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Modeling and Analysis on Gas Turbine Rotar Blade

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Abstract*— The blades are designed in such a way as to produce maximum rotational energy by directing the flow of the gas along its surface. The blades are made at specific angles in order to incorporate the net flow of gas over it in its favor. The blades may be of stationary or fixed and rotary or moving type. The aim of the project is to design a turbine blade using 3D modeling software CATIA by using the CMM point data available. CMM data taken from coordinate measuring machine. This project involves structural and model analysis by applying the angular velocities for different materials in evaluating stresses developed and mode shapes of the blade. This project also involves in thermal analysis for finding temperature distribution on blade. Thermal analysis aims to verify the thermal characteristics of the blade by varying temperatures. Structural, thermal and modal analyses are performed using commercial software ANSYS .CATIA is the standard in 3D product design, featuring industry-leading productivity tool that promote best practices in design. ANSYS is general purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system for approximate solutions under typical loading environment.

Key words: **Design; Analysis; Turbine Blade; Ansys.**

I. INTRODUCTION

The gas turbine in its most common form is a rotary heat engine operating by means of series of processes consisting of compression of air taken from the atmosphere, increase of gas temperature by constant-pressure combustion of the fuel in the air, expansion of hot gases and finally discharge of the gasses to the atmosphere, the whole process being continuous. It is similar to petrol and diesel engines in working medium and internal combustion but is akin to the stream turbines in its aspect of the steady flow of the working medium. Turbine blades are the most important components in a gas turbine power plant. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor. The blade is subjected to forces in three directions such as:

1. The rotor driving force along the axial direction.
2. Axial forces caused by the gas flow.
3. Force acting normal to the turbine shaft due to the centrifugal forces.
4. Differential thermal stress, erosion-corrosion and a host of other hostile parameters hampering its smooth functioning.

II. VELOCITY TRAINGLES FOR DIFFERENT

STAGES OF GAS TURBINES

Work is extracted from the gas at higher inlet pressure to the lower back pressure by allowing it to flow through a turbine. In a turbine as a gas passes through, it expands which is equal to the change of its enthalpy. Most turbines posses more than one stage with their respective wheels mounted on a common shaft. The stage consists of a ring of a fixed nozzle blades followed by the rotor blade ring.

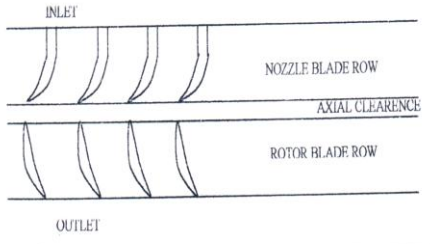

Fig.1: A Turbine Stage

Normally a turbine stage is classified as

1. An impulse stage
2. A reaction stage

An impulse stage is characterized by the expansion of gas, which occurs only in the stator nozzles. The rotor blades act as directional vanes to deflect the direction of the flow. They convert the kinetic energy of the gas in to work by changing the momentum of the gas more or less at constant pressure.

A reaction gas turbine is one which the expansion of gas takes place both in the stator and the rotor. The function of the stator is same as that in the impulse stage, but function in the rotor is two folds:

1. The rotor converts the kinetic energy of the gas in to work.
2. Contributes a reaction force on the rotor blades, which is due to the increase in the velocity of the gas relative to the blades.

III. LOSSES IN BLADES

Principle aerodynamic losses occurring in most of the turbo machines arise due to the growth of the boundary layer and its separation on the blade and passage surface. Aerodynamic loss occurring in a turbo machine blade cascade can be grouped in the following categories:

A. PROFILE LOSS

As the term indicates this loss is associated with the growth of the boundary layer on the blade profile. Separation of the boundary layers occurs when the adverse pressure gradients on the surfaces becomes too steep thus increasing the profile losses. the separation point depends on the degree of turbulence, Reynolds num and the incidence besides the blade profile.

B. ANNULUS LOSS

In stationary row of blades a loss of energy occurs due to the growth of the boundary layer on the end walls and in the

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rotating row blades, this occurs due to the rotation of the cascade.

C. SECONDARY LOSS

This loss occurs in the regions of flow near the end walls owing to the presence of unwanted circulatory or cross flows. Such secondary flows develop on account of turning of the flow through the blade channel in the presence of annulus wall boundary layers. The below fig depicts the pressure gradients across a blade channel and the secondary and trailing vortices. The static pressures at the four corners of the section of flow under considerations are:

$$Pb > pD > pC > pA$$

The secondary vortices in the blade channels induce vortices in the wake regions and trailing vortices lead to additional losses. The secondary flows in the cascade affect the profile and annulus losses. The magnitude of losses due to the secondary flows depends on the fraction of the passage ht. that is affected by this flow.hub tip ratio to be fully experiencing higher secondary losses. If the total losses in the blade passage are measured along its ht., they appear as peaks near the hub and tip on account of secondary loses. The flow In the central region, which is outside the influence of secondary flows, suffers only profile losses. the below fig depicts the pattern of the losses along the blade height.

D. TIP CLEARANCE LOSSES

This loss arises due to clearance between a moving blade and the casing. In a turbine rotor blade ring the suction sides lead and the pressure sides trail. The flow leaks from pressure side towards the suction side. The tip clearance loss and secondary flows are closely related and it is often convenient to estimate them together.

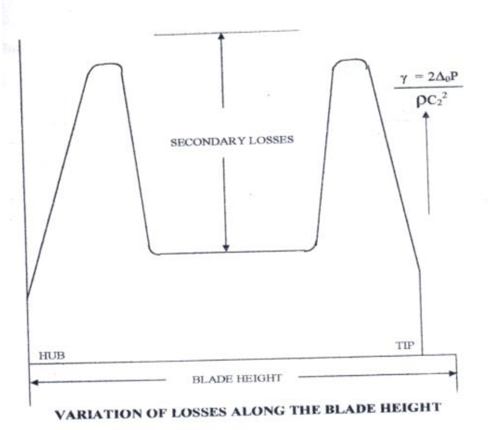

Fig.2: Loss along the Blade Height

IV. PART MODULE

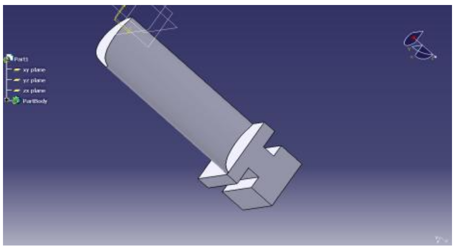

Fig 3: Turbine Blade developed in Part Module

A. Titanium Blade

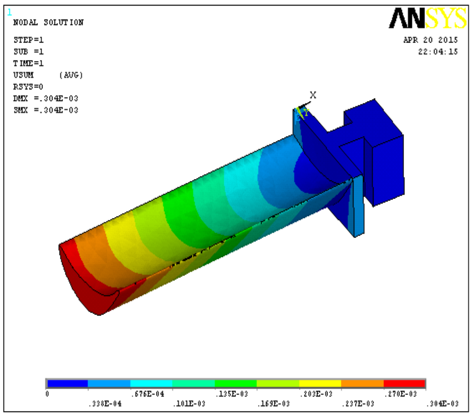

Fig 4: Displacement Vector Sum

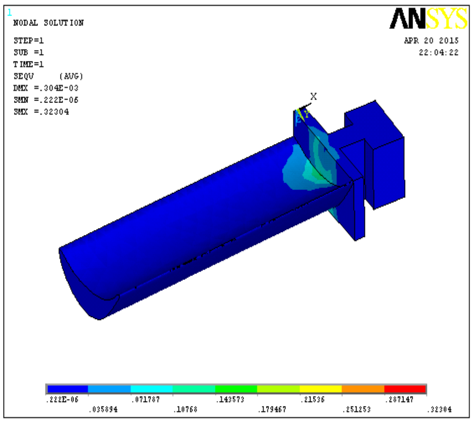

Fig 5: Von Misses Stress

B. Aluminum Blade

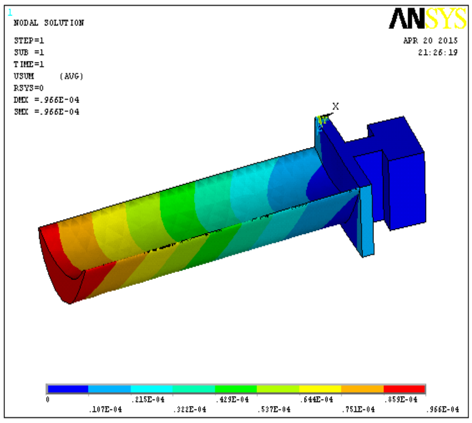

Fig 6: Displacement Vector Sum

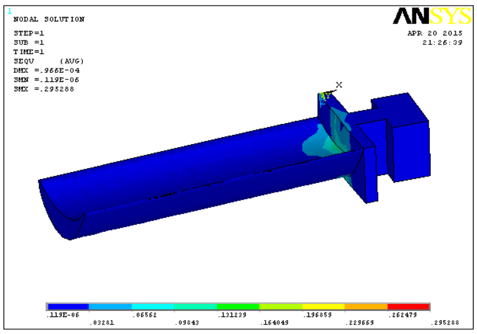

Fig 7: Von Misses Stress

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C. Niobium Blade

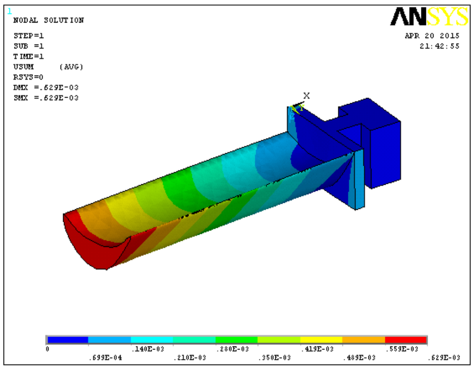

Fig 8: Displacement Vector Sum

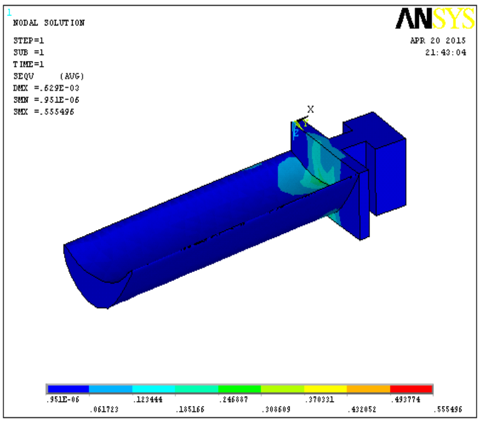

Fig 9: Von Misses Stress

D. Silicon Carbide Blade

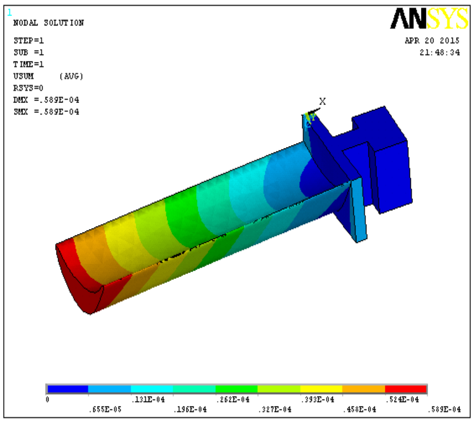

Fig 10: Displacement Vector Sum

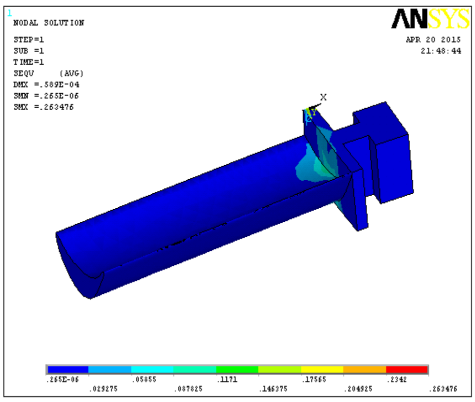

Fig 11: Von Misses Stress

VI. MODAL ANALYSIS

A. Titanium Blade

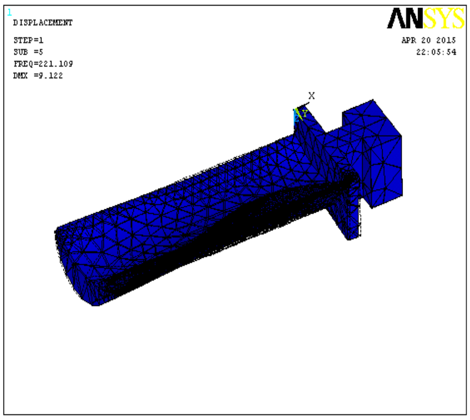

Fig 12: Mode Shape of Turbine

B. Aluminum Blade

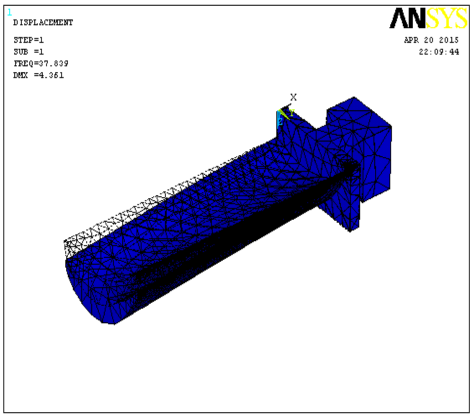

Fig 13: Mode Shape of Turbine

C. Niobium Blade

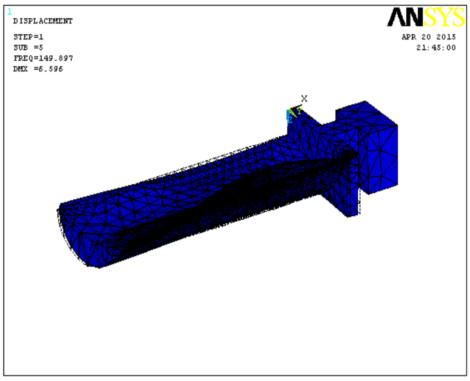

Fig 14: Mode Shape of Turbine

D. Silicon Carbide Blade

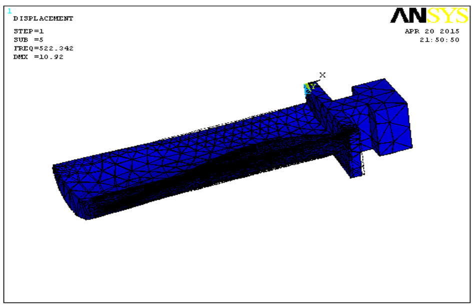

Fig 15: Mode Shape of Turbine

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VII. THERMAL ANALYSIS

A. Titanium Blade

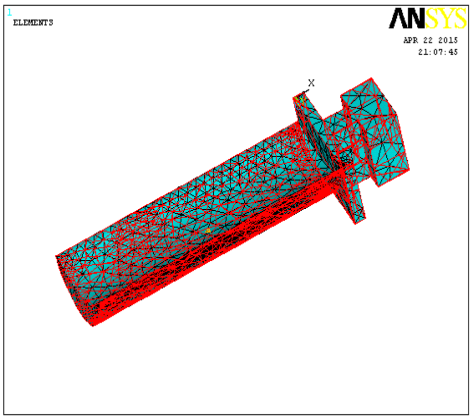

Fig 16: Shows Thermal Loads

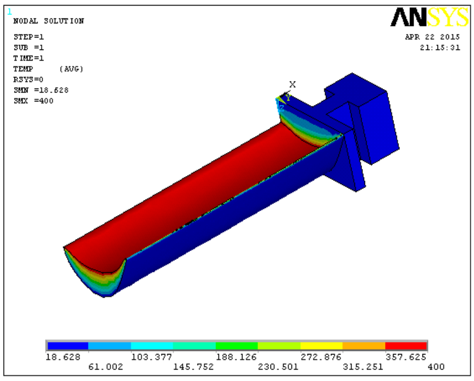

Fig 17: Nodal Temperature Vector sum

B. Aluminium Blade

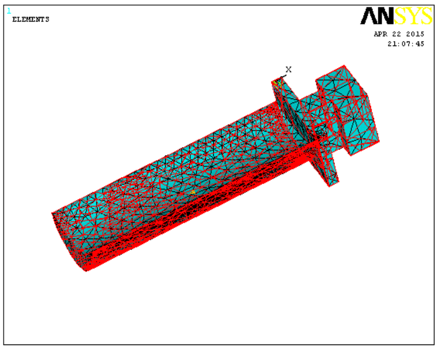

Fig 18: Shows Thermal Loads

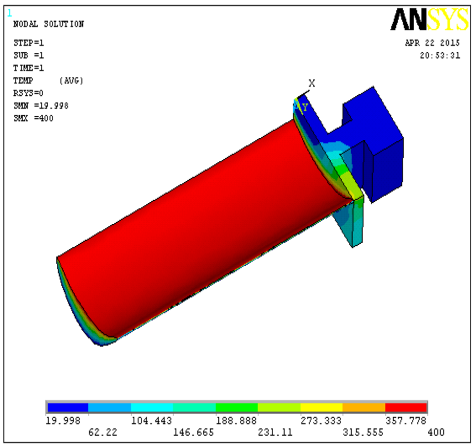

Fig 19: Nodal Temperature Vector sum

C. Niobium Blade

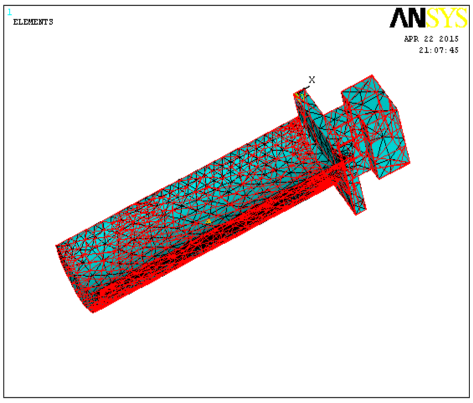

Fig 20: Shows Thermal Loads

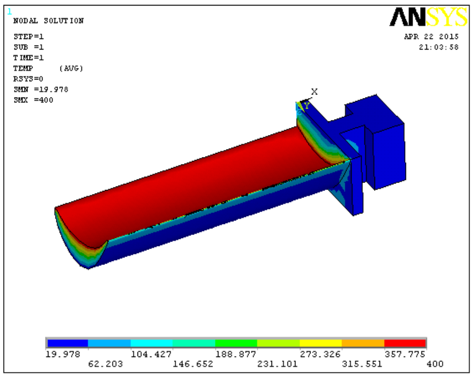

Fig 21: Nodal Temperature Vector sum

D. Silicon Carbide Blade

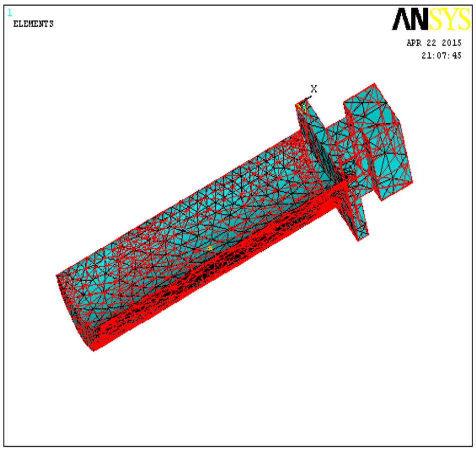

Fig 22: Shows Thermal Loads

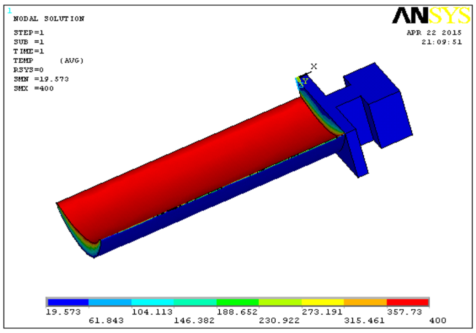

Fig 23: Nodal Temperature Vector sum

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VIII. RESULTS

A. *TITANIUM*

	RESULTS	PERMISSIBLE
DISPLACEMENT (mm)	0.304e^{-03}	
VONMISES STRESS (N/mm^2)	0.32304	140
	Frequency	Displacement
MODE 01	21.394	3.957
MODE 02	30.634	3.784
MODE 03	88.055	7.605
MODE 04	135.88	4.648
MODE 05	221.109	9.122

Table 1: Analysis Results for Titanium Blade

B. *ALUMINIUM*

	RESULTS	PERMISSIBLE
DISPLACEMENT (mm)	0.312e^{-4}	
VONMISES STRESS (N/mm^2)	0.575983	300
	Frequency	Displacement
MODE 01	308.789	2.48
MODE 02	342.214	4.202
MODE 03	349.478	3.777
MODE 04	395.236	3.218
MODE 05	447.602	4.167

Table 2: Analysis Results for Aluminum Blade

C. *NIOBIUM*

	RESULTS	PERMISSIBLE
DISPLACEMENT (mm)	0.629e^{-03}	
VONMISES STRESS (N/mm^2)	0.555496	300
	Frequency	Displacement
MODE 01	14.872	2.874
MODE 02	21.308	2.749
MODE 03	59.224	5.494
MODE 04	93.774	3.409
MODE 05	149.897	6.596

Table 3: Analysis Results for Niobium Blade

D. *SILICON CARBIDE*

	RESULTS	PERMISSIBLE
DISPLACEMENT (mm)	0.589e^{-04}	
VONMISES STRESS (N/mm^2)	0.263476	345
	Frequency	Displacement
MODE 01	48.292	4.755
MODE 02	69.638	4.547
MODE 03	212.9	9.245
MODE 04	309.324	5.457
MODE 05	522.342	10.92

Table 4: Analysis Results for Silicon Carbide Blade

	Displacement (mm)	Von Mises Stress (N/mm^2)	Nodal Temperature (K)	Thermal Gradient (K/mm)	Thermal Flux (W/mm^2)
Titanium	0.304e^{-3}	0.32304	400	14420	3158
Aluminum	0.966e^{-4}	0.295288	400	4745	1186
Niobium	0.629e^{-3}	0.555496	400	7124	3825
Silicon carbide	0.589e^{-4}	0.263476	400	14476	1737

Table 5: Comparison of materials for the obtained above results

IX. CONCLUSIONS

In the next step we have applied different materials for turbine blade to suggest best material.

- Over a Static Structural analysis the obtained Von Mises Stresses are 0.263476(SiC), 0.32304(Ti), 0.555496(Al), 0.575983(Nb).
- The displacement and stress values are less for Silicon carbide and its thermal gradient is more than other three materials.
- So we can conclude that Silicon Carbide is better material for turbine blade.
- From the obtained results it is found that Pure Aluminium has much lesser Thermal Gradient when compared to that of Silicon Carbide, Titanium, and Niobium.
- At constant nodal temperature for all the materials Thermal Flux is varying from 1186-3825 W/mm^2 from the Analysis.
- On Comparison to existing results it also seen that Silicon Carbide has much better stresses sustained over the turbine blade.
- The Frequencies obtained for Aluminium has gradually increased from (308.789 to 447.602 HZ) when compared

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to Substantial increase in Silicon Carbide (48.392 to 522.342 HZ) for a consequent displacement.

- Future scope is to identify Temperature resisting pure metals.

X FUTURE SCOPE OF THE PROJECT

The blade which has been analyzed is a first stage rotor used rotor used in a turbo jet engine. The boundary conditions assumed to be varying convective heat transfer coefficients under steady-state conditions with coupled effect. The temperature distribution observation is the main criteria. The above blade is not analyzed under transient conditions, which can be done in future. As a second approach different materials can be taken and their temperature distribution and other results can be reviewed and comparison can be done to decide the best suitable metal or alloy for the blade. Adding to this, future research also contains evolving technology which is based on fatigue, creep and crack analysis and resulting in producing enhanced blade structures.

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