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Vibration Analysis of Cooling Tower Fan Blades

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Abstract : *Structural vibration problems causes major hazards and design limitations of a very wide range of engineering products. The Cooling tower fan blades are exposed to severe conditions of excitation and vibration during their service life, thus it may have an effect on their dynamic behavior and this leads to structural damage that is the failure of cooling tower performance severely. The vibration stresses causes the severe threat to the operation of Fiber Reinforced Plastic (FRP) fans. In order to minimize vibration problems in FRP blades, a vibration analysis is to be carried out. The analysis is carried for blades by varying various sizes. The objectives of this project is to analytically extract the natural frequencies of cooling tower fan blades of different sizes, so that, the designer can ensure that the natural frequencies will not be close to the frequency of the main excitation forces in order to avoid resonance. The Rayleigh method has been applied to find the fundamental frequency of blades by considering blade as a Stepped, Taper, continuous cantilever beam. A MATLAB program has been developed to predict the fundamental frequencies. Also, three dimensional models of blades have been developed in Unigraphics NX 5 and modal analysis is carried out by ANSYS 14.5. Also, an experimental study carried out for FRP composite blades. Concurrence between MATLAB results, ANSYS results and Experimental results has been found in the frequency range of interest. This ensures that an effective method to compute the natural frequency of composite blades of different sizes has been developed.*

Keywords *- Vibration analysis, FRP fans blades, Matlab Program, Modal Analysis, FFT Analyzer, Natural Frequency.*

I. INTRODUCTION

It is necessary to undertake the vibration analysis, to avoid the resonance phenomenon due to the excitation of the blade to their natural frequencies. Under these circumstances, the blade structure must be designed strong enough to operate under the range of frequency interest, withstand the severe conditions and survive the maximum resistance to fatigue. To achieve these requirements, glass fiber-reinforced composites are frequently used in such structural applications, Because of their excellent formability, their mass saving advantage, their high stiffness-to-density and strength-to-density ratios and the greater freedom to use these properties in the desired orientation and position. Now, for a particular problem it is needed to find an analytical solution to determine natural frequency of non-uniform, tapered FRP composite blades of various dimensions and also to develop a program to predict the natural frequency of FRP fan blades. A vibration analysis of non-uniform, tapered, composite blade has been carried out by analytical method, and verified by numerical method and experimental method. Tartibu K.et.a [1] have identified the Flap-wise, edge-wise and torsional natural frequencies of a variable length blade. Different Configurations of the variable length blade are investigated. A MATLAB program was developed to predict natural frequencies. Similarly, three-dimensional models of the variable length blade have been developed in the finite element program Unigraphics NX5. The Concurrence between MATLAB and Unigraphics NX5 results has been found for the frequency range of interest. The good agreement between NX5 and MATLAB results has been found for the frequency range of interest using a composite material variable blade. This means that an effective method to compute natural frequencies of a variable length blade was developed. Modal analysis of a helicopter main rotor blade for different materials performed by Harsha et.al [2] They extracted the normal modes of a helicopter's main rotor blade and compare them for different materials such as Aluminum; Fiber reinforced plastic and Glass epoxy composite using the finite element method. It has been observed that the natural frequencies of the reinforced plastic and glass epoxy material are comparatively lesser than the aluminum materials, which conclusively suggest the use of composite material as the better option for the main rotor blade. Determination of Natural Frequency of Stepping Cantilever beam has been done by Dr. Luay S. et.al [3] by Rayleigh model and Finite elements model (ANSYS model). Modified Rayleigh model is much closer to the ANSYS model. The results shows the effect of the width for small and large part of beam, the length of large part of step, and the ratio of large to small width of stepping beam on the natural frequency of stepping beam. The natural frequency of stepping beam is increasing with increasing of the width of small and large parts of beam. In addition to the natural frequency of beam is increasing with increasing the length of large width until reach to (0.52 m) and decreasing then when the modified Rayleigh model or ANSYS model are used. Dr Brahim Attaf [4] has undertaken Vibration studies on glass reinforced polyester composite wind turbine blade to optimize its dynamic properties. Due to complexity of a mathematical solution and to overcome this problem, numerical and experimental studies were undertaken. Vibration modes (natural frequencies and mode shapes) of the composite wind blade were determined from both analyses and comparison of results was made. Use of glass-fiber composites has shown the achieved dynamic structural improvements. An Experimental Study on the Vibration Characteristics of the Rotor Blade with Fiber Reinforced Plastics carried out by Choong-Yul et.al [5]. They investigated the dynamic behavior characteristic of W.T.S (Wind Turbine System) to investigate the dynamic behavior characteristic of W.T.S; the experiments to measure the vibration of the blade from the attached accelerometer on the flap and edge section of the blade were performed. For validation of these experiments, the finite element analysis is performed by commercial F.E.M program (ANSYS) on the basis of the natural frequency and mode shape. The results indicate that experimental values have good agreements with the finite element analysis.

II. NEED OF WORK

In the reviewed literature it has been observed that the analysis of FRP fan blade has been carried out experimentally for a specific blade also, it takes longer time to determine the natural frequency of fan blade. Analytically as it is treated as continuous system having varying cross-section. Hence the need is felt to develop a generalized model based on analytical method which can take care of aerofoil profile cross section. In this work an attempt has been made to prepare a program which can identify the natural frequencies of various sizes of FRP blades having different properties in a general manner. The objective of this project is formulation for analytical determination of natural frequency of FRP fan blades having varying cross section and to develop a generalized solution. To develop a program to compute natural frequency of FRP composite fan blades. Verification of formulation and computation by Ansys simulation and Experimental validation.

III. FORMULATION FOR NATURAL FREQUENCY OF FRP FAN BLADES

Rayleigh's method can be applied to find the fundamental natural frequency of continuous systems. This method is much simpler than exact analysis for systems with varying distribution of mass and stiffness. This method is applicable to all continuous systems and has been applied it to FRP blades in this section. The FRP composite blade has been considered as a stepped, taper, continuous cantilever beam.

3.1 Equation for determination of natural frequency of FRP composite fan blade. A FRP composite fan blade is shown in Fig. 2.1and Profile of a cross-section of FRP composite blade shown in Fig. 2.2 Cooling tower fan blades are manufactured by Yashas manufacturing Pvt. limited, Indore. These blades are used for the fan having following specifications: No. of Blades as 4 to 10 Blades, Airflow Up to 900 m3/sec, Static pressure up to 325 Pa, Speed: Tip Speed up to 76.2 m/sec, Power Rating up to 360 KW and Operating Temp - 20 Deg. C to + 120 Deg. C.

Fig. 2.1 A FRP composite fan blade

Fig. 2.2 Profile of FRP composite blade.

For a stepped beam equation more conveniently written as

$$R(\omega) = (\omega^2) = \frac{E_1 * I_1 \int_0^{l_1} \left(\frac{d^2W}{dx^2}\right)^2 dx + E_2 * I_2 \int_{l_1}^{l_2} \left(\frac{d^2W}{dx^2}\right)^2 dx + \cdots}{\rho * A1 \int_0^{l_1} W^2\, dx + \rho * A2 \int_{l_1}^{l_2} W^2\, dx + \cdots}$$

Where E_i, L_i, A_i, I_i correspond to the i th step (i = 1, 2…)

For evaluation the FRP blade is divided into n sections (i =1, 2...n) the above equation rewritten as,

$$R(\omega) = (\omega^2) = \frac{E_1 * I_1 \int_0^{l_1} \left(\frac{d^2W}{dx^2}\right)^2 dx + E_2 * I_2 \int_{l_1}^{l_2} \left(\frac{d^2W}{dx^2}\right)^2 dx + \dots + E_n * I_n \int_{l_{(n-1)}}^{l_n} \left(\frac{d^2W}{dx^2}\right)^2 dx}{\rho * A1 \int_0^{l_1} W^2\, dx + \rho * A2 \int_{l_1}^{l_2} W^2\, dx + \dots + \rho * A_n \int_{l_{(n-1)}}^{l_n} W^2\, dx} \qquad \textbf{(2.1)}$$

Where, *En*= Modulus of Elasticity of n^{th} section of FRP Composite Material (N/mm^2), I_n = Moment of Inertia of n^{th} section of blade profile (mm^4), l_n= Length of n^{th} section of blade profile from fixed end of blade (mm), A_n= Area of n^{th} section of blade profile (mm^2), W = Deflection shape. = $(1 - (x/l))^2$, ω = Natural Frequency (rad/sec), n = Number of sections considered.

IV. DEVELOPMENT OF PROGRAM

A computer program has been developed to compute natural frequency of FRP fan blades. The Matlab codes have been written for the above expression (2.1). For computation purpose the total profile area of cross-section of FRP blade has been divided into standard shapes. Moment of inertia blade profiles of FRP blade has been determined by dividing blade profile shape into standard shapes (i.e. divide into four triangles) as shown in Fig. 3.1. Total moment of inertia of blade profiles obtained by combining moment of inertia of each standard shape (triangle) of respective blade profile. Similarly, Total profile area obtained by combining an area of each standard shape of the respective section.

Fig. 3.1 Profile of cross-section of FRP blade

Table 1 Material properties of FRP composite

FRP Material	Young's Modulus (E) (N/mm^2)	Poisson's ratio (μ)	Density (ρ) (Kg/mm^3)
Glass fiber epoxy	13425	0.265	$1.76*10^{(-6)}$

Table 2 Output of Matlab Program

Sr. No.	Blade Size ft / (m)	Analytical Results (Matlab Results) f_n (Hz)
1	36 (10.9728 m)	4
2	30 (9.144 m)	5
3	26 (7.9248 m)	6
4	24 (7.3152 m)	8

V. ANSYS SIMULATION AND EXPERIMENTAL WORK TO FIND NATURAL FREQUENCY OF FRP BLADES

A modal analysis has been done using Ansys workbench for simulating natural frequency of FRP blades. Ansys simulation has been used to analyze the modal parameters of various FRP blades. The results presented ahead are the List of natural frequencies of various FRP blades.

Table 3 Ansys Results

Blade Size ft / (m)	F_n (I) Hz	F_n (II) Hz	F_n (III) Hz	F_n (IV) Hz
36 (10.9728 m)	3.15	13.88	22.32	33.76
30 (9.144 m)	3.21	8.80	13.25	33.49

26 (7.9248 m)	4.39	10.97	17.82	44.98
24 (7.3152 m)	6.08	10.81	22.58	54.42

The experimental work has been carried out for comparison with the results obtained by Matlab program and Ansys simulation. The experimental tests have been carried out on a FRP composite blade. Initially the test has been carried for the 24ft FRP blade. These results are compared with the theoretically simulated results and Ansys results. In the next step, tests have been carried out on various FRP blades of different sizes. The trends of these results have been compared with those computed by the Matlab simulation. List of frequencies have been recorded for 24ft (7.3152 m), 26ft (7.3152 m), 30ft (7.3152 m), and 36ft (7.3152 m) FRP blades.

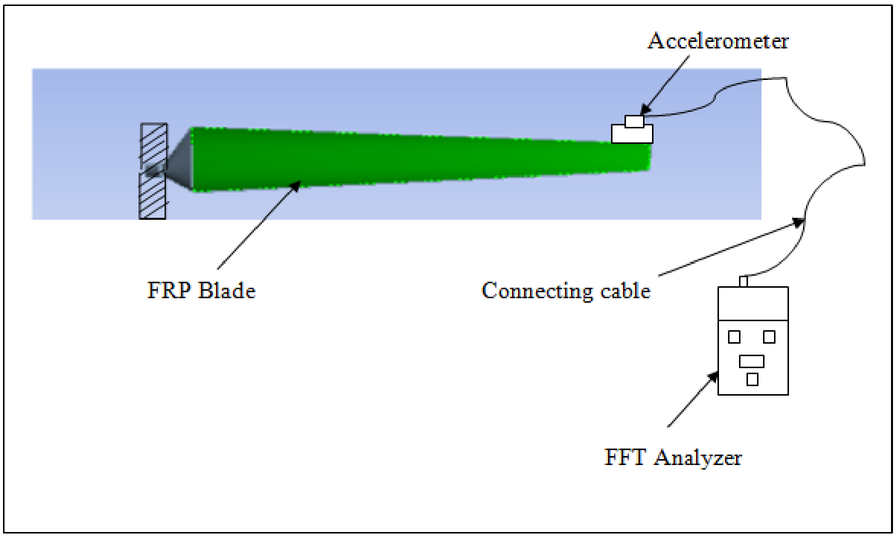

Figure 4.1 Block diagram of the experimental Set-up

Table 4 Result Table

Experimental Results fn (Hz)				
Blade Size ft /(m)	I	II	III	IV
36 (10.9728 m)	4	14	21	36
30 (9.144 m)	4	9	14	32
26 (7.9248 m)	5	10	18	46
24 (7.3152 m)	7	9	24	52

VI. DISCUSSION OF RESULTS AND CONCLUSION

In present work the analytical determination of natural frequency of FRP fan blades of various materials and dimensions has been studied. The Ansys simulation and experimental validation has been done. The Matlab results and Ansys results have been verified by conducting experiments on FRP blades. Comparing the computed and the experimental results shows both results are correct.

VII. CONCLUSIONS

The following conclusions have been drawn.

1. This work gives the analytical solution of the determination of natural frequency of FRP blades of different dimensions and material properties.
2. The Matlab program can predict the natural frequency of FRP blades.
3. The Modal analysis has been done with Ansys; it gives natural frequencies, mode shapes and total deformation for 24ft, 26ft, 30ft, and 36ft FRP blades.
4. The experimental work has been carried out on the FRP blades and results are compared with the analytical obtained results and Ansys results.
5. As compared with MATLAB results, the ANSYS and Experimental results are in good agreement.

6. ANSYS results and experimental results has been found in the frequency range of interest for a FRP composite blades, the analytical solution gives slightly higher values than the experimental values, assumed shape w(x) has introduces a constraint on the system, (which amounts to adding additional stiffness to the system) and so the frequency given by analytical solution will be slightly higher than the exact value.
7. Ansys results are close to the experimental results. Therefore, both MATLAB and ANSYS can be used to calculate the natural frequencies of FRP composite blades as well as other similar types of blades.
8. The Rayleigh method is the suitable method to calculate fundamental frequency of FRP composite blades.

This means that an effective analytical solution for determination of natural frequency of FRP composite blades of various dimensions and material properties has been developed. The MATLAB codes have been written was valid for different inputs of a FRP fan blades. This process of solving the problems results in accuracy in solution as well as saving of time and reducing common errors that may usually occur in manual calculations.

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