspect ratio. When compared between the materials, the deformations and stresses are less for Titanium alloy than other two materials. So it can be concluded that increasing aspect ratio yields better results, using Titanium alloy is better as per structural analysis.

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