Modal Analysis & Eigen Value Analysis of Multilayered Composite Drive Shaft Using ANSYS

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Abstract. This paper examines the effect of fiber orientation angles on the natural frequency and buckling strength composite drive shaft (CDS). Finite element analysis (FEA) has been used to predict the mode shapes to obtain the natural frequency of CDS using modal analysis for different fiber angles of carbon and glass fiber. FEA results showed that the natural frequency increases with decreasing fiber orientation angles. The CDS has a reduction equal to 51.7% of its frequency when the orientation angle of carbon fibers at one layer, among other three glass ones, transformed from 0˚ to 90˚. On the other hand, the critical buckling torque has a peak value at 90˚

Keywords – Composite Drive Shaft, Fiber Angle, Natural Frequency, Buckling Torque

I. INTRODUCTION

The drive shaft is an inseparable part of any automobile having front engine and rare wheel drive system. The torque that is produced from the engine and transmission must be transferred to the rear wheels to push the vehicle forward and reverse. The drive shaft must provide a smooth, uninterrupted flow of power to the axles. The drive shaft and differential are used to transfer this torque. The general layout of an automobile drive shaft is shown in the Figure 1.

A. Requirements of an automobile drive shaft-

The drive shaft must operate through constantly changing angles between the transmission, the differential and the axles. As the rear wheels roll over bumps in the road, the differential and axles move up and down. This movement changes the angle between the transmission and the differential.

The length of the drive shaft must also be capable of changing while transmitting torque. Length changes are caused by axle movement due to torque reaction, road deflections, braking loads and so on. A slip joint is used to compensate for this motion in conventional drive shaft. The slip joint is usually made of an internal and external spline. It is located on the front end of the drive shaft and is connected to the transmission.

B. Merits of composites

They have high specific modulus, strength, reduced weight, high damping capacity, good corrosion resistance.

The fundamental natural frequency of the carbon fiber composite drive shaft can be twice as high as that of steel or aluminium because the carbon fiber composite material has more than 4 times the specific stiffness of steel or aluminium, which makes it possible to manufacture the drive shaft of passenger cars in one piece. A one-piece composite shaft can be manufactured so as to satisfy the vibration requirements. This eliminates all the assembly, connecting the two piece steel shafts and thus minimizes the overall weight, vibrations and the total cost.

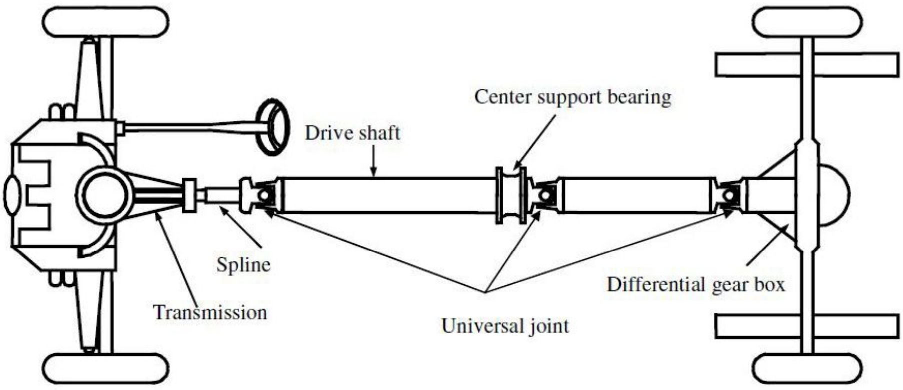


Figure 1. Conventional Two Piece Steel Drive Shaft

II. DESCRIPTION OF THE PROBLEM

Owing to the advantages noted down from literature available like excellent vibration damping, reduction in wear, increase in traction, reduction in assembling time, reduction in part complexity and so on; the use of composites in drive shafts can be further made more effective by making proper combinations of materials. One more advantage that can be extracted with the use of composites is that the cracks terminate at holes of fibers unlike metals where cracks lead to complete fracture of the component. Thus notches and holes are less dangerous in case of composites. The following design variables are considered in this work:

- ✓ Base material
- ✓ Composite materials
- ✓ Fiber orientation

III. DESIGN OF COMPOSITE DRIVE SHAFT

The design of CDS targets at the following functional requirements

- ✓ Maximum buckling torque
- ✓ Maximum critical speed (natural frequency)
- ✓ Maximum load carrying capacity

In the analysis carried out the requirements of maximum buckling torque and maximum natural frequency are considered. The requirement of maximum load carrying capacity is considered for future work.

IV. FEA OF COMPOSITE SHAFT

In this work the analysis is done with the help of the finite element solver, ANSYS. The basic step in using such solvers is to go for preprocessing. In preprocessing a finite element model of the component is generated with mesh of the component and the mesh is provided with all the necessary attributes of the components. The preprocessing starts with selecting the element type. SHELL281 is suitable for analyzing thin to moderately-thick shell structures. It is an 8-node element with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z-axes. (When using the membrane option, the element has translational degrees of freedom only.) For better accuracy, ANSYS recommends quadrilateral shaped elements. Use degenerate triangular shapes sparingly. SHELL281 is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses. The element accounts for follower (load stiffness) effects of distributed pressures. SHELL281 may be used for layered applications for modeling laminated composite shells or sandwich construction.

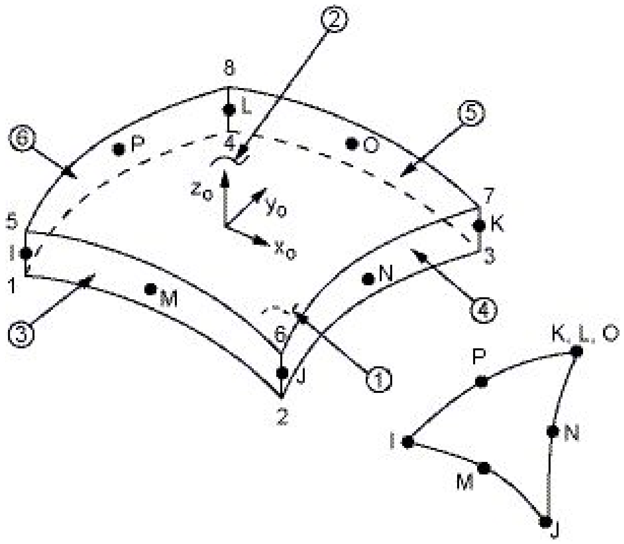


Figure 2. SHELL 281 Description

V. MODAL ANALYSIS OF DRIVE SHAFT IN ANSYS

The simulation to study the effect of carbon fiber orientation on the natural frequency of the drive shaft was carried out with angles varying from 0˚ to 90˚. The combination considered was three layers of glass fiber and one layer of carbon fiber. The minimum number of carbon was considered so as to keep the cost minimum. Figure 3 shows the geometric model of a 1.73m long drive shaft with mean diameter of 100 mm. The first two layers of the Glass fiber are kept at constant orientation of ±45˚. The fiber angle of the third layer i.e. of carbon fiber is varied from 0˚ to 90˚ and the modal analysis is carried out. Figure 4 shows the fiber orientation and stacking sequence represented as [+45˚glass/-45˚glass/90˚carbon/0˚glass]. Figure 5 shows the boundary conditions applied for the modal analysis. The mode shapes obtained for the combination of [+45˚glass/-45˚glass/0˚carbon/90˚glass] are shown in figure 6. The results obtained for the various combinations are compiled in table 1 and the graph indicating the effect of varying the carbon fiber orientation in the third layer is shown in figure 7.

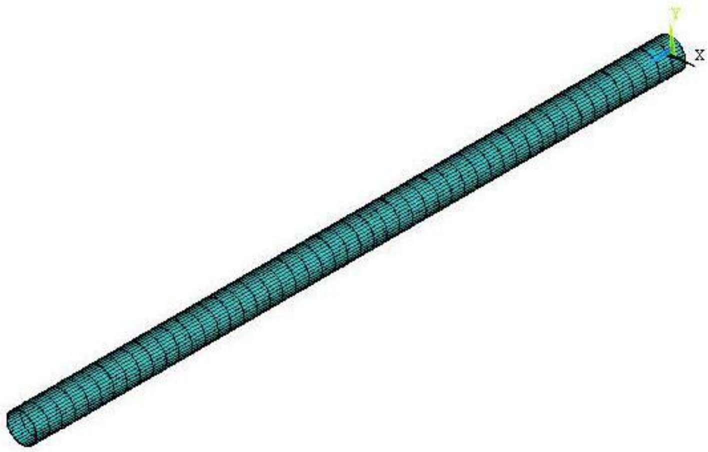


Figure 3. Geometric Model of the Drive Shaft

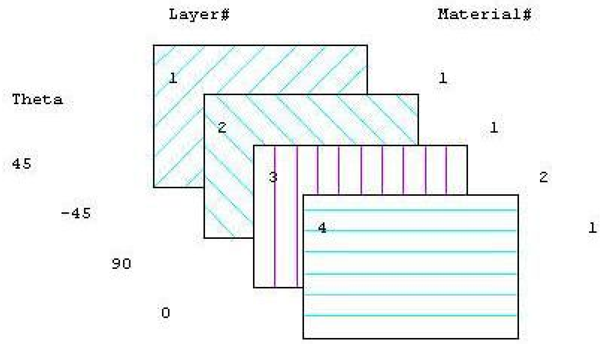


Figure 4. Layered Elements for the combination of [+45˚glass/-45˚glass/90˚carbon/0˚glass]

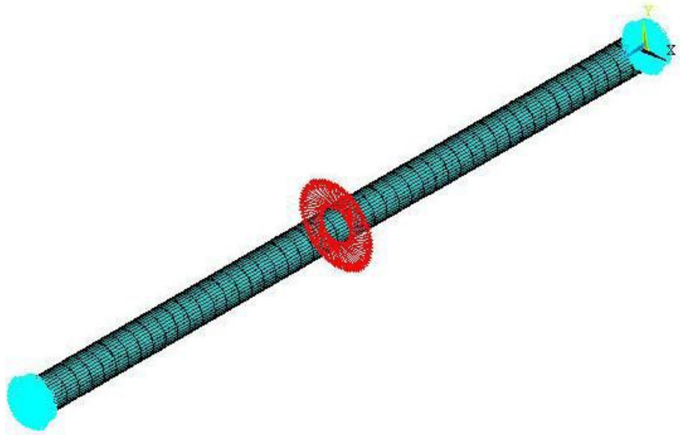
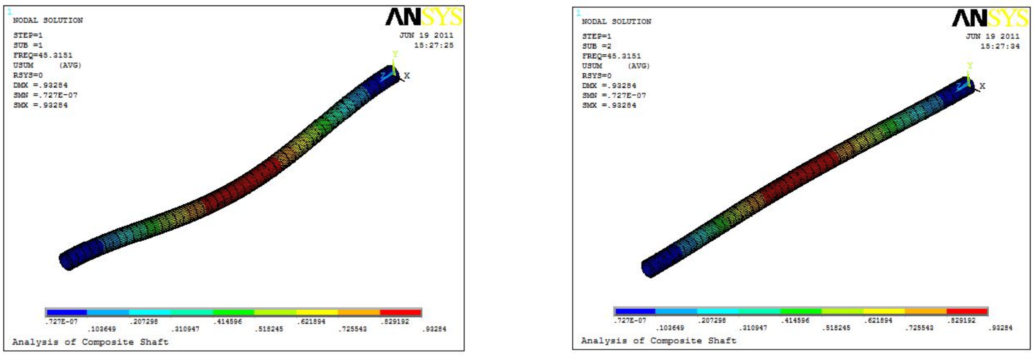


Figure 5. Boundary Conditions for Modal Analysis



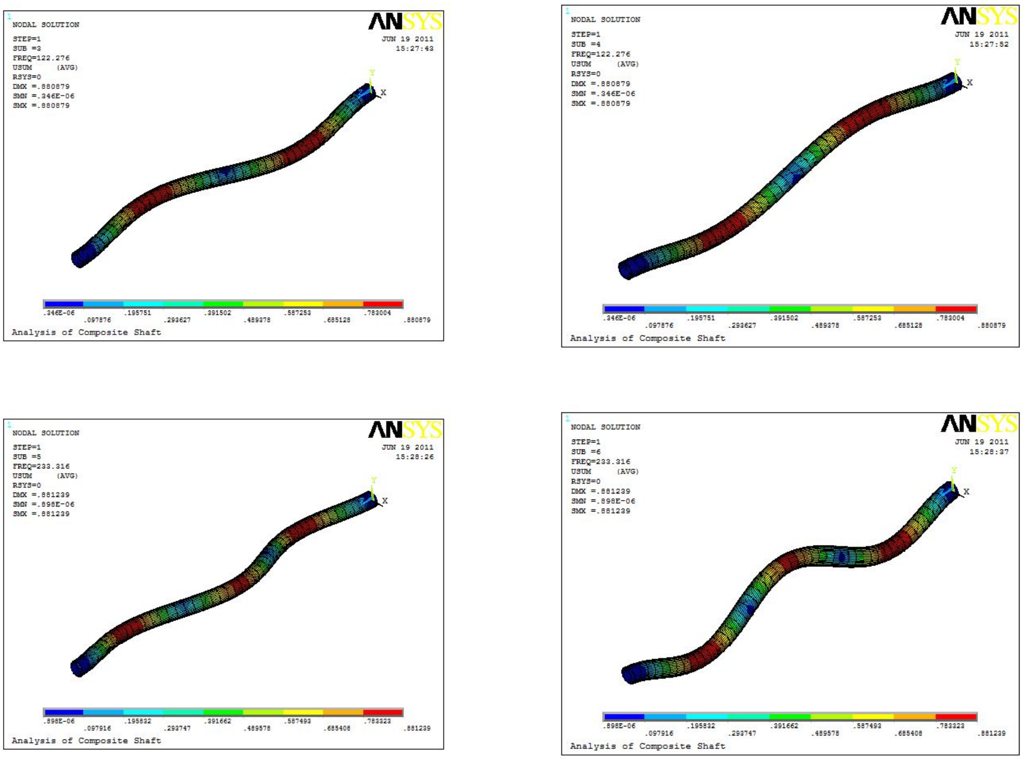


Figure 6. Mode Shape Results for [+45˚glass/-45˚glass/0˚carbon/90˚glass].

Table-1 Effect of Carbon Fiber Angle on Natural Frequency of Drive Shaft

Carbon Fiber Angle (Degrees)	**0**	**5**	**20**	**30**	**45**	**65**	**70**	**75**	**85**	**90**
Natural Frequency (Hz)	**93.94**	**92.24**	**74.84**	**63.37**	**52.44**	**46.34**	**45.79**	**45.49**	**45.32**	**45.32**

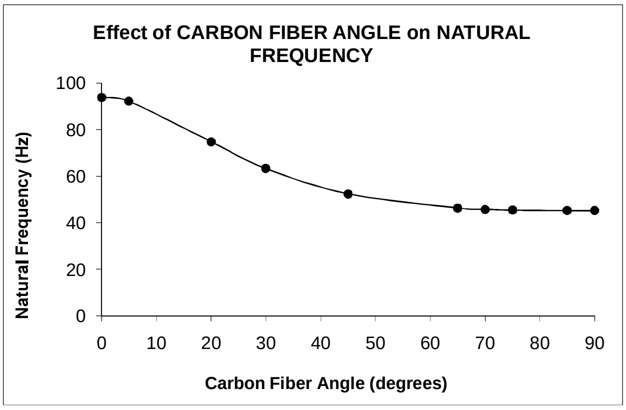


Figure 7. Effect of Carbon Fiber Angle on Natural Frequency of Drive Shaft

In the next simulation orientation of first two layers of the Glass fiber are varied from 0˚ to 45˚ keeping the third layer orientation of carbon fiber constant at 0˚ and fourth layer orientation of glass fiber at 90˚. The modal analysis to study the effect of variation on natural frequency is carried out. Table 2 shows the results for the simulation and figure 8 represents the graphical summary of the same.

Table-2 Effect of Glass Fiber Angle on Natural Frequency of Drive Shaft

GLASS FIBER ANGLE (Degrees)	0	5	10	15	20	25	30	35	40	45
Natural Frequency (Hz)	94.97	94.93	94.80	94.54	94.12	93.54	92.81	91.98	91.10	90.25

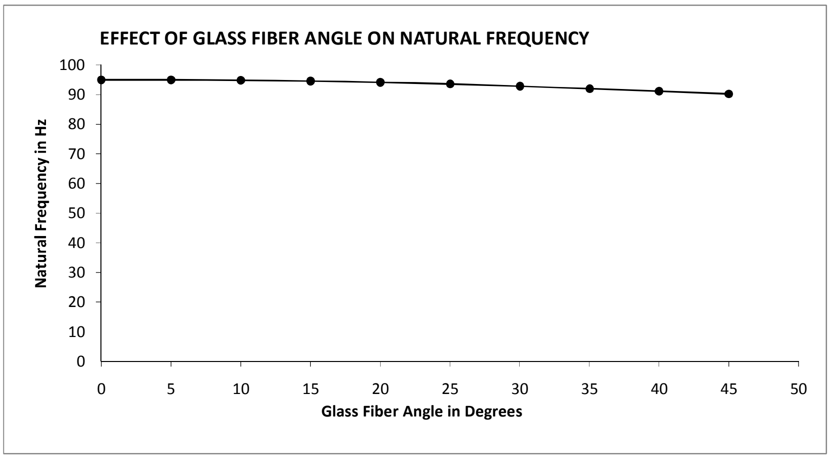


Figure 8. Effect of Glass Fiber Angle on Natural Frequency of Drive Shaft

VI. BUCKLING ANALYSIS OF DRIVE SHAFT IN ANSYS

The Eigen value analysis to study the effect of glass fiber orientation on the buckling torque of the drive shaft was carried out in ANSYS. The boundary conditions are shown in figure 9. Here, the third layer of carbon fiber was kept at 0˚ and fourth layer of glass fiber was kept at 90˚ throughout the iterations. The first two layers of glass fiber were varied with respect to fiber orientations. Figure 10 shows the result obtained for the combination of [15˚ glass /-15˚ glass /0˚ carbon /90˚ glass]. Table 3 indicates the similar results obtained for variation of first two glass fiber layers with respect to orientation of 0˚ to 90˚. Figure 11 represents the graphical plot of the same.

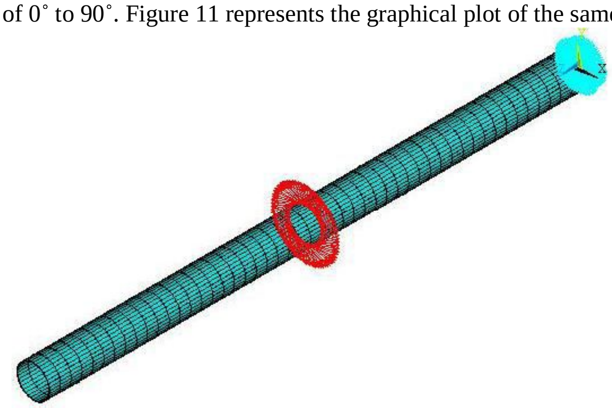


Figure 9. Boundary Conditions for Buckling Torque Analysis

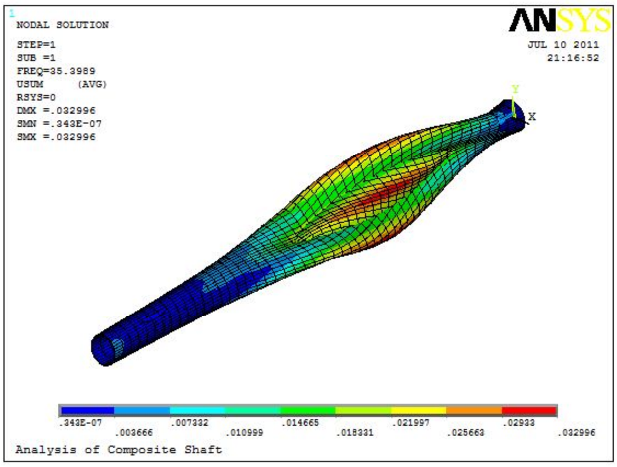


Figure 10. Nodal Solution for Buckling Torque Analysis of [15˚ glass /-15˚ glass /0˚ carbon /90˚ glass] combination

Table-3 Effect of Glass Fiber Angle on Buckling Torque of Drive Shaft

Glass Fiber Angle (Degrees)	**5**	**15**	**25**	**35**	**45**	**55**	**65**	**70**	**80**	**90**
Buckling Torque (Nm)	**1747.5**	**1793.8**	**1962.9**	**2143.3**	**2253.7**	**2573.9**	**2693.5**	**2769.8**	**2837.3**	**2847.2**

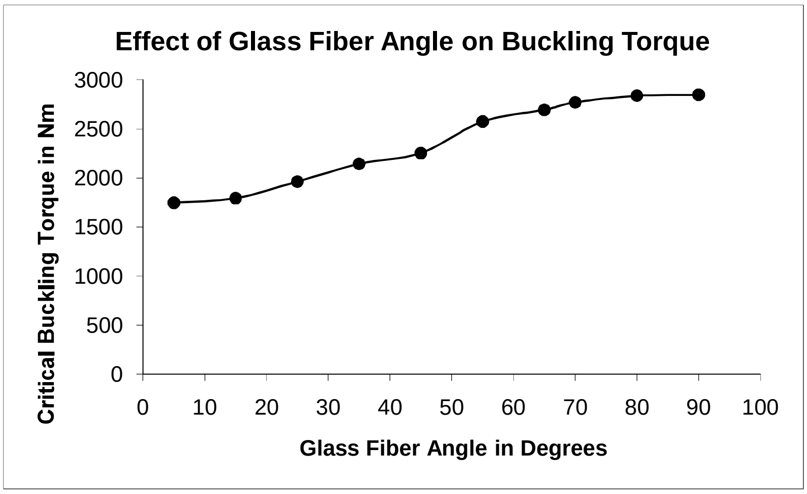


Figure 11. Effect of Glass Fiber Angle on Buckling Torque of Drive Shaft

VII. CONCLUSION

The structure consisting of four Layers stacked as [+45˚glass/-45˚glass/0˚carbon/90˚glass] shows that fibers must be oriented at 0˚ to increase the natural frequency by increasing the modulus of elasticity in longitudinal direction of the shaft. The drive shaft loses 51.7% of its natural frequency when the carbon fibers are oriented at 90˚ instead of 0˚. A linear Eigen value buckling analysis conducted to estimate the maximum torque that can be supported prior to losing stability. In this analysis, the specified load must be closer to the collapse load in order to obtain accurate results. The output from the analysis is a factor and this factor multiplied by the actual magnitude of the applied load to obtain the critical torque. The best fiber orientation angle for maximum buckling strength is 90˚. At this angle the fibers oriented in the hoop direction and therefore the modulus increased. The fiber orientation angles of only two glass/epoxy layers on the buckling torque is shown.

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