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Natural Frequency for a Composite Structure Made with a Combination of Metal and Laminated Composites

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***Abstract:** The need for low weight and high strength of the component is in high demand in various aerospace and defense industries and in line with this utilization of the combination of metal and composite increases. In this work, the natural frequency analysis of the structure, is carried out which is a combination of metal and composite. The natural frequency of the system is directly proportional to the stiffness of the system i.e. high natural frequency reflects high stiffness of materials. The structure considered like a cantilever beam, initially considering Titanium alloy the finite element analysis to get natural frequency carried out and validated using an analytical method. Then modal analysis performed using FEA for laminated composite structure and validate with the experimental results and received good agreement. The laminated composite beam manufactured using a hand layup method. Lastly, the structure modeled as a combination of laminated composite material & metal and FEA modal analysis done. The various volume percentage of composite and metal is studied and the best one finds out. The structure considered related to the last stage of the steam turbine blade.*

***Keywords:** Composite, Steam turbine blade, Natural frequency, Stiffness, FFT.*

I. INTRODUCTION

In the steam turbine, rotary blade is a critical component. LP blades are usually more predisposed to failure compare to the blade in HP & IP so detail investigation needed over the different turbine blade material. Steam turbine blades are the most critical components in the steam turbine as which receive impulse directly from high-pressure steam. The height of low-pressure blade is high as compare to high and Low-pressure stage blades and due to this, its fails regularly. Now a day's steam turbine blade made from titanium alloy. The steam turbine usually operates at a speed range of 1500rpm to 4000 rpm, which causes centrifugal forces on it. Apart from this, the stresses arise due to uneven steam flow, resonance condition at operating speed. The majority of failure is due to fatigue. LP blades are usually more predisposed to failure compared to blades in HP or IP turbines. Due to this force, the life of the turbine blade decreases. To avoid such effects selection of material should considered priority. The composite material has high strength high modulus, and excellent fatigue resistance. With low density compared to other materials so, composite material makes a better choice. The weight of the blade causes high centrifugal forces with the use of composite material centrifugal force will decreased. A patent name 'Poly component blade for steam turbine' [1] shows the airfoil profile of the blade is made by the combination of metal on the outer surface and elastomer in the inside part. A metallic section having considerable mass density bonded to the elastomer having low mass density & good resilient over an operating temperature range.

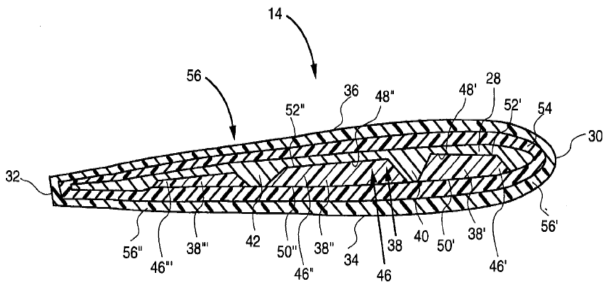

Figure 1 Metal and composite blade [1]

Fig.1 shows the drawing details of the airfoil section of the blade which comprising the metal and composite parts. All section details given in the reference [1].

The elastomer gives the benefit of low cost and low weight. 'Composite turbine blade' patent [2] shows the lightweight construction for the blade made by a composite material for use in the gas turbine. The pressure side made by high temperature resistant material like ceramic matrix composite or carbon fiber composites, which can withstand at high temperature & without requiring cooling air. A patent [3] describes a blade in which the core section made by composite material. The core composite part starts from the root section & extends towards the tip section and the area where airfoil exposed to erosion joined with sheath protection materials. The natural frequency of the beam depends on its stiffness and due to crack the stiffness is get affected & its shows impact on natural frequency shows in [4].

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A research paper [5] reveals the adjustment in thermal expansion of polymer matrix composite with giant negative thermal expansion filler. Antiperovskite manganese nitride used as negative thermal expansion material that filled in composite material.

The thermal expansion of composite controlled from negative to positive for composite material and its convert demerits of composites into merits. This overcomes the problem of thermal expansion between the composite and metal bonding. Composite to metal bonding applications, properties in bonding and various surface finishing techniques explained in [6]. The vibration parameters for a laminated composite beam having constant and varying cross section area is shown in [7][8]. A review paper and case studies [9][10][11] explains the various causes of failure in steam turbine blade and concludes the fatigue is the main reason for failure and its come to know the fatigue strength is important an parameter in the blade and its indicate that there is scope to use composite blades.

Most of the researchers focused on the natural frequency of the composite structure alone, as the applications of the composite to metal bonding increase, create the thrust to focus on it. The natural frequency for the steam turbine blade, which considered as a cantilever beam made by titanium alloy, found using FEA and analytical method. Modal analysis using an FFT analyzer for the composite beam carried out and had good agreement with FEA results. It assumed that the composite beam and metal beam perfectly bonded to each other and there is no relative displacement between them. For various volume percentages of metal and composite, the FEA done and natural frequency found out.

II. PROBLEM STATEMENT

In steam turbine LP blades are usually more predisposed to failure compared to blades in HP or IP turbines. During the operation of turbine blades, there are various forces acting on blades. These forces occur due to high pressure, high temperature, and different mechanical stresses. Due to this forces life of turbine blade decreases. To avoid such effects selection of material should be consider a priority. The composite material has high strength high modulus, and excellent fatigue resistance. With low density compared to other materials so, composite material makes a better choice. The weight of the blade causes high centrifugal forces with the use of composite material centrifugal force will be decrease.

A. BLADE SPECIFICATIONS

Practically low-pressure stage steam turbine blade is having aerofoil cross section and lengthwise curvature. For simplicity, we can consider it a constant rectangular cross section.

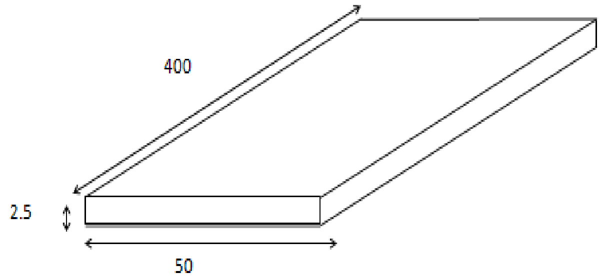

Figure 2 Blade dimensions

A steam turbine blade is consider as a cantilever beam having length 400mm, width 50mm and thickness is 2.5mm as shown in Fig.2. These dimensions consider with reference to the industrial steam turbine blade. It assumed that the Lines perpendicular to the surface of the laminate remain straight and perpendicular to the surface after deformation, the laminae and laminate are linear elastic, the through-the-thickness stresses and strains are negligible.

III. MANUFACTURING OF THE COMPOSITE STRUCTURE

The composite structure is manufacture using the hand lay-up method, which is an easy and economical method. Firstly, the flat plate taken as mold and cleaning done to remove all foreign particles. The mold surface treated by antiadhesive so that the resin should not stick to it. Then the hardener mixed with epoxy resin in 1:2 proportions. The carbon fiber fabric sheet cut in the required portion and placed in the mold. The epoxy resin then infused on the fiber sheet and again another fiber sheet placed on it. To a get clear infusion of the resin in the fiber, the pressure applied using a metallic roller. The layer-by-layer addition is done up to the required thickness and it cures for 12 hours at room temperature.

IV. ANALYSIS OF TURBINE BLADE MADE UP OF TITANIUM ALLOY (METAL)

The blade is consider as a cantilever beam and performed modal analysis using finite element analysis software and first mode frequency shown in Fig.3.

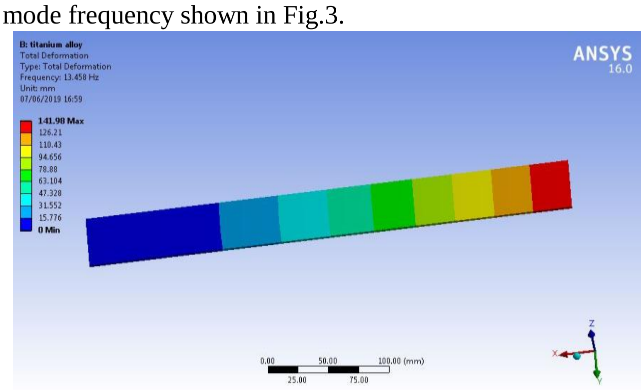

Figure 3. First mode frequency for metal material

Following material properties are used. Modulus of elasticity (E) 1.1e11Pa, density 4000Kg/m3 poisons ratio 0.34. Using analytical method a FEA solution is validate.

$$E = 1.1e11\ N/m^2$$

$$\alpha_1 = 1.875,\ \alpha_2 = 4.94,\ \mu = 0.34,\ K = 17W/mk$$

$$B = 0.05m,\ H = 0.0025m,\ L = 0.4m\ .$$

$$I = bh^3/12,\ \omega = \alpha^2\sqrt{EI/\rho AL^4},\ F_{n1} = \omega/2\pi$$

By putting all values will get $F_{n1} = 13.23Hz$ which is similar to FEA value 13.45Hz.

V. ANALYSIS OF TURBINE BLADE MADE UP OF CARBON EPOXY (COMPOSITE MATERIAL)

Carbon fiber reinforced plastic (CFRP or CRP), is a very strong, light and expensive composite material or fiber-reinforced plastic. The properties of this composite is consider as follows. Density= 1.6e-6 Kg/m3., young modulus=1.2e11, poisons ration= 0.23, bulk modulus=6.79e10, shear modulus=4.47e10.

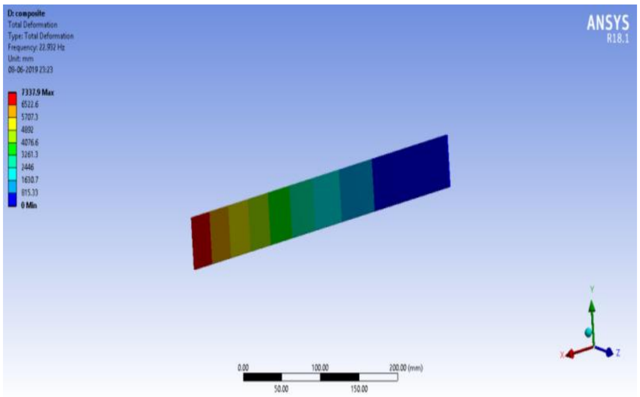

Figure 4 First mode frequency of composite material

The first frequency using finite element analysis is obtained as 22.91Hz as shown in Fig.4. For validating this FEA result, the impact hammer tests with FFT spectrum analyzer carried out. The impact hammer test is conducted is as shown in Fig.5 and Fig.7. In this test, the whole setup kept stationary, the hammer impacted in one place, readings are recorded, and for next reading, the hammer is moved in one direction and it is impacted at equal distance and readings are recorded on the computer.

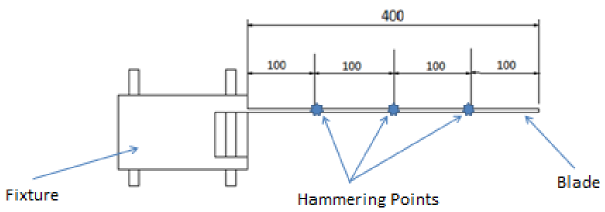

Figure 5 Experimental setup

The blade fixed in the fixture and divided in four equal parts. The three points are marked for hammering.

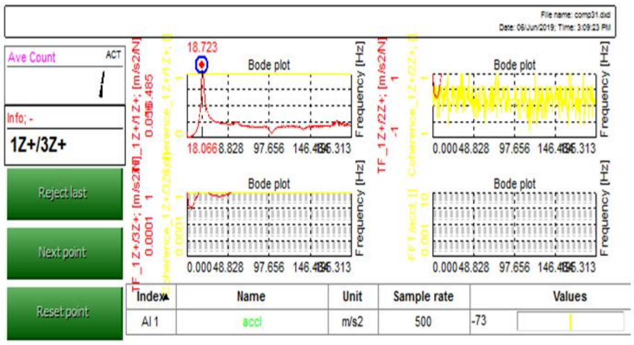

Figure 6 FFT result.

Figure 6 shows FFT result for composite blade testing. The three transverse frequency response curves obtained for corresponding hammering points. The coherence value, which indicated by yellow line, is good for first plot. The pick of curve is at 18.723 Hz, which is the first frequency for blade and its close with frequency obtained by finite element analysis.

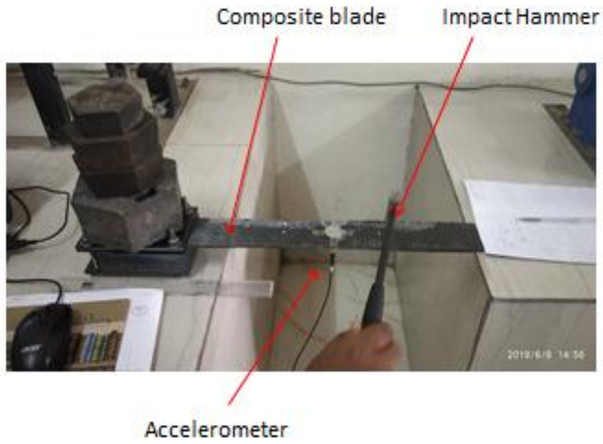

Figure 7 FFT testing of composite structure

VI. ANALYSIS OF TURBINE BLADE MADE UP OF 65% METAL + 35% COMPOSITES

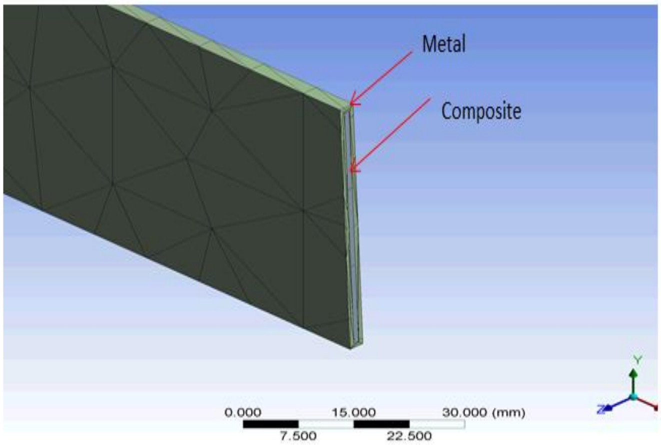

Fig. 8 model of structure made up of metal + composite

Now, by keeping the overall

size same the blade material is divided into two materials i.e. combination of metal and layered composites. The various percentage of volume combination of composite and metal is studied. Figure 8 gives the idea of metal and composite combination. The outer part is made of metallic material as it is directly is in contact with hot and corroded media. The metal part is made of Titanium and composite is Carbon epoxy. Here it is assume that the coefficient of thermal expansion for metal and composite are same and bonding between them is perfect. Fig. 9 shows finite element analysis for it and obtained first transverse natural frequency 16.01Hz.

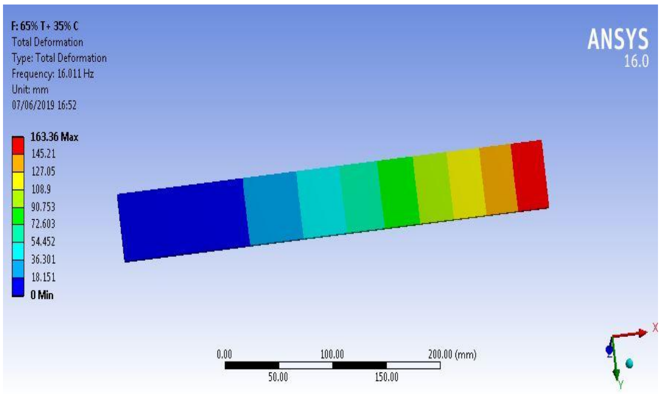

Figure 9 First transverse frequency for 65% metal + 35% composite.

VII. ANALYSIS OF TURBINE BLADE MADE UP OF 50% METAL + 50% COMPOSITE

The blade made by 50% metal and 50% composite and finite element analysis done for natural frequency. The first transverse frequency obtained 18.15Hz.

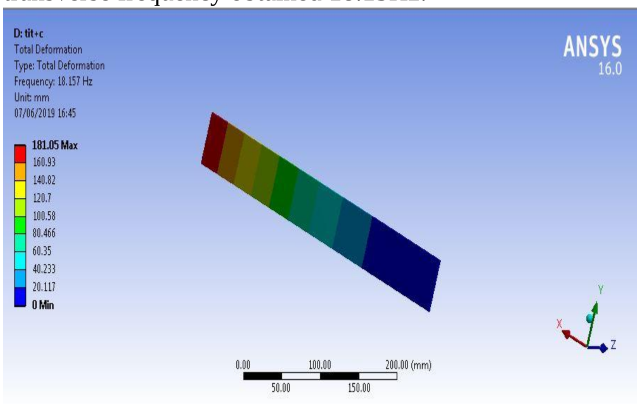

Figure 10 First transverse frequency for 50% metal + 50% composite.

VIII. RESULT AND DISCUSSION

The transverse vibration natural frequency for Titanium metal, carbon fiber composite and combination of Titanium and carbon fiber composite shown below table no. 1 & 2.

Table 1 Natural frequency for Titanium alloy

Mode No.	FEA	Mathematical method
	13.45Hz	13.33Hz

1

Table 2 Natural frequency for composite

Mode No.	FEA	FFT modal analysis
1	22.93Hz	18.72Hz

Table 3 Natural frequency for Metal + Composite

Mode No.	65%Ti+35% Composites (Hz)	50%Ti+50% Composites (Hz)	35%Ti+65% Composites (Hz)
1	16.011	18.157	17.87
2	133.64	154.56	127.71
3	258.74	287.38	295.05
4	293.63	322.98	333.91
5	453.89	514.3	418.69
6	974.74	1127.8	1003.2

The natural frequency value difference for 35%Ti+65% Composites and 50%Ti+50% Composites is small i.e. it shows significantly less stiffness difference. Although the frequency value is somewhat big for 50%Ti+50% Composites compare to 35%Ti+65% Composites, but its density will be significantly more.

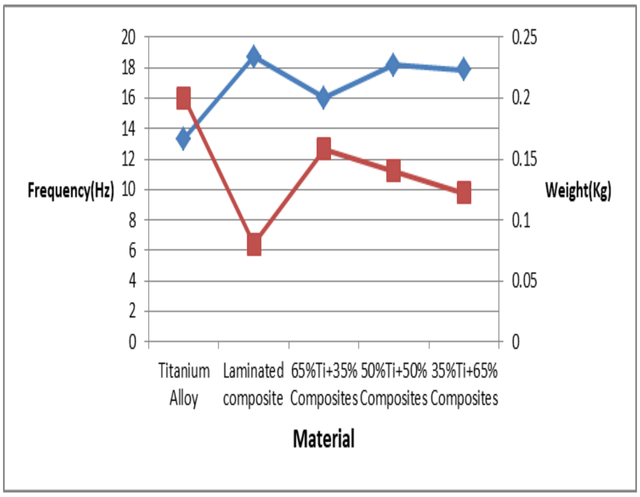

Figure 11 Effect of Composition on Frequency and Weight

IX. CONCLUSION

The natural frequency for the structure made by Titanium alloy material found out using the FEA and validated the result with an analytical method with good agreement.

The experimental modal analysis for the beam made with laminated composite contains carbon fiber done using an FFT analyzer and the same done with FEA. The natural frequencies for various combinations of metal and composite are obtained & show that 35%Ti+65% Composites combination having frequency 17.87 Hz i.e. its stiffness is near to Titanium alloy and as a composite share is more so the weight of the blade will be less. Although the 50% Ti+50% composite shows higher natural frequency, it means having high stiffness but the weight of the structure increases.

The enhancement in natural frequency (from 16.01Hz to 18.15Hz) occurs as the percentage of composite increases and indirectly it shows the growth in the stiffness. Further increasing the composite share shows the downfall in the frequency (from 18.15Hz to 17.87Hz) i.e. it shows a decrease in stiffness and the weight of the structure.

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