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Dynamic Analysis of Composite Propeller of Ship Using FEA

Md. Yahiya[1], Mohammed Aqeel Ahmed[2], Md. Naser Ahmed[3]
Assistant Professor[1, 2,3]
Department of Mechanical Engineering
Muffakham jah College of Engineering & Technology, Hyderabad, India[1]
Khaja Banda Nawaz College of Engineering & Technology, Gulbarga, India[2]
Nawab Shah Alam Khan College of Engineering & Technology, Hyderabad, India[3]

Abstract:
Ships and underwater vehicles like submarine and torpedoes use propeller for propulsion. In general, propellers are used as propulsors and they are also used to develop significant thrust to propel the vehicle at its operational speed and RPM. The blade geometry and design are more complex involving many controlling parameters. Propeller with conventional isotropic materials creates more vibration and noise in its rotation. It is undesirable in stealth point of view. In current years the increased need for light weight structural element with acoustic insulation has led to use of fiber reinforced multi layered composite propeller. The present work is to carry out the dynamic analysis of aluminum, composite propeller which is a combination of GFRP (Glass Fiber Reinforced Plastics) and CFRP (Carbon Fiber Reinforced Plastics) materials.

Keywords: composite propeller, dynamic analysis, modal analysis, harmonic analysis,

I. INTRODUCTION

Ships and under water vehicles like submarines, torpedoes and submersibles etc., uses propeller as propulsion. The blade geometry and its design is more complex involving many controlling parameters. The strength analysis of such complex 3D blades with conventional formulas will give less accurate values. In such cases numerical analysis (Finite Element Analysis) gives comparable results with experimental values. In the present project the propeller blade material is replaced from aluminum metal to fiber reinforced composite material for underwater vehicle propeller. Such complex analysis can be easily solved by finite element method techniques.

II. LITERATURE REVIEW

The strength requirements of propellers dictate that not only the blades be sufficiently robust to withstand long periods of arduous service without suffering failure or permanent distortion, but also that the elastic deflection under load should not alter the geometrical shape to such an extent as to modify the designed distribution of loading .A first approach to strength problem was made by Taylor [1] who considered a propeller blade as a cantilever rigidly fixed at the boss. J.E.Connolly [2] addressed the problem of wide blades, tried to combine both theoretical and experimental investigations. Terje sonntvedt [3] studied the application of finite element methods for frequency response under hydrodynamic loading. Chang-sup lee [4] et.al investigated the main sources of propeller blade failures and resolved the problem systematically. M.Jourdain [5] recognized that the failure of in-numerous blades was due to fatigue, which cannot be taken into account in a conventional static strength calculation. G.H.M.Beek [6] the interference between the stress conditions in both parts. George [7] used the distribution of thrust and torque along the radius to compare actual performance of a propeller with calculated performance. P.Castellini [8] describes the vibration measurements on blades of a propeller rotting in water with tracking laser vibrometer. W.J Colclough [9] et.al, studied the advantages of a composite propeller blade made of fiber reinforced plastic over that of the propeller blade made from other materials. J.G.Russel [10] developed a method for blade construction employing CFRP in a basic load carrying spar with a GFRP outer shell having aerofoil form.

III. ANALYSIS

3.1 DYNAMIC ANALYSIS:

Static analysis does not take in to account variation of load with respect to time. Output in the form of stress, displacement etc. with respect to time could be predicated by dynamic analysis. In static analysis velocity and acceleration (due to deformation of component) are always zero. Dynamic analysis can predict these variables with respect to time, frequency and to determine natural frequency of component, it is a basic design property. Natural frequency information is always helpful for avoiding resonance, reducing noise. When the excitation frequency is close to natural frequency of component, there would be big difference in static and dynamic results. Static analysis would probably show stress magnitude within yield stress and safe but in reality it might fail.

3.1.1 Modal (Eigen value) analysis:

Modal analysis does not represents the response due to any loading but yields by natural frequencies and corresponding mode shapes in the form of Eigen when there is no dissipation of energy due to damping. In short it is the analysis of undamped free vibration of propeller blade in the absence of damping and applied loads. Eigen value analysis is carried out by using Block Lanczos method.

3.1.2 Harmonic analysis:

Harmonic response analysis is a technique used to determine the steady-state response of a linear structure to loads that vary sinusoidally (harmonically) with time. The idea is to calculate the structure's response at several frequencies and obtain a graph of some response quantity (usually displacements) versus frequency. "Peak" responses are then identified on the graph and stresses reviewed at those peak frequencies. This analysis technique calculates only the steady-state, forced vibrations of a structure.

3.2 STEPS IN FINITE ELEMENT ANALYSIS OF PROPELLER USING ANSYS:

- Modeling of propeller using CATIA, and mesh generation and application of boundry condition using HYPERMESH.
- Importing the hypermesh file to ANSYS.
- Material properties are incorporated into the material data.
- 3D composite element layers were stacked according the measured thickness of each element.
- Two fiber orientation angles are considered for GFRP and CFRP materials i.e. 90, 0 degrees.
- Processed the static analysis.
- The nodal displacements and stresses are plotted.
- Interlaminar shear stresses are also plotted.
- Verified the deformed levels with the allowable limits or not.
- Eigen value analysis is carried out by using Block Lanczos method.
- First eight natural modes are obtained for both aluminum and composite propeller.
- Harmonic analysis is carried out for aluminum propeller.
- Harmonic analysis is carried for different number of layers for composite propeller.
- Amp-frequency graphs are plotted for both aluminum and composite propellers.

3.2.1 MECHANICAL PROPERTIES OF ALUMINUM:

Casting Condition: Chill Cast
HT condition: WP
Proof stress: 230 N/sq.mm
Tensile strength: 280 N/sq.mm
Young's modulus: 7.00xe4 N/sq.mm
Rigidity modulus: 2.71xe 4 N/sq.mm
Poisson's ratio: 0.29
Density: 2.7g/cc
%Elongation: 2
Hardness: 105 BHN
Melting point: 650°c
The loading and boundary conditions are given in Ansys, the finite element model is solved.

3.2.3 MECHANICAL PROPERTIES OF COMPOSITE:

Material 1**:** GFRP (R glass roving/epoxy):
E_1=53 N/mm^2
E_2=25.4 N/mm^2
E_3=25.4 N/mm^2
Y_1=0.32
Y_2=0.28
Y_3=0.28
G_{12}=6.6 N/mm^2
G_{23}=4.14 N/mm^2
G_{13}=4.14 N/mm^2
Density= 2e^{-9} tons/mm^2
Material 2: GFRP (S2 glass fabric/epoxy):
E_1=22.925 N/mm^2
E_2=22.925 N/mm^2
E_3=12.4 N/mm^2
Y_1=0.2
Y_2=0.3
Y_3=0.3
G_{12}=4.7 N/mm^2
G_{23}=4.2 N/mm^2
G_{13}=4.2 N/mm^2
Density= 18e^{-10} tons/mm^2
Material 3: CFRP (Carbon U/D epoxy):
E_1=150 N/mm^2
E_2=10 N/mm^2
E_3=10 N/mm^2
Y_1=0.32
Y_2=0.25
Y_3=0.25
G_{12}=5.2 N/mm^2
G_{23}=3.8 N/mm^2
G_{31}=6 N/mm^2
Density= 16e^{-10} tons/mm^2

IV. RESULTS AND DISSCUSSIONS

4.1 MODAL (EIGEN VALUE) ANALYSIS OF PROPELLER:

Modal (Eigen value) analysis is carried out for both aluminum and composite propeller. Type of analysis is changed to model, the required boundary conditions and density are given for extracting the first eight mode shapes of both aluminum and composite propeller blade and first eight natural frequencies (Table 4.1) and mode shapes (Fig 8.29 to 8.76) are obtained for aluminum and composite propeller.

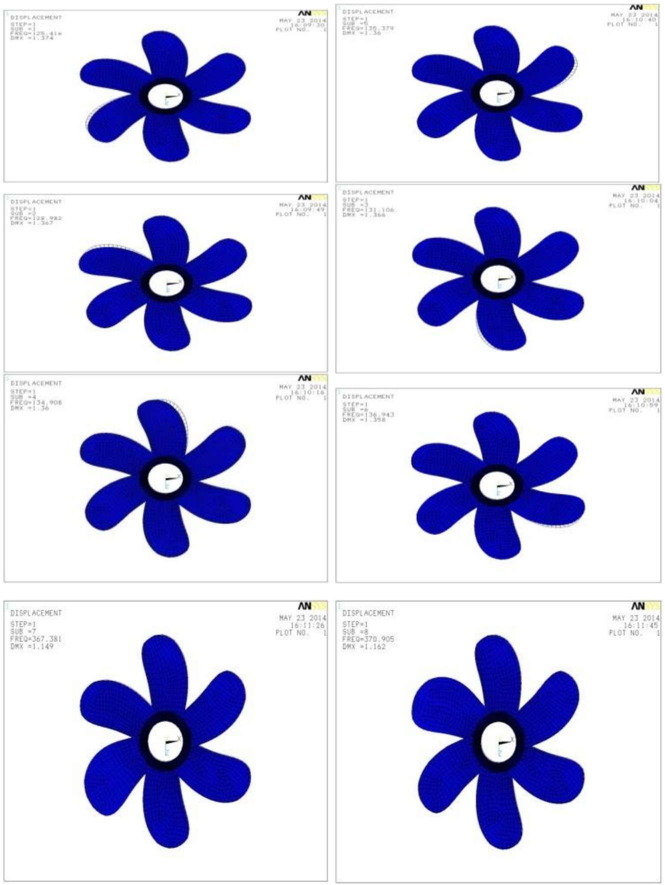
Table.4.1 Natural frequencies of aluminum and composite propeller blade.

Sl. no	Aluminum propeller (Frequency in Hz)	Composite propeller (Frequency in Hz)				
		Case1 :4 layers	Case 2:8 layers	Case3 : 12 layers	Case4 : 16 layers	Case5 : 20 layers
1.	125.42	368.7	351.6	407.0	442.2	423.5
2.	128.98	376.7	360.4	421.8	452.7	433.5
3.	131.11	383.6	366.6	423.1	458.6	439.3
4.	134.91	398.7	381.7	441.6	479.9	460.0
5.	135.38	399.2	382.4	441.9	481.3	461.1
6.	136.94	404.7	389.1	442.4	487.3	467.2
7.	367.38	940.	913.2	1021	1120	1093.
8.	370.91	942.9	916.4	1030	1121	1095.

The natural frequencies of aluminum and composite propeller are compared. The natural frequencies of composite materials were found to be 66% more for 4 layers, 64.33% more for 8 layers, 69.2% more for 12 layers, 71.64% more for 16 layer, to 70.5% more for 20 layers as the mass of the composite materials were less than that of aluminum.

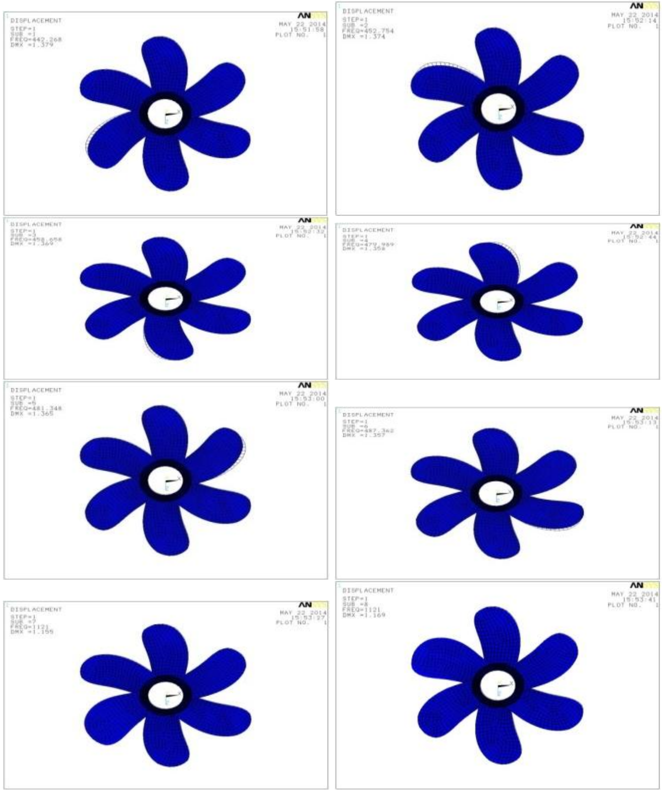
4.1.1 MODE SHAPES:

For aluminum propeller



Figures. 4.1: 1^{st} to 8^{th} mode of aluminum propeller

For composite propeller



Figures. 4.2: 1^{st} to 8^{th} mode of 16 layers composite propeller

4.2 HARMONIC ANALYSIS OF PROPELLER:

The required frequency range for aluminum is given as 0-500 Hz for aluminum and 0-1500 Hz for composite propeller with 8 sub steps. Harmonic analysis for composite propeller is done by varying the number of layers viz., 4, 8, 12, 16 and 20. Amp vs. Frequency graphs are plotted to check the vibrations at various frequencies.

4.2.1 Harmonic analysis of aluminum propeller:

In this harmonic analysis for aluminum propeller, Amplitude vs. Frequency graphs are plotted. It is observed that resonance occurs in the frequency range of 150 Hz in X direction, was found same in other two directions as shown in figures 8.77-8.79.

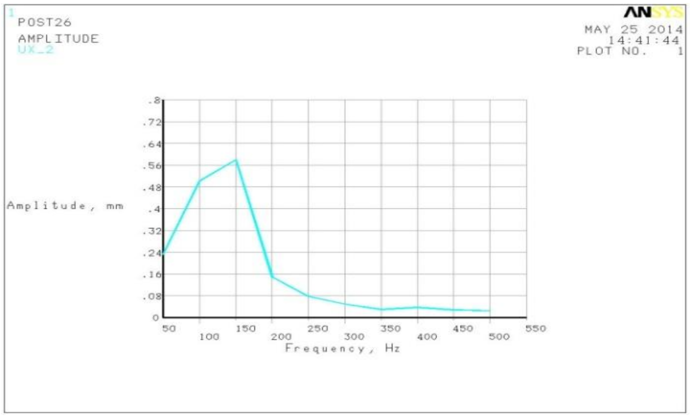


Figure. 8.77: amp-freq graph for aluminum propeller in X direction

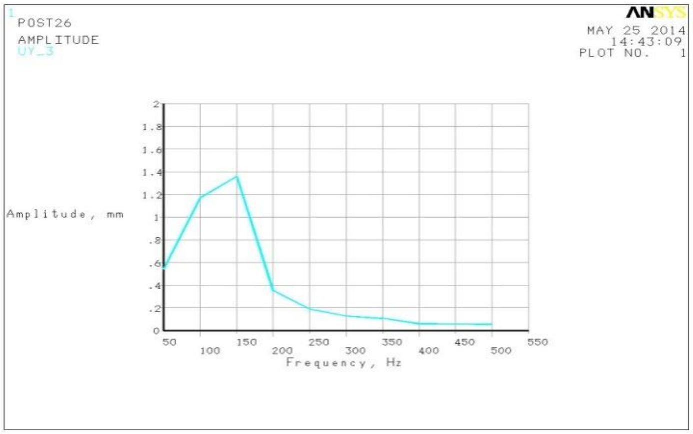


Figure. 8.78: amp-freq graph for aluminum propeller in Ydirection

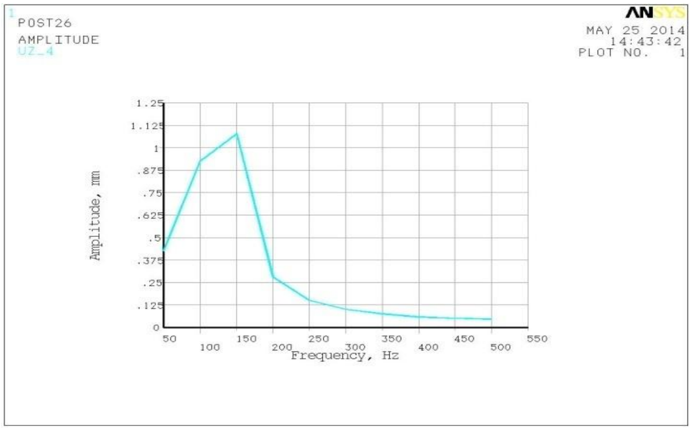


Fig 8.79: amp-freq graph for aluminum propeller in Zdirection

4.2.2 Harmonic analysis of 16 layers composite propeller:

In this harmonic analysis with 8 layers, Amplitude vs. Frequency graphs are plotted. It is observed that resonance occurs in the frequency nearer to 400Hz in X direction, was found same in other two directions as shown in figures 8.89-8.91

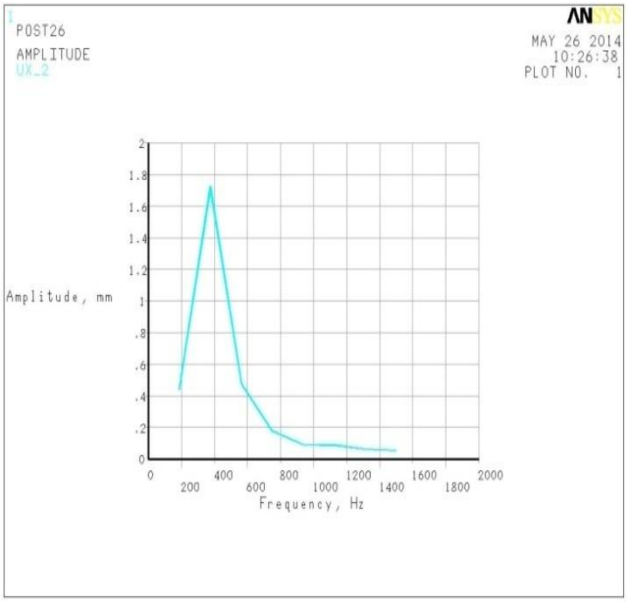


Figure. 8.89: amp-freq graph for 16 layers in X direction

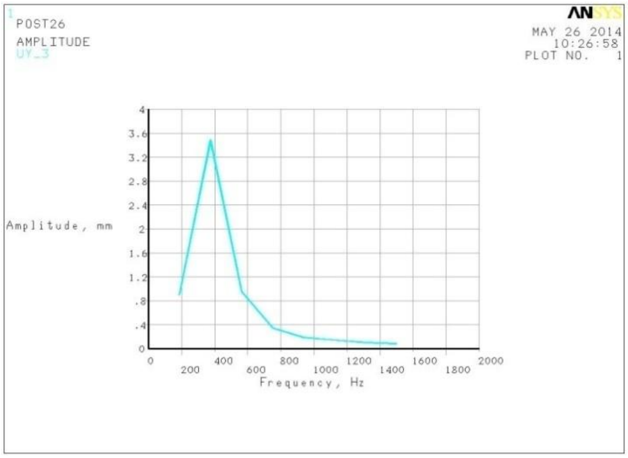


Figure. 8.90: amp-freq graph for 16 layers in Y direction

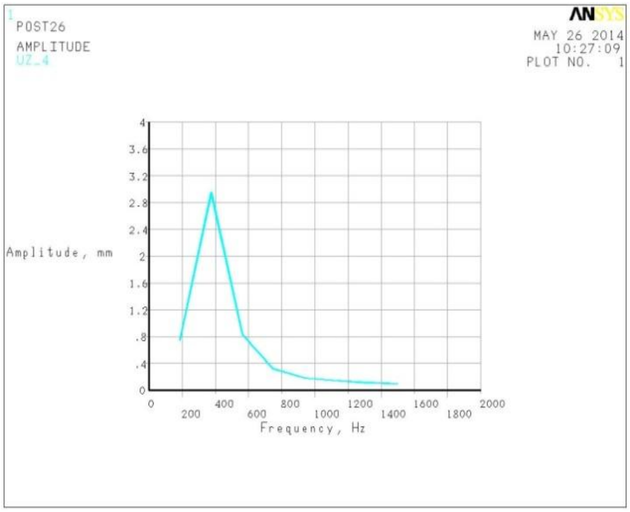


Figure. 8.91: amp-freq graph for 16 layers in Z direction

V. CONCLUSIONS:

The following conclusions are drawn from the present work:

- Eigen value analysis results showed that the natural frequencies of composite propeller were 64 to72% more than aluminum propeller, which indicates that the operation range of frequency is higher for composite propeller.

- Harmonic analysis results for aluminum and composite propeller shows that the resonance frequency range for composite propeller is 62.5% more than that of aluminum propeller.

VI. FUTURE SCOPE OF WORK:

- The present work only consists of Modal (Eigen value) analysis and harmonic analysis, which can be extended for transient and spectrum analysis in case of both aluminum and composite materials.

- There is also a scope of future work to be carried out for different types of materials. For present purpose only modeling and analysis of a propeller blade is carried only for GFRP and CFRP materials.

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