STATIC AND DYNAMIC ANALYSIS OF COMPOSITE TURBINE BLADE

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ABSTRACT

Turbine blades made of composite materials which form the fundamental element of many structural components like turbine blades, airplane propellers. These plates are subjected to in-plane load on account of fluid or aerodynamic pressures so the blades are subjected to high dynamic loadings. It is necessary to do vibration analysis to know the dynamic character accurately as they are working at high speeds.The existing steam turbine blade made up of N155 material is replaced with the material as Al/SiC-MMC, thereby decrease the weight of the blade for improving the efficiency. Al/SiC-MMC have a more strength when compared to the Existing material. The frequency range and mode of vibrations are determined by using ANSYS software. These frequency ranges are also coded using MATLAB. From Ansys results von mises stress and deformation of the Al/SiC-MMC blade is decreased when compared to Existing N155 material blade.

Keywords: ***Composite Turbine blade, N155, Al/SiC-MMC, ANSYS software, MATLAB***

I. INTRODUCTION

The rotor blades of the turbo machine are very critical components and reliable operation of the turbo machine as a whole depends on their repayable operation. The major cause of break down in turbo machine is the failure of rotor blade. The failure of the rotor blade may lead to catastrophic consequences both physically and economically. Hence, the proper design of the turbo machine blade plays a vital role in the proper functioning of the turbo machine

A good design of the turbo machine rotor blading involves the following

- Determination of geometric characteristics from gas dynamic analysis.
- Determination of steady loads acting on the blade and stressing due to them.
- Determination of natural frequencies and mode shapes.
- Determination of unsteady forces due to stage flow interaction.

Determination of dynamic forces and life estimation based on the cumulative damage fatigue theories

1.1 Importance of Present Work

In the present work, N155 turbine blades are being used in power plant now-a-days. To increase the efficiency of the plant by decreasing the mass of the blade. The Existing blade material N155 is replaced with a Al/SiC Composite, which is the glass-ceramic matrix systems reinforced with silicon carbide. In comparison with the N155 these composites have strength and stiffness and low density. So we get more output in steam turbines by increasing the inlet temperature of steam. The material has proven to be a reliable to both extreme heat (close to 600ºC in some areas) and high vibrations.

1.2 Composite Used in Blade Materials

Composite materials are extending the horizons of all branches of engineering as they have marked their presence in different engineering structures with the domain ranging in the field of aerospace, marine, civil, biomedical, automobiles etc. The composites undergo the process of optimization where materials are combined in such a way that their virtues such as high specific strength, excellent fatigue resistance, high hygroscopic sensitivity and high resistance, can be put to use in a better way while minimizing the extents of the effect of their deficiencies.

Thermo Mechanical Properties of N155

Properties	Units	N155
E	Pa	143e9
ρ	kg/cu m	8249
K	W/m-K	20
μ	---	0.3
α	e-06/^{0}C	16.5
Melting Point	^{0}C	900
Yield stress	MPa	275

1.3 Aluminum Silicon Carbide Composite

Aluminum is used widely as a structural material especially in the aerospace industry because of its light weight properties. Its low strength and low melting point of aluminum were always a problem. An effective method of solving these problems is to use a reinforced element such as SiC particles and whiskers. The high-strength, high-specific modulus and low density aluminium alloy-based composites with silicon carbide reinforcement have generated significant interest in the industries where strength to weight ratio is the primary concern. The combination of light weight, environmental resistance and useful mechanical properties such as modulus, strength, toughness and impact resistance has made aluminium alloys well suited for use as matrix materials. Moreover, the melting point of aluminium is high enough to satisfy many application requirements. Among various reinforcements, silicon carbide is widely used because of its high modulus and strengths, excellent thermal resistance, good corrosion resistance, good compatibility with the aluminium matrix, low cost and ready availability. The main objective of using silicon carbide reinforced aluminum alloy composite system for advanced structural components to replace the existing super alloys

Thermo Mechanical Properties of Al/SiC

Properties	Units	AL/SiC
E	Pa	100e9
ρ	kg/cu m	2600
K	W/m-K	17
μ	---	0.25
α	e-06/^{0}C	14
Melting Point	^{0} C	700
Yield stress	MPa	430

II. MATHEMATICAL FORMULATION FOR DYNAMIC ANALYSIS

For our model consider as a cantilever beam subjected to free vibration, and the system is considered as continuous system in which the beam mass is considered as distributed along with the stiffness of the shaft, the equation of motion can be written as:

$$\frac{d^2}{dx^2}\left\{EI(x)\frac{d^2y(x)}{dx^2}\right\} = \omega^2\, m(x)y(x)$$

Where, E is the modulus of rigidity of blade material,

I is the moment of inertia of beam cross section,

Y(x) is displacement in y direction at distance x fron fixed end,

ωis the circular natural frequency,

m is the mass per unit length, m = ρA(x)

ρ = Material density

x= Density measured from the fixed end.

Boundary Conditions for the blade

y=deflection;

$$\frac{d^2y}{dx^2} = \frac{d\theta}{dx} = curvature$$

$$= \rho = \frac{1}{R} = \frac{M}{EI};$$

If EI = unity→ M

$$\frac{dy}{dx} = slope = \theta;$$

$$\frac{d^3y}{dx^3} = \frac{d^2\theta}{dx^2} = \frac{d\rho}{dx} = \frac{F}{EI};$$

If EI = unity→ F, stress

$$\frac{d^4y}{dx^4} = \frac{d^3\theta}{dx^3} = \frac{d^2\rho}{dx^2}\frac{dF}{dx} = \frac{W}{EI};$$

At $x = 0$, $y(x) = 0, \quad \frac{dy(x)}{dx} = 0$

At $x = L$, $\frac{d^2y(x)}{dx^2} = 0, \frac{d^3y(x)}{dx^3} = 0$

For uniform beam under free vibration from eq.(1),

$$\frac{d^4y(x)}{dx^4} - \beta^4 y(x) = 0$$

$$\beta^4 = \frac{\omega^2 m}{EI}$$

The mode shapes for a cantilever beam(continuous) is,

$$f_n(x) = A_n\{(\sin\beta_n L - \sin h\beta_n L)(\sin\beta_n x - \sin h\beta_n x) + (\cos\beta_n L \quad - \cos h\beta_n L)(\cos\beta_n x - \cos h\beta_n x)\}$$

Where, n=1,2,3,.., ∞ and $\beta_n L = n\pi$

A closed form of the circular natural frequency ω_{nf}, from above equation of motion and boundary conditions can be written as,

$$\omega_{nf} = \sqrt[\alpha_n^2]{\frac{EI}{mL^3}}$$

Where α_n= 1.875, 4.694 , 7.885

So,First natural frequency,

$$\omega_{nf} = \sqrt[1.875^2]{\frac{EI}{\rho AL^4}}$$

Second natural frequency,

$$\omega_{nf} = \sqrt[4.694^2]{\frac{EI}{\rho AL^4}}$$

Third natural frequency,

$$\omega_{nf} = \sqrt[7.885^2]{\frac{EI}{\rho AL^4}}$$

The natural frequency is related with the circular natural frequency as

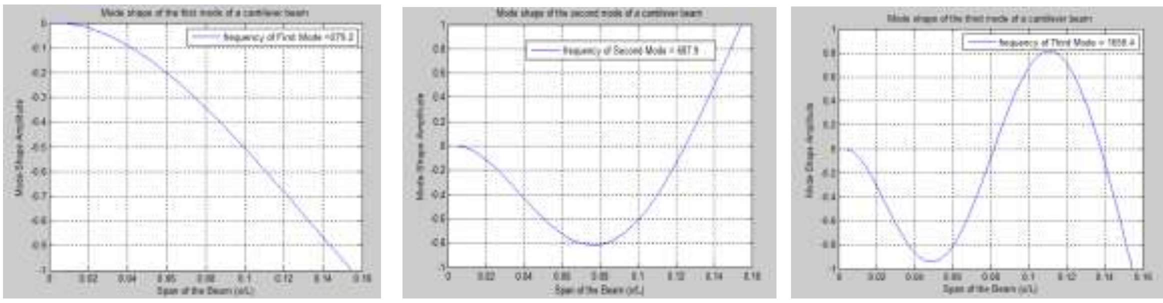
$$f_{nf} = \frac{\omega_{nf}}{2\pi}$$

2.1 Computer Programming Through Matlab

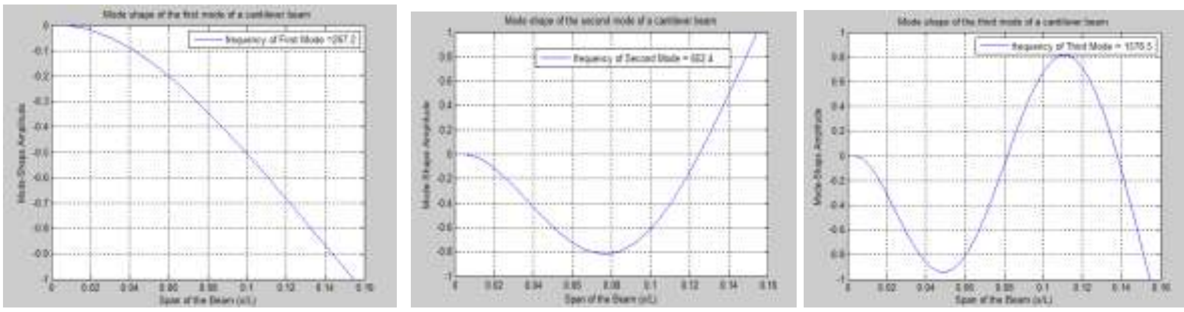
A program is coded in MATLAB for the comparison of the ANSYS results.

The boundary condition assumed in the code is Cantilever Where as one end is fixed and the other is free.

Mode of frequency for N155 blade

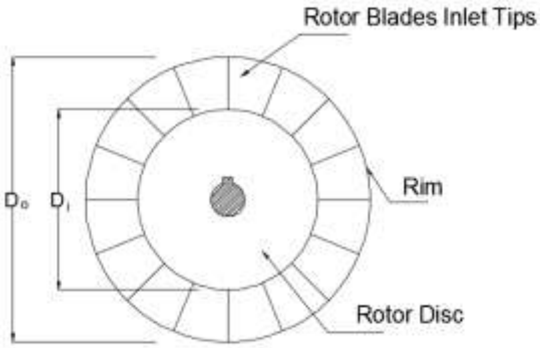


Mode of frequency for Al/SiC blade



III. DESIGN AND ANALYSIS

3.1 Design Data

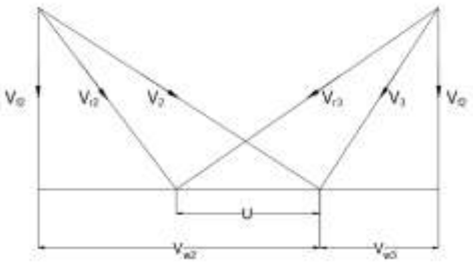


Blade Tip Diameter, D0 =1416mm, Blade Root Diameter, Di=1191mm,

Turbine Speed, N=3426 rpm, Number of blades =120

3.2 Evaluation of Gas Forces on the Rotor Blade

Gas forces acting on the blades of the rotor in general have two components namely tangential (Ft) and axial (Fa). These forces result from the gas momentum changes and from pressure differences across the blades. These gas forces are evaluated by constructing velocity triangles at inlet and outlet of the rotor blade.



3.3 Typical Problem Explanation

At the inlet of the Gas turbine rotor blades,

- Absolute flow angle $\alpha_2 = 23.85^0$
- Absolute velocity $V_2 = 462.21$ m/s
- Diameter of blade mid-span D = 1.3085 m.
- Design speed of turbine N = 3426 r.p.m.
- Peripheral speed of rotor blade at its mid-span $U = \pi DN/60 = 234.72$ m/sec

From the velocity triangles in figure we get,

- Whirl velocity $Vw_2 = 422.74$ m/s
- Flow Velocity $Vf_2 = 186.89$ m/s
- Relative velocity $Vr_2 = 265.09$ m/s
- Blade angle at inlet $\theta_2 = 45\ ^0$

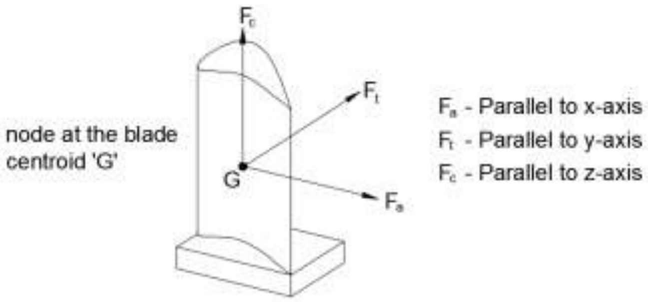
At the exit of Gas turbine rotor blades,

- Flow velocity $Vr_3 = 180.42$ m/s
- Relative flow angle $\theta_2 = 37.88\ ^0$

From the velocity triangles (Figure), we get

- Whirl velocity at exit $Vw_3 = 2.805$ m/s
- Relative velocity at exit $Vr_3 = 293.83$ m/s

3.4 Forces acting on each rotor blade

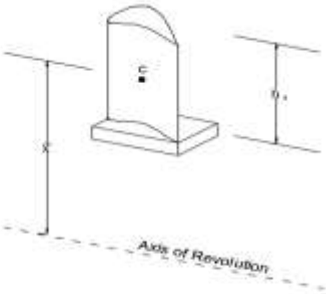


3.5 Evaluation of Forces

- Tangential force, $Ft = M [(Vw_2 – (+Vw_3)]$
- Axial Force, $Fa = M [(Vf_2 – (+Vf_3)]$
- $\rho_2 = 0.6104$ kg/m^3
- $M = \rho_2 \times \pi (D_0^2 - D_i^2)/4 \times Vf_2 = 52.55$ kg/sec
- Total tangential force on Gas turbine rotor, Ft = 22362.38 N

- Total axial force on Gas turbine rotor, Fa = 339.98 N
- Number of blade passages in Gas turbine rotor = 120
- Tangential force on each rotor blade, Ft = 186.35 N
- Axial force on each rotor blade, Fa = 2.833 N

3.6 Centrifugal Forces Experienced by the Rotor Blades



Centrifugal force, Fc= M x $\{(2\pi N/60)^2 \times (\underline{x})\}$ = 5294.6 N

Where

M = Total mass of rotor blade

N = 3426 r.p.m.

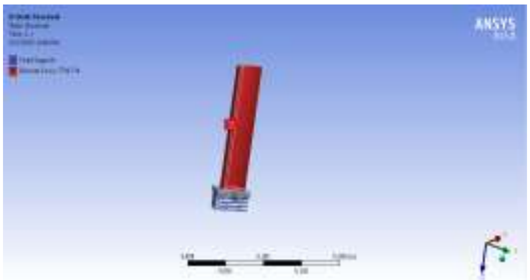
($\underline{x}$) = Distance of centroid from the axis of revolution

= 112.5mm

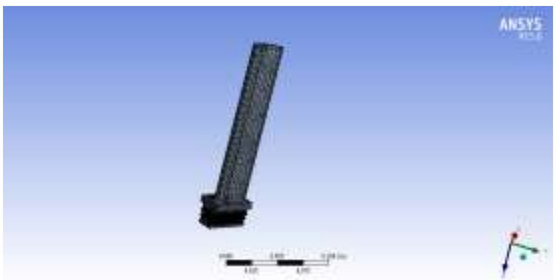
IV. RESULTS AND DISCUSSION

3DModel of Blade in CATIA

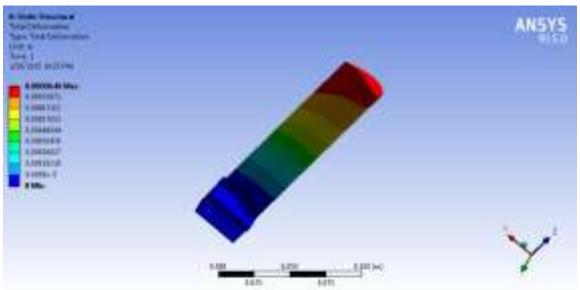
Boundary conditions



Tetra-Mesh



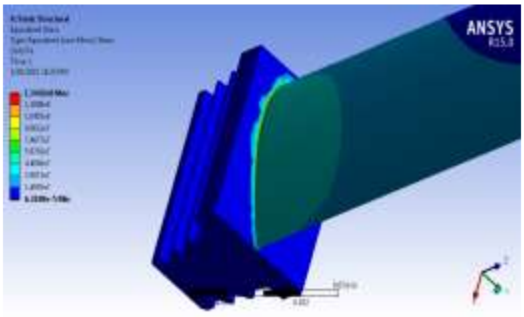
N155-Blade deformation



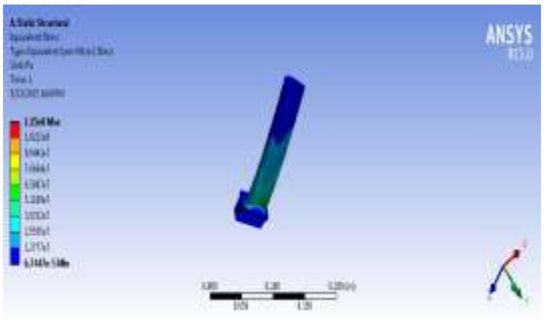
Element Type Solid 187

Elements	30247
Nodes	17047

N155-Von-Mises Stress



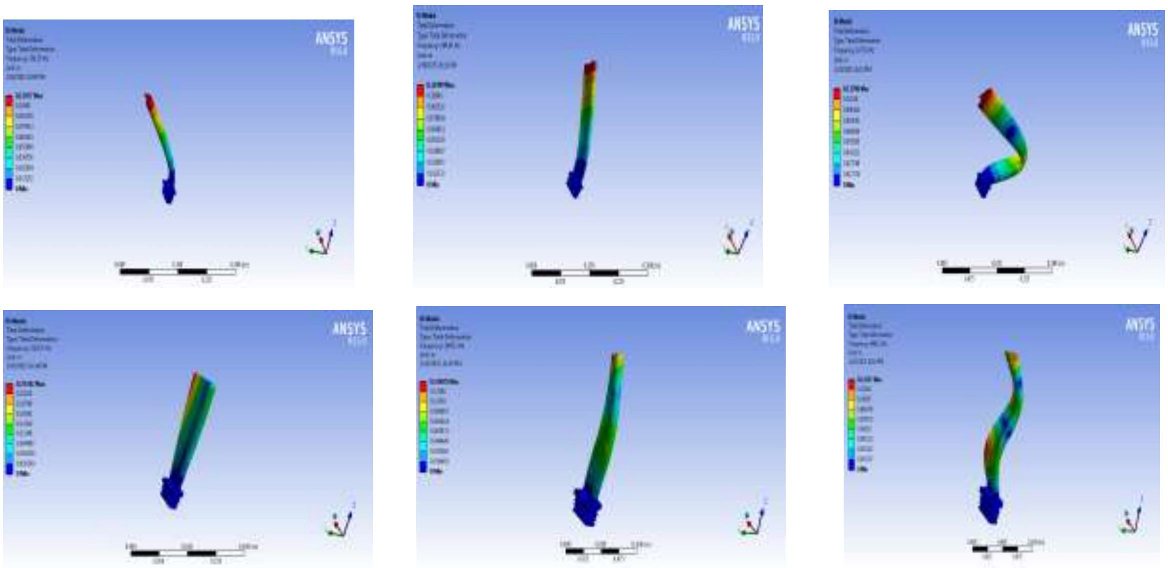
Al/SiC-Von-Mises Stress



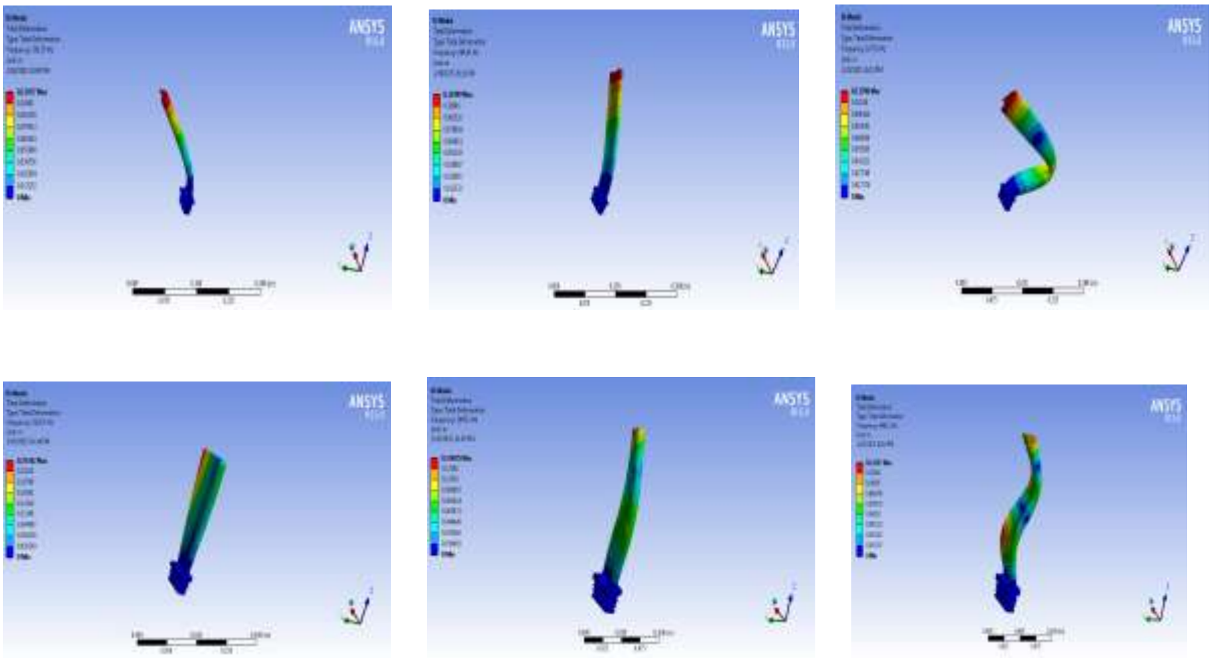
N155 & Al/SiC Von mises stresses & Deformation

Material	Von-mises Stress (Pa)	Total Deformation (mm)
N155	134e6	0.80
Al/SiC MMC	115e6	0.19

N155-Mode Shape



Al/SiC-Mode Shapes



Mode Frequencies For N155 and Al/SiC MMC

	N155 (Hz)	Al/SiC Metal Matrix Composite (Hz)
1st Mode frequency	282.7	262.9
2nd Mode frequency	694.4	660.8
3rd Mode frequency	1677.8	1586.6
4th Mode frequency	2326.5	2298.2
5th Mode frequency	3845.2	3693.3
6th Mode frequency	4488.1	4264.6

The Al/SiC-MMC material turbine blade has vonmises stress of maximum of 115e6Pa this is low compared to the 134e6Pa of N155 material blade. The Al/SiC-MMC material turbine blade has maximum deformation is 0.19mm this also very low compared to 0.8mm of N155.

The frequencies coming from matlab is very close to the Ansys results. Turbine blades are normally subjected to a very severe vibration environment due to which, they are subjected to periodic forces with frequencies equal to the rotational speed and its harmonics because of imbalances in the steam flow. These blades being flexible members are liable to be excited at their resonant frequencies during the operation whenever the excitation frequency coincides with one of the natural frequencies of the blade. It is possible,

V. CONCLUSION

The Static and Dynamic analysis of N155 Turbine blade and Composite Blade has analyzed. The effect of various parameters on the vibration characteristics of a blade subjected to free vibration, using ANSYS and MATLAB. Based on the results obtained following conclusions can be drawn:

- The Al/SiC Metal Matrix Composite Blade material have von-mises stresses is low when compared to N155
- The Al/SiC Metal Matrix Composite Blade material have deformation is low when compared to N155
- The N155 and Al/SiC Metal Matrix Composite blade frequency values came from ANSYS and MATLAB.
- The frequencies coming from Matlab and Ansys are very close.
- It is possible, to design the blades and tune them to rotate without the desired range of natural frequency so that no resonance will occur.

VI. FUTURE SCOPE

- Experimental Vibration Analysis to be done on the Existing N155 blade.
- The blade to be manufactured by use of Al/SiC Metal matrix composite.
- Experimental Vibration Analysis to be done on the Al/SiC-MMC manufactured blade.

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