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Design and Analysis of Stator, Rotary, and Blades of Axial Flow Compressor

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ABSTRACT

An axial flow compressor is one in which the flow enters the compressor in an axial direction (parallel with the axis of rotation), and exits from the gas turbine, also in an axial direction. The axial-flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase.

Now a day research and developmental efforts in the area of axial flow compressors for gas turbine application are aimed to improving its operating range without sacrificing efficiency. An increase in aspect ratio (the ratio of blade height to chord length) has been observed to have an adverse effect on the performance of single-stage axial flow compressors.

In this thesis, an axial flow compressor will be designed and modeled in 3D modeling software Pro/Engineer. The present designs will be modified by changing the aspect ratios. The present used material is Chromium Steel, it will be replaced with Titanium alloy and Nickel alloy.

Structural analysis will be done on all the compressor models using steel, titanium alloy and nickel alloy to verify the strength of the compressor using finite element analysis software Ansys. CFD analysis will also be done to determine the fluid behavior in Ansys Fluent.

INTRODUCTION TO AXIAL FLOW COMPRESSOR

An axial compressor is a compressor that can continuously pressurise gases. It is a rotating, airfoil-based compressor in which the gas or working fluid principally flows parallel to the axis of rotation, or axially. This differs from other rotating compressors such as centrifugal compressors, axi-centrifugal compressors and mixed-flow compressors where the fluid flow will include a "radial component" through the

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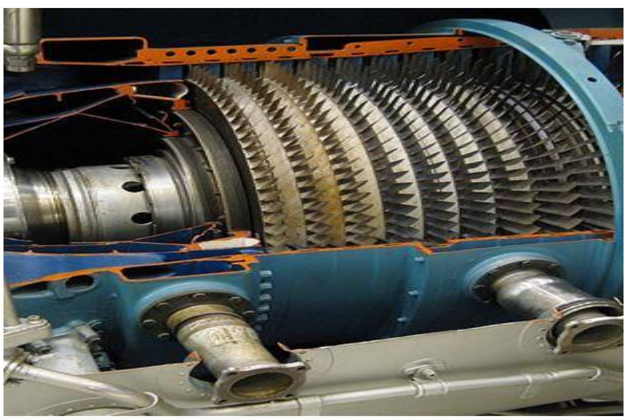
compressor. The energy level of the fluid increases as it flows through the compressor due to the action of the rotor blades which exert a torque on the fluid. The stationary blades slow the fluid, converting the circumferential component of flow into pressure. Compressors are typically driven by an electric motor or a steam or a gas turbine.

DESCRIPTION



The compressor in a Pratt & Whitney TF30 turbofan engine.

Axial compressors consist of rotating and stationary components. A shaft drives a central drum, retained by bearings, which has a number of annular airfoil rows attached usually in pairs, one rotating and one stationary attached to a stationary tubular casing. A pair of rotating and stationary airfoils is called a stage. 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.[3] The cross-sectional area between rotor drum and casing is reduced in the flow direction to maintain an optimum Mach number using variable geometry as the fluid is compressed.

WORKING

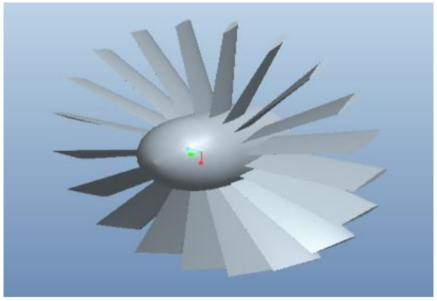
As the fluid enters and leaves in the axial direction, the centrifugal component in the energy equation does not come into play. Here the compression is fully based on diffusing action of the passages.The diffusing action in stator converts absolute kinetic head of the fluid into rise in pressure. The relative kinetic head in the energy equation is a term that exists only because of the rotation of the rotor. The rotor reduces the relative kinetic head of the fluid and adds it to the absolute kinetic head of the fluid i.e., the impact of the rotor on the fluid particles increases its velocity (absolute) and thereby reduces the relative velocity between the fluid and the rotor. In short, the rotor increases the absolute velocity of the fluid and the stator converts this into pressure rise. Designing the rotor passage with a diffusing capability can produce a pressure rise in addition to its normal functioning. This produces greater pressure rise per stage which constitutes a stator and a rotor together. This is the reaction principle in turbomachines. If 50% of the pressure rise in a stage is obtained at the rotor section, it is said to have a 50% reaction.

LITERATURE REVIEW

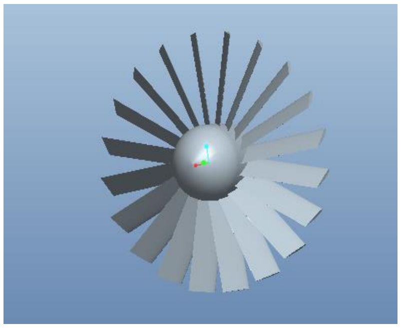
Design and Optimization of Axial Flow Compressor
Koduru. Srinivas1, Kandula. Deepthi2, K.N.D.MalleswaraRao3
An axial flow compressor is one in which the flow enters the compressor in an axial direction (parallel with the axis of rotation), and exits from the gas turbine, also in an axial direction. The axial-flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase. In an axial flow compressor, air passes from one stage to the next, each stage raising the pressure slightly. 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 thesis, an axial flow compressor is designed and modeled in 3D modeling software Pro/Engineer. The present design has 30 blades, in this thesis it is replaced with 20 blades and 12 blades. The present used material is Chromium Steel; it is replaced with Titanium alloy and Nickel alloy. Structural analysis is done on the compressor models to verify the strength of the compressor. CFD analysis is done to verify the flow of air.

MODELLING AND ANALYSIS

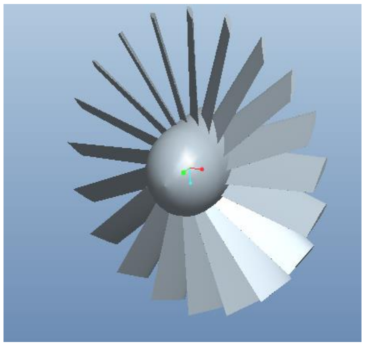
Case 1: rotor angle 12.1^0, stator angle 24.9^0



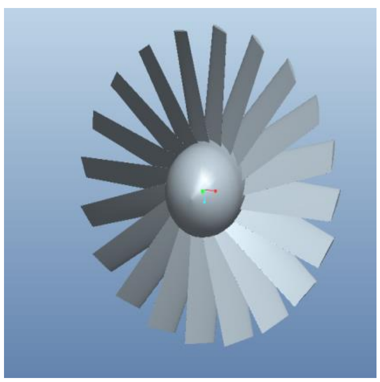
Case 2: rotor angle 26.4^0, stator angle 29.0^0



Case 3: rotor angle 39.8^0, stator angle 33.1^0



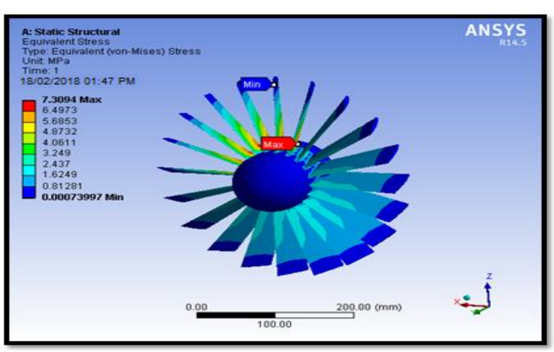
Case 4: rotor angle 45.9^0, stator angle 35.2^0



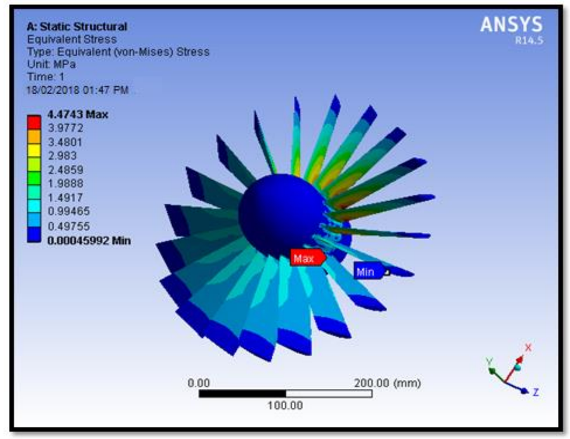
STATIC ANALYSIS OF AXIAL FLOW COMPRESSOR

Case 1: rotor angle 12.1^0, stator angle 24.9^0

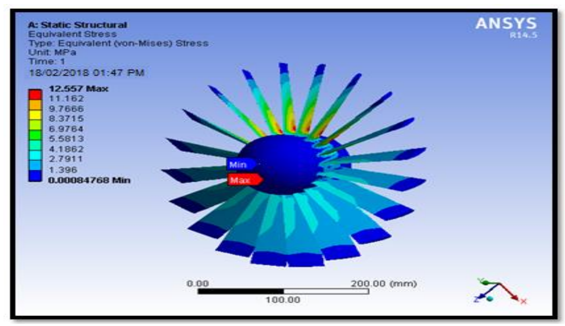
MATERIAL- CHROMIUM STEELSTRESS



MATERIAL- TITANIUM ALLOY STRESS

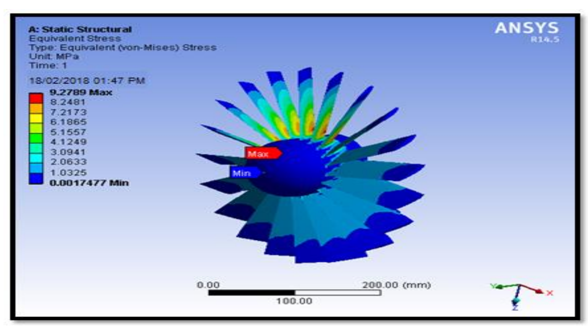


MATERIAL- NICKEL ALLOY STRESS



Case 2: rotor angle 26.40, stator angle 29.00

MATERIAL- CHROMIUM STEEL STRESS



MATERIAL- TITANIUM ALLOY STRESS

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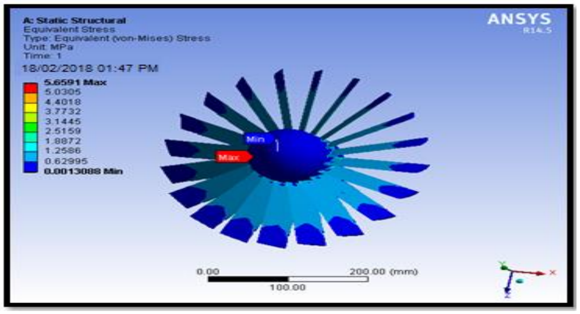
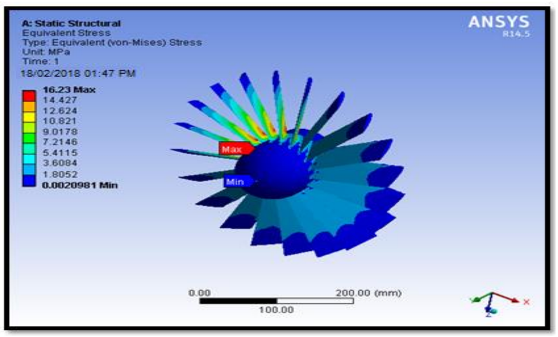
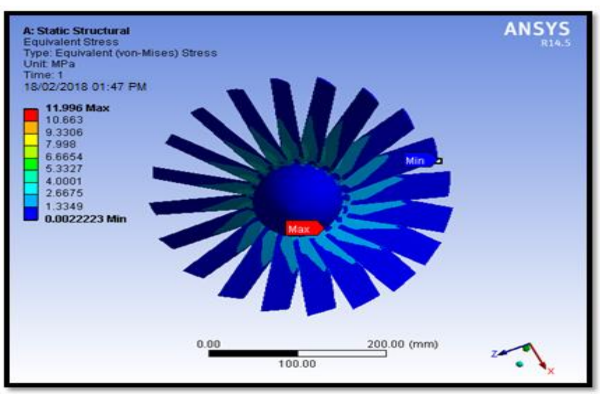


MATERIAL- NICKEL ALLOY STRESS



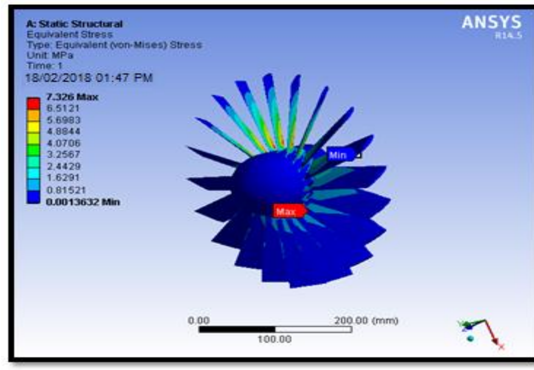
Case 3: rotor angle 39.8^0, stator angle 33.1^0

MATERIAL- CHROMIUM STEEL STRESS

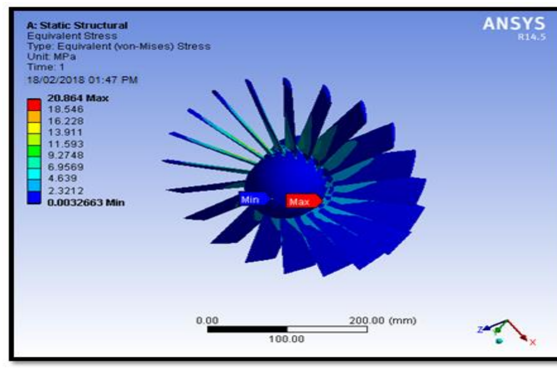


MATERIAL- TITANIUM ALLOY

STRESS

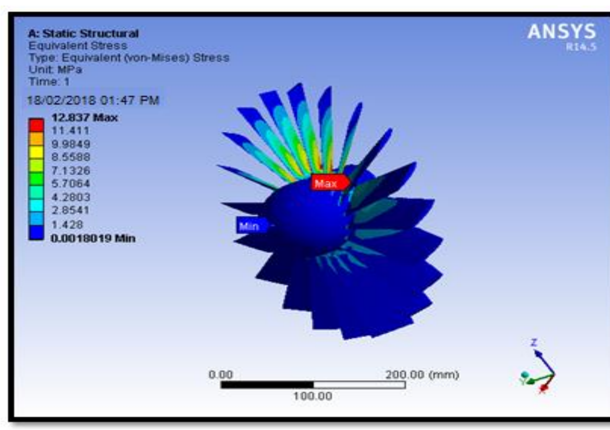


MATERIAL- NICKEL ALLOY STRESS



Case 4: rotor angle 45.9^0, stator angle 35.2^0

MATERIAL- CHROMIUM STEEL STRESS



MATERIAL- TITANIUM ALLOY STRESS

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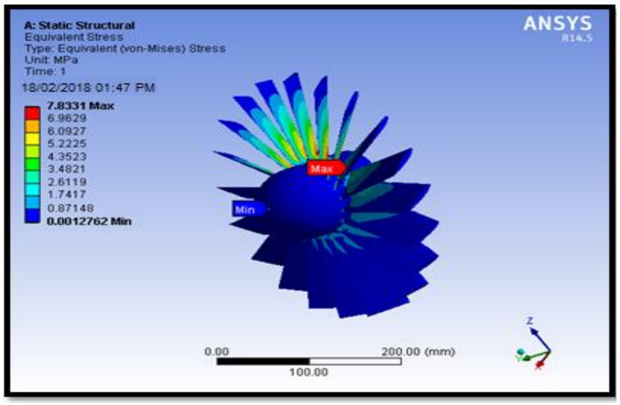

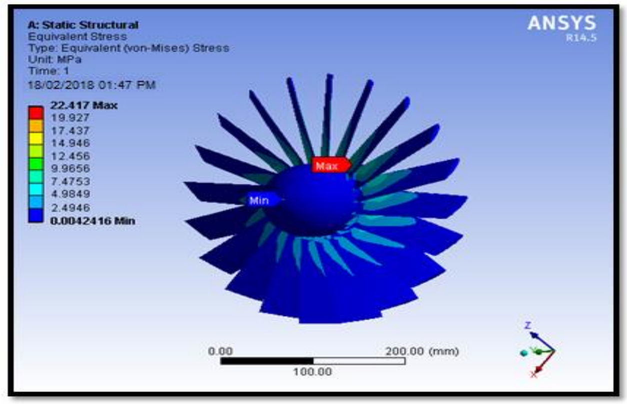

MATERIAL- NICKEL ALLOY STRESS

STATIC ANALYSIS RESULTS TABLE

Case 1: rotor angle 12.1^0, stator angle 24.9^0

Material	Deformation(mm)	Stress(MPa)	strain
Steel	0.02397	7.3094	3.667e-5
Titanium alloy	0.02654	4.4743	4.0818e-5
Nickel alloy	0.035879	12.557	5.3577e-5

Case 2: rotor angle 26.4^0, stator angle 29.0^0

Material	Deformation(mm)	Stress(MPa)	strain
Steel	0.041448	9.2789	4.6479e-5
Titanium alloy	0.045884	5.6591	5.1544 e-5
Nickel alloy	0.062088	16.23	6.9165 e-5

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Case 3: rotor angle 39.8^0, stator angle 33.1^0

Material	Deformation(mm)	Stress(MPa)	strain
Steel	0.056658	11.996	6.0042e-5
Titanium alloy	0.06273	7.326	6.6677e-5
Nickel alloy	0.084821	20.864	8.8846e-5

Case 4: rotor angle 45.9^0, stator angle 35.2^0

Material	Deformation(mm)	Stress(MPa)	strain
Steel	0.062991	12.837	6.4299e-5
Titanium alloy	0.069759	7.8331	7.1341e-5
Nickel alloy	0.094202	22.417	9.5533e-5

FATIGUE ANALYSIS RESULTS TABLE

Case 1: rotor angle 12.1^0, stator angle 24.9^0

Material	life		Damage	Safety factor	
	Max.	Min.		Max.	Min.
Steel	$1\times e^6$	3574.4	2.7976e5	15	0.23586
Titanium alloy	$1\times e^6$	17179	58212	15	0.38531
Nickel alloy	$1\times e^6$	798.15	1.25529e6	15	0.1373

Case 2: rotor angle 26.4^0, stator angle 29.0^0

Material	life		Damage	Safety factor	
	Max.	Min.		Max.	Min.
Steel	$1\times e^6$	289.01	3.4601e6	15	0.092899
Titanium alloy	$1\times e^6$	1045.6	9.5638e5	15	0.15232
Nickel alloy	$1\times e^6$	72.131	1.3864e7	15	0.053111

Case 3: rotor angle 39.8^0, stator angle 33.1^0

Material	life		Damage	Safety factor	
	Max.	Min.		Max.	Min.
Steel	$1 \times e^6$	150.2	6.6578e6	15	0.071858
Titanium alloy	$1 \times e^6$	534.33	1.8715e6	15	0.11766
Nickel alloy	$1 \times e^6$	40.145	2.491e7	15	0.041315

Case 4: rotor angle 45.9^0, stator angle 35.2^0

Material	life		Damage	Safety factor	
	Max.	Min.		Max.	Min.
Steel	$1 \times e^6$	126.92	7.87e6	15	0.067148
Titanium alloy	$1 \times e^6$	448.97	2.2273e6	15	0.11005
Nickel alloy	$1 \times e^6$	34.049	2.9369e7	15	0.038452

CFD ANALYSIS RE SULTS TABLE

models	Pressure(Pa)	Velocity(m/s)	Mass flow rate (kg/s)
Case 1: rotor angle 12.1^0	**7.49e+01**	**2.40e+01**	**9.8943e-06**
Case 2: rotor angle 26.4^0	**6.49e+01**	**6.49e+01**	**0.0016580**
Case 3: rotor angle 39.8^0	**1.31e+02**	**1.31e+02**	**0.00074821**
Case 4: rotor angle 45.9^0	**3.94e+03**	**1.90e+03**	**0.00728**

CONCLUSION

An axial flow compressor is one in which the flow enters the compressor in an axial direction (parallel with the axis of rotation), and exits from the gas turbine, also in an axial direction. The axial-flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a pressure increase.

In this thesis, an axial flow compressor will be designed and modeled in 3D modeling software Pro/Engineer. The present designs will be modified by changing the aspect ratios. The present used material is Chromium Steel; it will be replaced with Titanium alloy and Nickel alloy.

By observing the static analysis the deformation and stress increasing by increasing the angles of axial flow compressor blade and less stress value of rotor angle 12.1^0, stator angle 24.9^0 for nickel alloy and less stress value for titanium alloy.

By observing the fatigue analysis of the safety factor value less for titanium alloy compare to steel and nickel alloy for rotor angle 12.1^0, stator angle 24.9^0.

By observing the cfd analysis the pressure drop, velocity and mass flow rate increases by increasing the blade angles of the axial flow compressor.

So it can be conclude the titanium alloy is the better material for axial flow compressor.

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