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Dynamic Analysis of Propeller Shaft

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Abstract- At present fuel economy is one of the major challenge for any automotive industry. The use of composite materials for various components of automobile not only reduces overall weight of vehicle but also ensures required strength. Since weight of the vehicle is one of the major factor influencing the specific fuel consumption, in this study conventional metallic propeller shaft is replaced with various composite materials. Static and modal analysis of propeller shaft is done for E-glass/epoxy, carbon/epoxy, Steel and Titanium alloy in ANSYS APDL 16.0. Propeller shafts modeled with E-glass/epoxy, carbon/epoxy is also studied for different fiber angle orientations. Deflection, Von-misses stresses and natural frequency are generated for different materials and various fiber angles.
Keywords: Propeller shaft, composites, ANSYS APDL 16.0, Carbon epoxy composite.

I. INTRODUCTION

Propeller shaft is one of the important components in power transmission system. From earlier work in this area it has been concluded that in case of passenger cars propeller shaft should have torque transmission capacity greater than 3500 Nm and to prevent whirling vibrations fundamental bending natural frequency should be greater than 9200 rpm. Since fundamental bending natural frequency for propeller shaft made of steel with 1.5 m length is lower than 5700 rpm designers go for two piece steel shaft. But problem with two piece design is it requires three universal joints, bracket and center bearing which unnecessarily increases total weight and reduces fuel economy. Since carbon/E-glass fiber epoxy composite materials are excellent in terms of specific stiffness over conventional metals, it allows manufacturing of single piece shaft of required length without any whirling vibrations. Other benefits such as weight reduction, lower level of noise and vibration, improved fatigue life and corrosion resistance are also achieved[1].

Filament winding is the widely used procedure for fabricating propeller shafts made of composite materials, as it is less expensive and accurate in locating fibers[2].Mechanical joining, adhesive bonding and welding are various means used to join propeller shaft. Each of these having its own advantages and disadvantages such as adhesive bonding distributes total load over larger area and it don’t requires any kind of holes, making it superior and lighter. On the other hand it needs proper surface preparation which needs controlled environment and its dismantling is difficult. Mechanical joints are better in terms of making modifications but it adds more weight due to fasteners[3].

The other benefits of using composite propeller shafts includes its excellent vibration absorption capability and less wear of components of drive train. The main advantage of using polymer composites for the manufacturing of propeller shafts include its higher fatigue strength as micro cracks/voids developed cannot freely propagate and are terminated at the fibers which is not possible in case of metals. Also the composites are less prone to the stresses induced by the notches and the holes in comparison with metals[4].

In order to obtain optimum design with various factors like lateral natural frequency, Torsional vibrations a new factor of fiber angle orientation which corresponds to strength is considered. In present study an attempt has been made to find out the substitute for conventional steel material with composite materials for different fiber angles[5].

A. Modeling and analysis

Finite element analysis is used to find stresses, deflection, mode shapes, and etc.From static analysis deflection and von misses stresses can be calculated and natural frequency and mode shapes are found by modal analysis[6]. Following dimensions are taken to draw the model of propeller shaft.

Table 1: Design parameter

Sr. No.	Parameters	Dimension
1	Inner diameter	55mm
2	Length of the shaft	640mm
3	No. of plies	5
4	Thickness of ply	1mm

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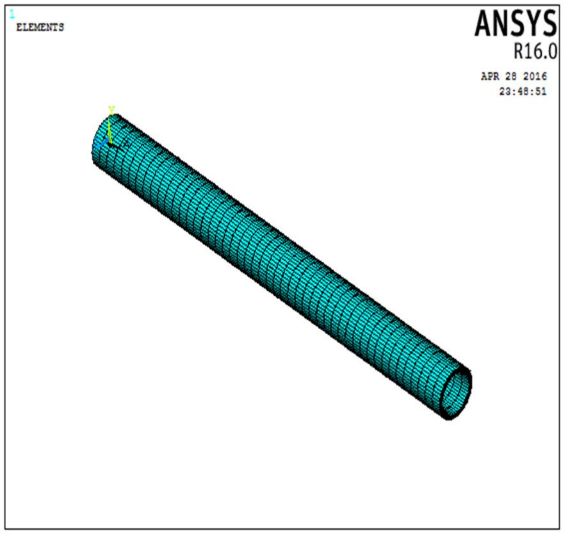

Fig.1: Meshed model of propeller shaft

Table 2: Material properties of E-Glass epoxy and HM-Carbon epoxy used for analysis[1]

Property	E-glass/epoxy	HM-carbon/epoxy
E11 (GPa)	48.3	133.4
E22 (GPa)	7.2	8.78
G12 (GPa)	2.78	3.25
ϑ12	0.25	0.26
σT1=σC1 (MPa)	880	890
σT2=σC2 (MPa)	38	43
τ12 (MPa)	86	42
ρ (kg/m3)	1915	1600
Vf (no unit)	0.55	0.6

Table 3: Material properties of Steel and titanium Used for analysis

Material	Steel	Titanium
Modulus of elasticity	210GPa	905MPa
Poisson ratio	0.3	0.3
Density	7850 Kg/m^3	4530 Kg/m^3

Table 2 And 3 shows the material properties used for analysis

Shell element is used for analysis purpose. This element has six degrees of freedom and 8 nodes, each node has 3 translation and 3 rotational degree of freedom. This element is used for layered applications for modeling of composite materials. Different orientation of fiber angles is shown in fig. 2 and 3

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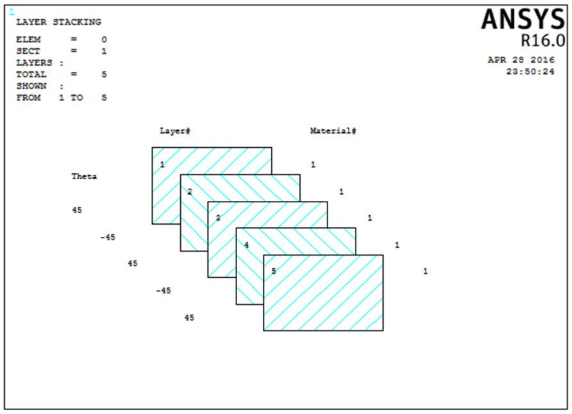

Fig 2 Fiber angle orientation 45,-45, 45,-45, 45

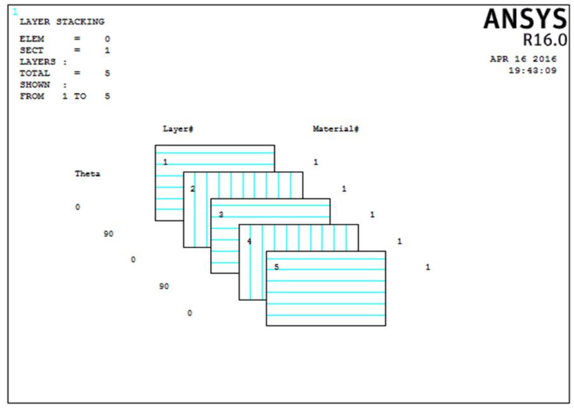

Fig 3 Fiber angle orientation 0,90,0,90,0

B. Static analysis

The boundary conditions used to perform the static analysis are:

1) Propeller shaft is fixed at one end and

2) Torque of 275Nm is applied on the other end.

The analysis of Propeller shaft for above boundary conditions for different materials and different fiber angle orientations were performed on ANSYS APDL 16.0 and Results were plotted as follows:

Table 4: Von misses stresses and Deflection obtained for E-glass/epoxy and HM-carbon/epoxy

Fiber angle orientation	E-glass/epoxy		HM-carbon/epoxy	
	SMX(MPa)	DMX(mm)	SMX(MPa)	DMX(mm)
0-90-0-90-0	439	18.32	554	18.2
30-45-30-45-30	793	5.25	1170	4.32
45-(-45)-45-(-45)-45	780	2.77	941	2.29

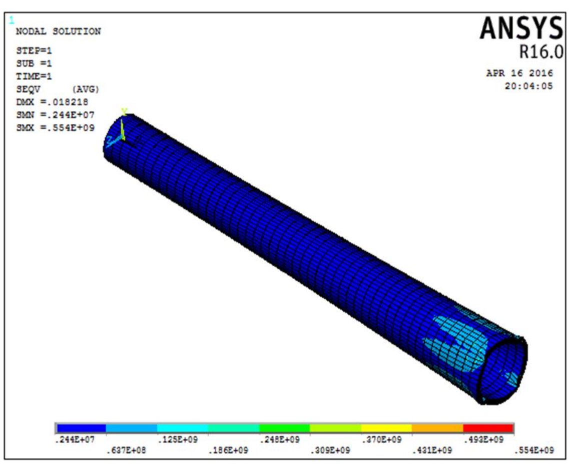

Fig.4: Nodal solution of HM carbon epoxy for 0, 90 fiber angle orientations

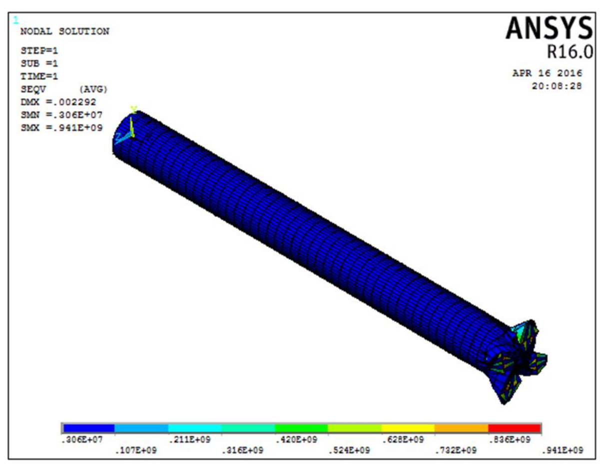

Fig.5: Nodal solution of HM carbon epoxy for 45,-45 fibre angle orientation

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Table 5: Von misses stresses and Deflection obtained for steel and titanium alloys

Materials	SMX (MPa)	DMX (mm)	Density (kg/m^3)	Weight (Kg)
Steel	318	0.217	7850	4.73
Titanium alloy	271	46.68	4530	2.73

Weight of E-glass/epoxy is 1.15 Kg whereas that of HM-carbon/epoxy is 0.96 Kg.

C. *Modal analysis*

Any system occurring in the universe has a property of vibrating. The frequency at which natural vibration occurs can be determined by using the mode shapes. This mode shapes can be determined analytically using the modal analysis.

Modal Analysis is a field of science which mainly deals with the study of the structures or components dynamic properties during the vibration excitation. It is mainly done in order to determine the natural frequency of the syatem which helps in determining the speed at which component can satisfactorily work without compromising with the stability of the vehicle.

In modal analysis coarse mesh can be used because stresses are not taken into consideration. Natural frequency and different mode shapes are found by modal analysis. Natural frequency is a function of stiffness and mass. Fiber angle orientation affects natural frequency of system. For modal analysis one end of shaft is fixed[7].

Table 6: Natural frequency of propeller shaft for different material and fiber angle orientation

Mode	E-glass/epoxy		Carbon epoxy		Titanium alloy
	45,-45	30,45	45,-45	30,45	
1	35.37	48.34	39.72	69.77	11.79
2	35.37	48.34	39.72	69.77	11.79
3	219.87	294.51	248.21	423.49	69.07
4	219.87	294.51	248.21	423.49	69.07
5	517.55	501.8	583.71	673.37	108.28
6	611.71	788.39	696.66	915.26	174.76
7	611.71	788.39	696.66	915.26	177
8	996.55	906.05	1058.5	938.07	177
9	996.55	906.05	1058.5	938.07	312.67
10	1011.3	948.53	1080.9	1021.1	312.67

Following figure shows mode shape for propeller shaft for material HM-carbon epoxy with fiber angle orientation 30-45

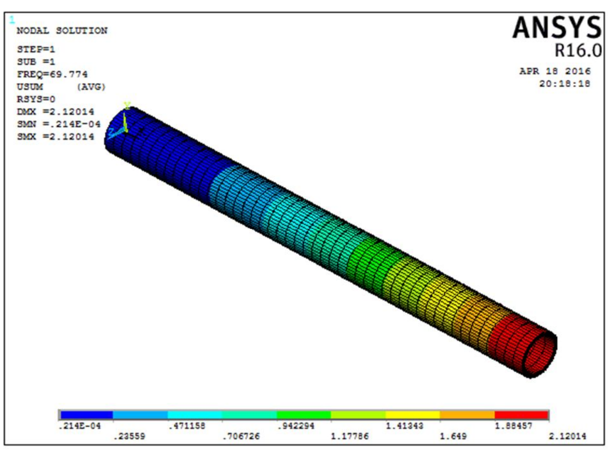

Fig.6: Mode shape at frequency 69.77 Hz

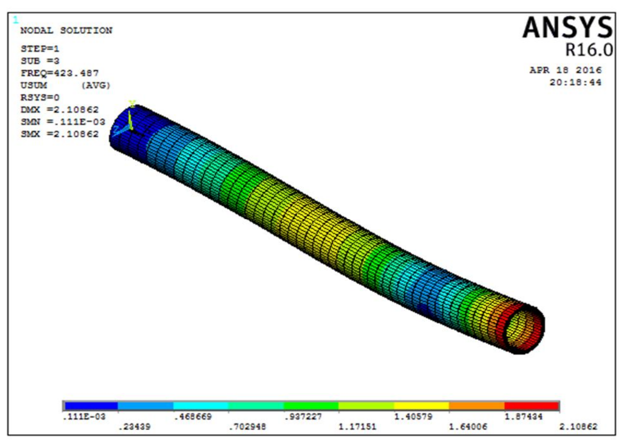

Fig.7: Mode shape at frequency 423.48 Hz

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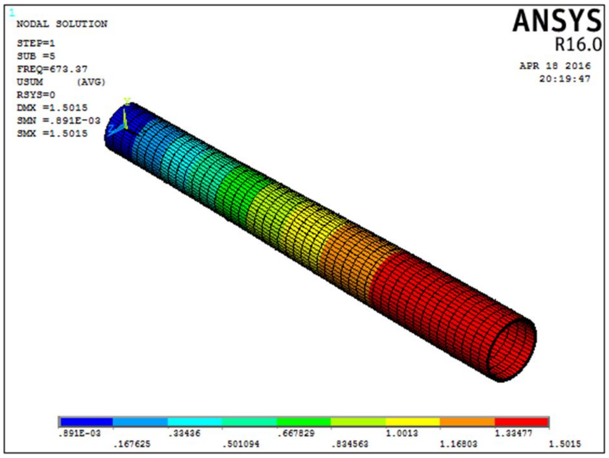

Fig.8: Mode shape at frequency 673.37Hz

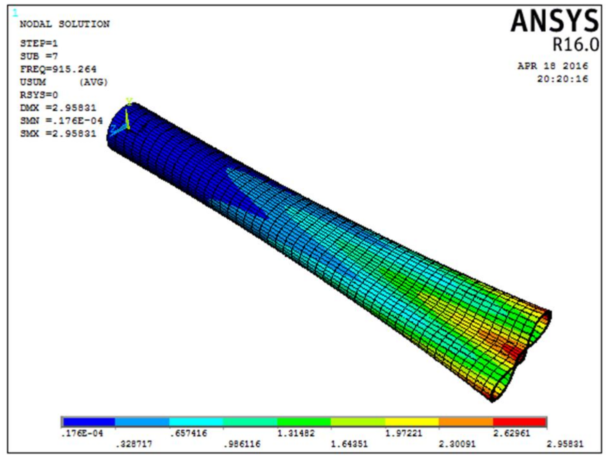

Fig.9: Mode shape at frequency 915.26 Hz

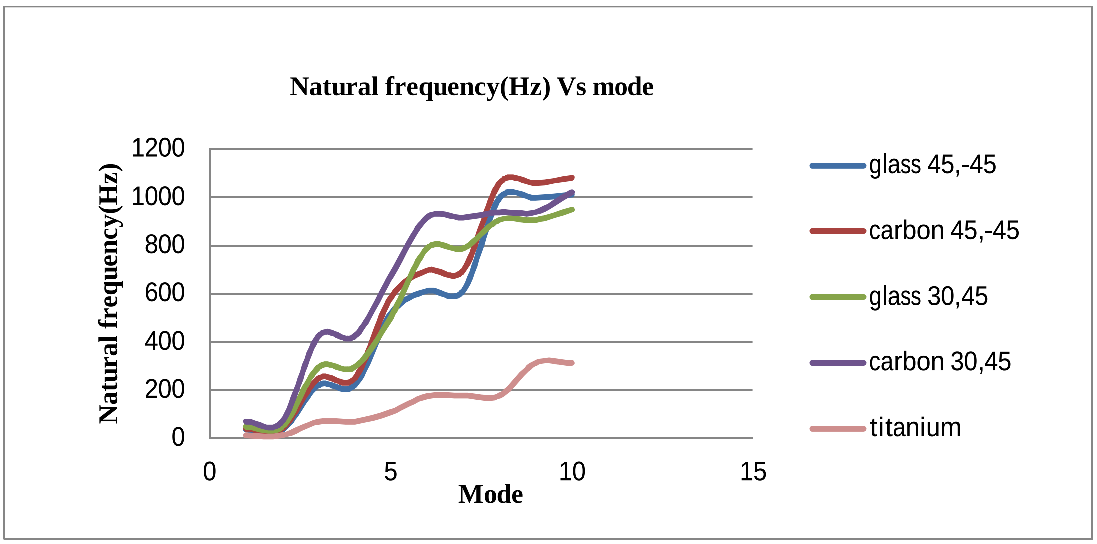

Fig.10: Comparison of natural frequency for different materials

Fig.10 shows variation of natural frequency for different materials and fiber angle orientations. It depicts that natural frequency for HM-carbon epoxy material with fiber angle orientation 30-45 has highest natural frequency. Higher the natural frequency leads to higher stiffness with lower weight. As natural frequency of titanium is significantly lower than those composites, composites are superior over titanium.

II. CONCLUSION

Propeller shaft made of steel shows lowest deflection among other materials but it is heavier than other materials. HM-carbon epoxy composite shaft is lighter than E glass epoxy. Steel is nearly four times heavier than these composite materials. As a result if we replace the Steel propeller shafts by HM-Carbon epoxy shafts even though its deflection increases to a small extent but it gives a large variation in the weight which ultimately helps in reducing the overall weight of the vehicle.

For same boundary and loading conditions carbon epoxy composite shows minimum defection and maximum stress for fiber angle orientation 45-(-45)-45-(-45)-45.

Natural frequency for HM-carbon epoxy material with fiber angle orientation 30-45-30-45-30 has highest natural frequency.

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