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Design and Analysis Of Composite Propeller Using ANSYS

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***Abstract:* -** The present thesis deals with modeling and analyzing the propeller blade of underwater vehicle for its strength. A propeller is a complex geometry which requires high end modeling software. The solid model of propeller is developed using CATIA V5 R17. Tetrahedral mesh is generated for the model using HYPER MESH. Static, Eigen and frequency responses analysis of both aluminum and composite propeller are carried out in ANSYS. Inter laminar shear stresses are calculated for composite propeller by varying the number of layers. The stresses obtained are well within the limit of elastic property of the materials. 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, Static analysis,Eigen value analysis, Harmonic analysis, FEA*

I. INTRODUCTION

Ships and under water vehicles like submarines, torpedoes and submersibles etc., use propeller for propulsion. The blade geometry and its design are 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 finite element analysis gives comparable results with experimental values. In the present analysis the propeller blade material is converted from aluminum metal to fiber reinforced composite material for under water vehicle propeller. Such complex analysis can be easily solved by finite element method techniques. The propeller is a vital component for the safe operation of ship at sea. It is therefore important to
ensure that ship propeller has adequate strength to with stand the forces that act upon them. Fiber reinforced plastic composite have high strength to weight and these materials have better corrosion resistance, lower maintenance, non magnetic property and it also have stealth property for naval vessels. The forces that act on a propeller blade arise from thrust and torque of the propeller and the centrifugal force on each blade caused by its revolution around the axis. Owing to somewhat complex shape of propeller blades, the accurate calculations of the stresses resulting from these forces is extremely difficult. The stress analysis of propeller blade with aluminum and composite material is carried out in the present work.

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. MODELING OF PROPELLER:

Modeling of the propeller is done using CATIA V5R17. In order to model the blade which is compatible for shell mesh, it is necessary to have sections midline (profile) of the propeller at various radii. These sections are drawn with the help of Macros. That Profiles (Midlines) drawn are then rotated through their respective pitch angles from their stack point. Then all rotated sections are projected onto right circular cylinders of respective radii.

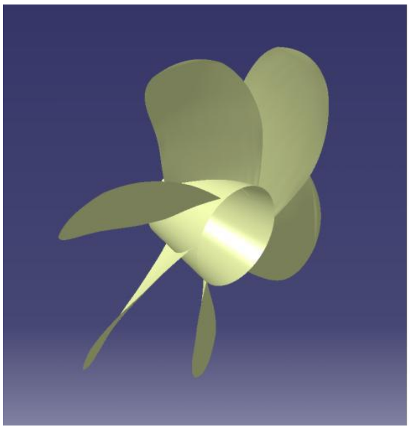

Fig1: Final model of Propeller

IV. MESH GENARATION USING HYPERMESH

The solid model is imported to HYPERMESH 10.0 and tetrahedron mesh is generated for the same. Boundary conditions are applied to meshed model. The contact surface between hub and shaft is fixed in all degrees of freedom. Thrust of 4000 N is uniformly distributed on face side of blade, since it is the maximum loading condition region on each blade. The loading condition is as shown in below fig.

Numbers of nodes created were and numbers of elements created are 1,65,238. Then the meshed model is imported into the ANSYS. Solid 46 element is selected for composite propeller and solid 92 element type is selected for aluminum propeller.

V. MATERIAL PROPERTIES OF PROPELLER

Aluminum properties
Young's modulus E= 70000 MPa
Poisson's ratio =0.29
Mass density =2700 gm/cc
Damping co-efficient =0.03

Material properties for composite Propeller used for present work

Mat no 1: S2Glass fabric/Epoxy
E1=20 N/mm2
E2=20 N/mm2
E3=12.4 N/mm2
υ1=0.08
υ2=0.41
υ3=0.41
G12=4.05 N/mm2
G23=3.4 N/mm2
G13=3.4 N/mm2
Density= 2gm/cc

Mat no 2: Carbon UD/Epoxy
E1=116.04 N/mm2
E2=9.709 N/mm2
E3=9.709 N/mm2
υ1=0.334
υ2=0.328
υ3=0.5
G12=8 N/mm2
G23=6 N/mm2
G13=3.1 N/mm2
Density= 16gm/cc

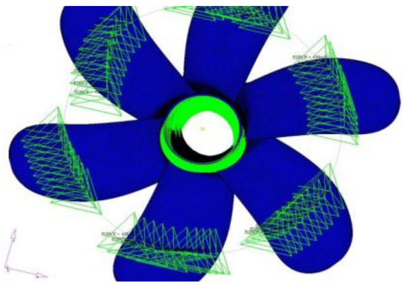

Fig2: Loading on meshed model

VI. EIGEN VALUE ANALYSIS

The required boundary conditions and density are given for extracting the first ten mode shapes of both aluminum and composite propeller blade. Type of analysis is changed to model and first ten mode shapes are obtained.

VII. HARMONIC ANALYSIS

Type of analysis is changed to harmonic. Frequency range in which the propeller operates is given as 0-2000 for aluminum and 0-5000 for composite propeller. Five sub steps are given. Ampfreq graph is plotted for aluminum as well ascomposite (i.e. 4, 8, 12, and 16) layers.

VIII. RESULTS AND DISSCUSSIONS

Linear static analysis is concerned with the behavior of elastic continua under prescribed boundary conditions and statically applied loads. The applied load in this case is thrust acting on blades. Under water vehicle with contra rotating propeller is
chosen for FE analysis. The FE analysis is carried out using ANSYS. The deformations and stresses are calculated for aluminum (isotropic) and composite propeller (orthotropic material). In composite propeller 4 cases are considered, those are number of layers is varied as 4, 8, 12, 16. For propeller blade analysis 3D solid element type 92 is considered for
aluminum and solid 46 for composite propeller.

Static analysis of aluminum propeller:

The deformation pattern for aluminum propeller is shown in figure 3. The maximum deflection was found as 6.883mm in y-direction. Maximum principal stress value for the aluminum
propeller are shown in figure 4.The Von mises stress on the basis of shear distortion energy theory also calculated in the present analysis. The maximum von mises stress induced for aluminum blade is 525.918 N/mm2 as shown in figure 5.

Table 1. Deflections & Stresses in aluminum propeller under static condition

Result: Aluminum propeller
Deflection in mm 6.883
Max. normal stress N/mm2 485.337
Von mises N/mm2 525.918
1st principal stress N/mm2 518.775
2nd principal stress N/mm2 206.945

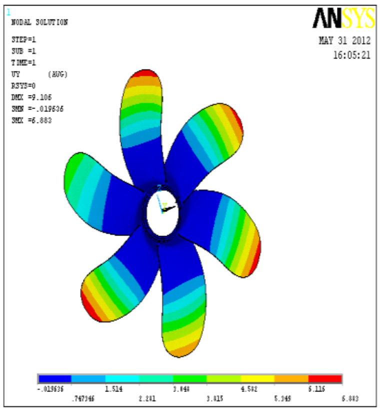

Fig 3: max deflection of aluminum Propeller

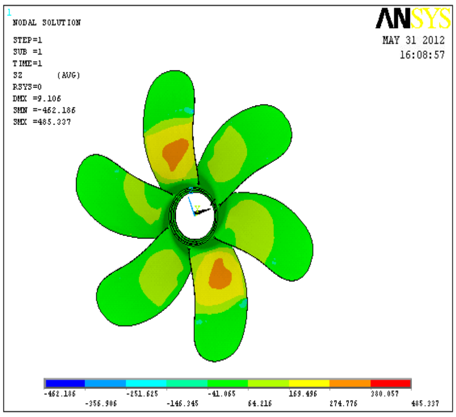

Fig 4: max normal stress of aluminum propeller

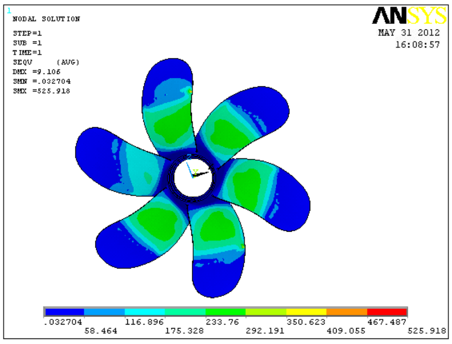

Fig5: max von mises stress of aluminum propeller

Static analysis of composite propeller:
Four cases are considered for static analysis of composite propeller by varying the number of layers to check the bonding strength. Interlaminar shear stresses are calculated for all cases.

Case 1: 4 Layers
Case2: 8 layers
Case 3: 12 layers
Case 4: 16 layers.

Table 2. Static analysis results of composite propeller

No. of layers	Max deflection in mm	Max. normal stress, N/mm2	von mises stress, N/mm2	Inter laminar shear stress, N/mm2
4 0.479367 77.555 97.038 51.327	4 0.479367 77.555 97.038 51.327	4 0.479367 77.555 97.038 51.327	4 0.479367 77.555 97.038 51.327	4 0.479367 77.555 97.038 51.327

Case1: Analysis results of 4 layers
Maximum deflection for composite propeller with 4 layers was found to be 0.47939mm Z-direction i.e. perpendicular to fibers of the blade as shown in figure 6. The maximum normal stress was found to be 77.555 N/mm2 as shown in figure 7.The maximum von mises stress was found to be 97.038 N/mm2 as shown in figure 8. The maximum interlaminar shear stress was found to be 51.327 N/mm2 as shown in figure 9 at top of 4th layer.

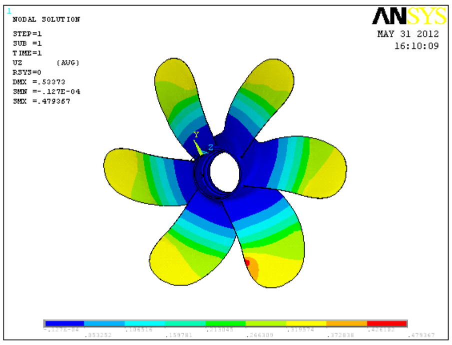

Fig6: max. Deflection of composite propeller with 4 Layers

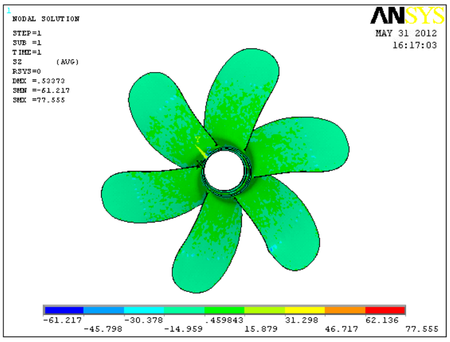

Fig7: max. Normal stress in composite propeller with 4 layers

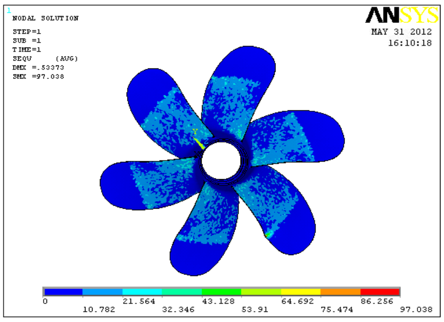

Fig8: max. Von mises stress of composite propeller with 4 layers

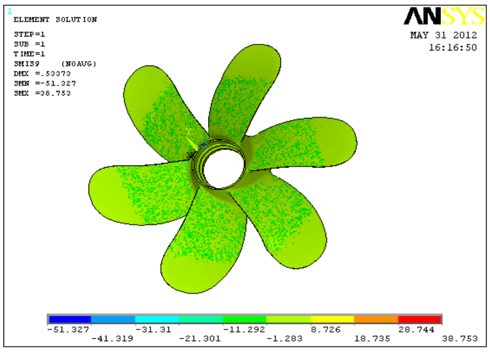

Fig9: max. Interlaminar shear stress of composite propeller with 4 layers

Case2: Analysis results of 8 layers

Maximum deflection for composite propeller with 8 layers was found to be 0.47721mm Z-direction i.e. perpendicular to fibers of the blade as shown in figure 10. The maximum normal stress was found to be 77.611 N/mm2 as shown in figure 11.The maximum von mises stress was found to be 99.276 N/mm2 as shown in figure 12. The maximum inter laminar shear stress was found to be 52.146 N/mm2 as shown in figure 13 in compression at top of 8th layer.

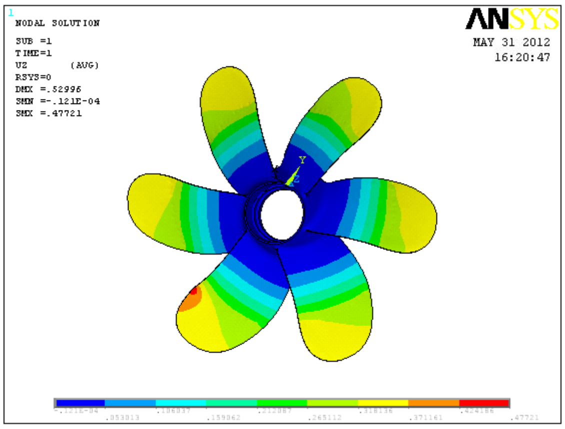

Fig10: max. Deflection of composite propeller with 8 Layers

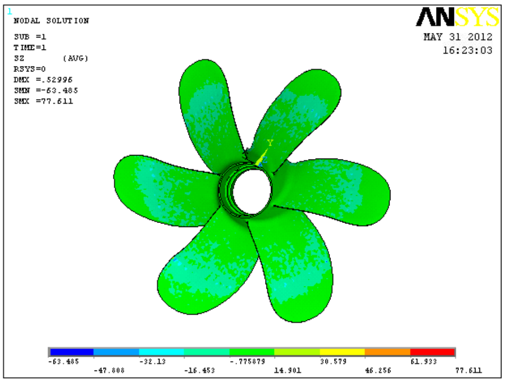

Fig11: max normal stress of composite propeller with 8 layers

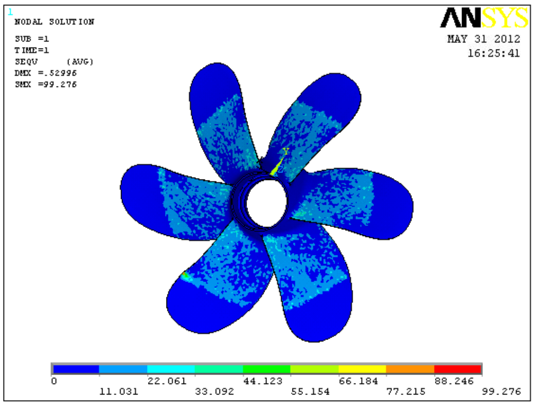

Fig12: max. Von mises stress of composite propeller with 8 layers

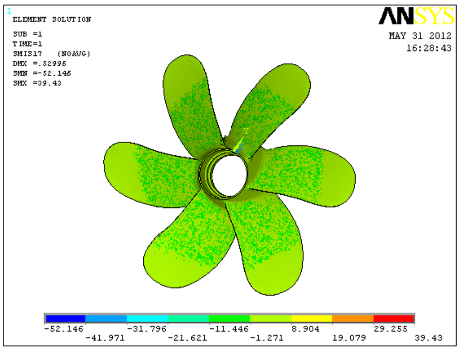

Fig13: max. Interlaminar shear stress of composite with 8 layers

Case3: Analysis results of 12 layers

Maximum deflection for composite propeller with 12 layers was found to be 0.4846mm Z-direction i.e. perpendicular to fibers of the blade as shown in figure 14. The maximum stress was found to be 78.784 N/mm2 as shown in figure 15.The maximum von mises stress was found to be 101.099 N/mm2 as shown in figure 16. The maximum interlaminar shear stress was found to be 52.744 N/mm2 as shown in figure 17 in compression at top of 12th layer.

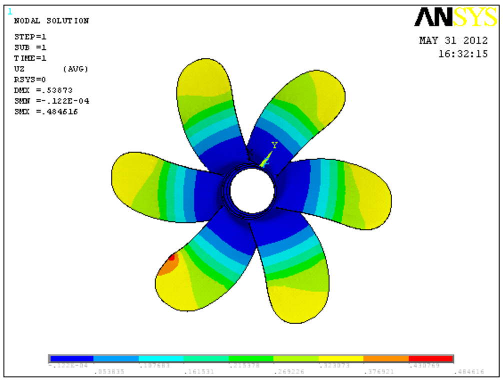

Fig14: max deflection of composite propeller with 12 Layers

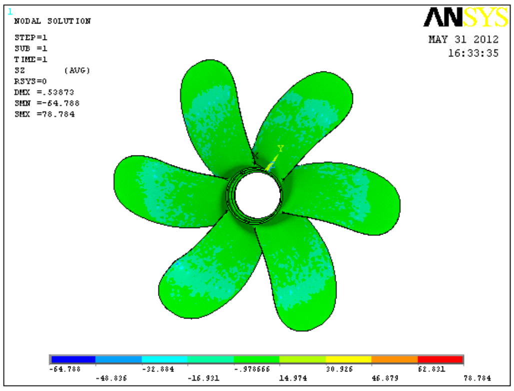

Fig15: max normal stress of composite propeller with 12 layers

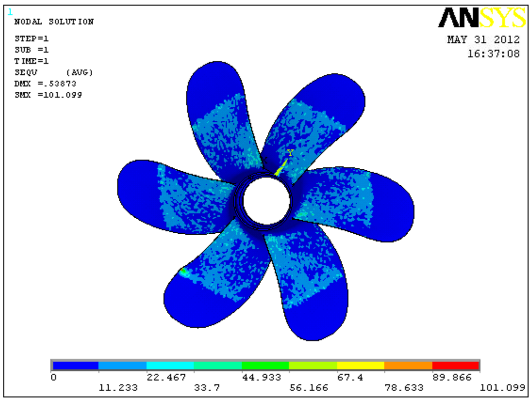

Fig16: max.von mises stress of composite propeller with 12 layers

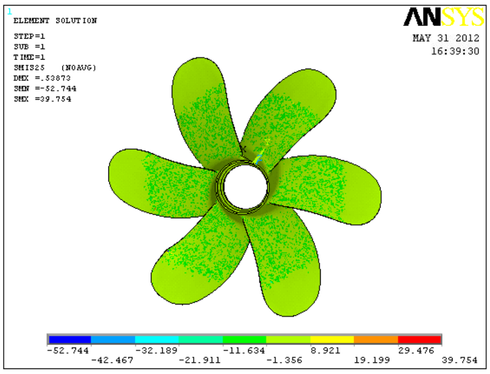

Fig17: max. Interlaminar shear stress of composite propeller with 12 layers

Case 4: Analysis results of 16 layers

Maximum deflection for composite propeller with 16 layers was found to be 0.488923m Zdirection i.e. perpendicular to fibers of the blade as shown in figure 18. The maximum stress was found to be 79.511 N/mm2 as shown in figure 19. The maximum von mises stress was found to be 101.876 N/mm2 as shown in figure 20. The maximum interlaminar shear stress was found to be 53.07 N/mm2 as shown in figure 21 in compression at top of 16th layer.

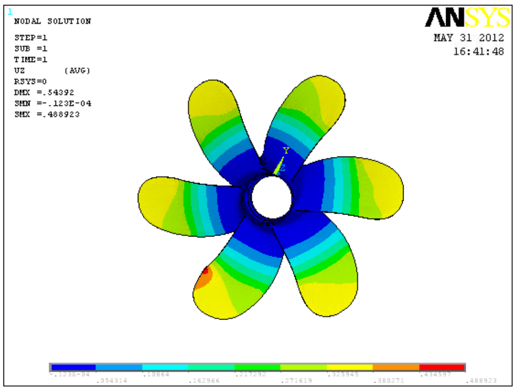

Fig18: max. Deflection of composite propeller with 16 layers.

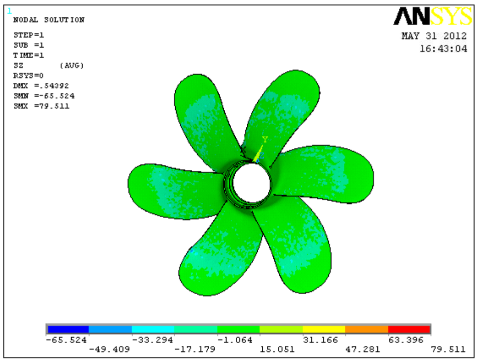

Fig19: max stress of composite propeller with 16 Layers

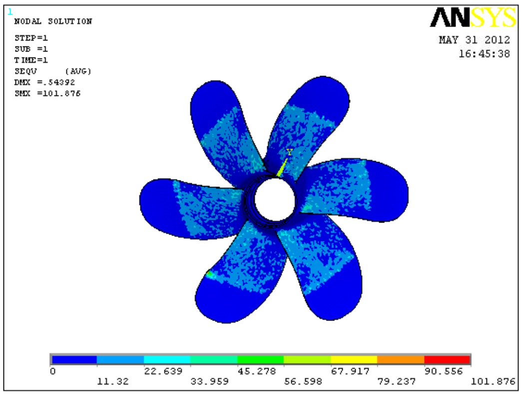

Fig20: max.von mises stress of composite propeller with 16 layers

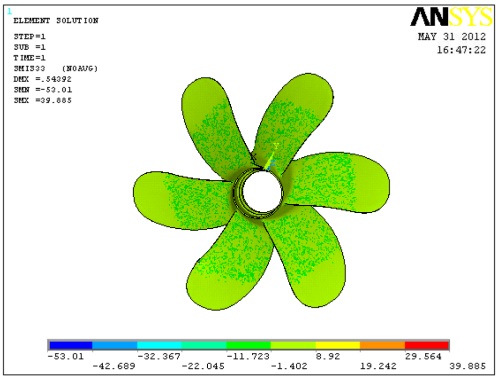

Fig21: max. Interlaminar shear stress of composite propeller with 16 layers

EIGEN VALUE ANALYSIS OF PROPELLER:

Eigen value analysis is carried out by using Block Lanczos method. First ten natural frequencies are obtained for aluminum. The natural frequencies of aluminum and composite propeller are compared. The natural frequencies of composite materials were found 80.5% more as the mass of the composite materials were less than that of aluminum.

Table 3. Natural frequencies of aluminum propeller Blade

S. No	Eigen value analysis for aluminum in HZ	Eigen value analysis for composite propeller in HZ
1	439.76	2257.4
2	439.77	2266.4
3	439.8	2268.6
4	439.86	2272.5
5	439.95	2275.3
6	439.96	2277.9
7	1178.4	3159.5
8	1178.5	3174.0
9	1178.5	3177.8
10	1178.5	3181.9

HARMONIC ANALYSIS OF ALUMINUM PROPELLER

In this harmonic analysis for aluminum propeller, Amplitude vs. frequency graphs is plotted. It is observed that resonance occurs in the frequency range of 400 Hz in UX direction, was found same in other two directions as shown in figures 22-24.

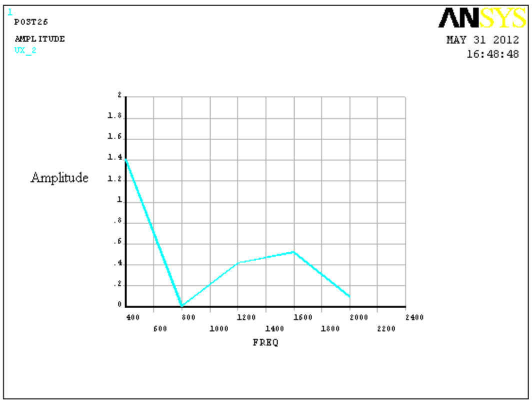

Fig22: amp-freq graph of aluminum propeller in Ux Direction

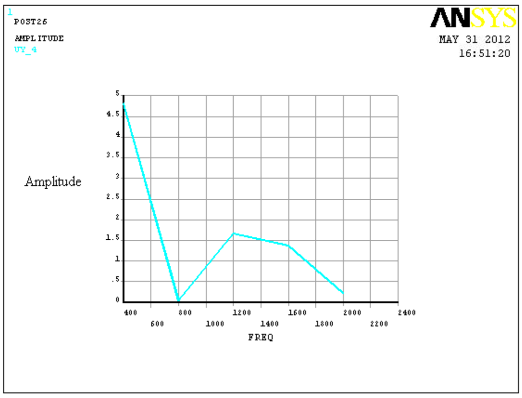

Fig23: amp-freq graph of aluminum propeller in Uy Direction

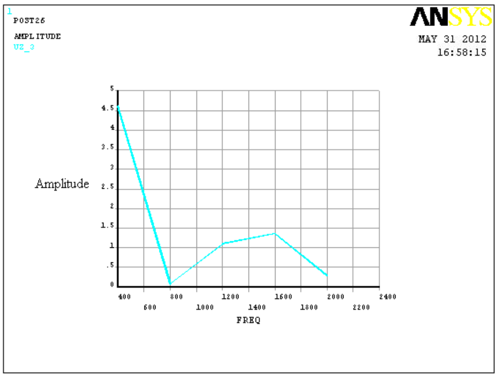

Fig24: amp-freq graph of aluminum propeller in Uz Direction

HARMONIC ANALYSIS OF COMPOSITE PROPELLER
16 Layers

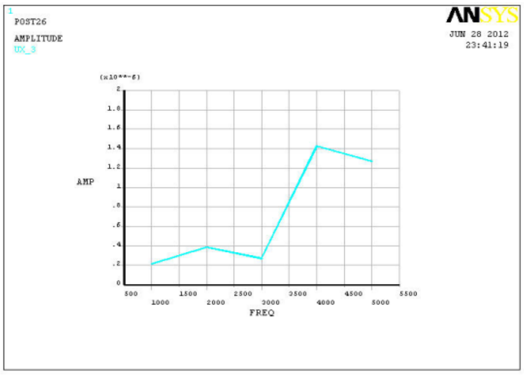

Fig25: amp-freq graph of Composite propeller in Ux Direction

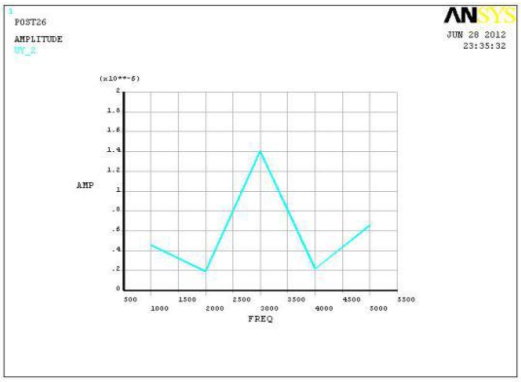

Fig26: amp-freq graph of Composite propeller in Uy direction

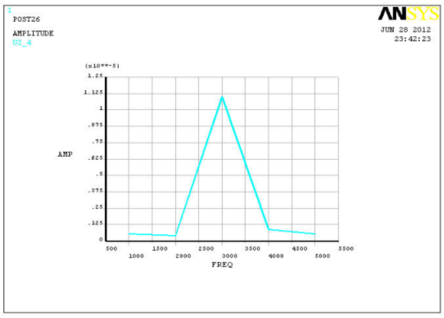

Fig27: amp-freq graph of Composite propeller in Uz Direction.

4 Layers

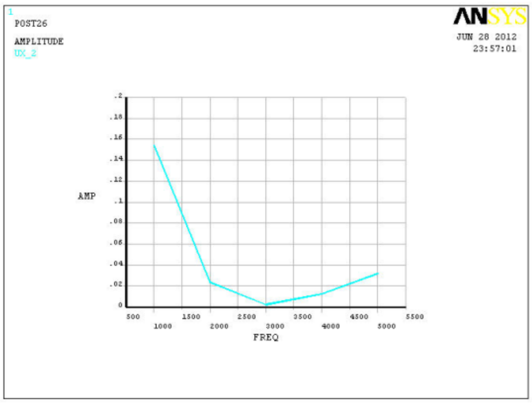

Fig28: amp-freq graph of Composite propeller in Ux Direction

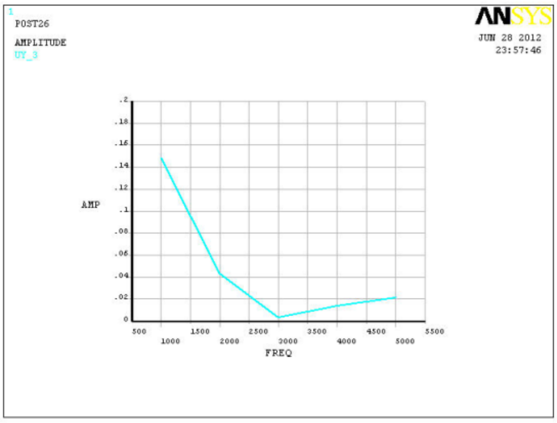

Fig29: amp-freq graph of Composite propeller in Uy Direction

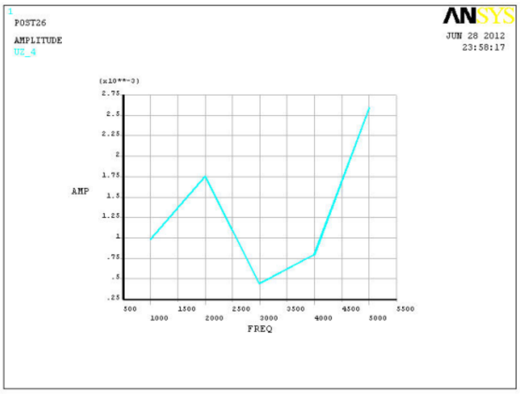

Fig30: amp-freq graph of Composite propeller in Uz direction

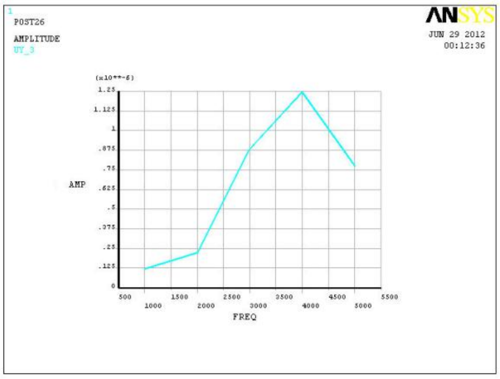

Fig32: amp-freq graph of Composite propeller in Uy Direction

IX. CONCLUSIONS

The deflection for composite propeller blade was found to be around 0.5mm for all layers which is much less than that of aluminum propeller i.e 6.883mm, which shows composite materials is much stiffer than aluminum propeller.Interlaminar shear stresses were calculated for composite propeller by incorporating different number of layers viz. 4,8,12,16 and was found that the percentage variation was about 3.147%,which shows that there is strong bonding between the layers and there's no peel-off. Eigen value analysis results showed that the natural frequencies of composite propeller were 80.5% more than aluminum propeller, which indicates that the operation range of frequency is higher for composite propeller. Harmonic analysis results for aluminum propeller shows that the resonance occurs in the frequency range of 400 Hz in Ux, Uy, Uz directions, so the propeller may be operated in frequency range other than 400Hz. Harmonic analysis results for composite propeller shows that the resonance occurs in the frequency range of 2000-2500Hz in Ux, 2500-3000 Uy, around 2000Hz in Uz directions, so the propeller may be operated in frequency range other than 2000-3000Hz.

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