Design and Analysis of Solid Composite Propeller Shaft

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Abstract: ***Propeller shaft is an important component in power transmission of an automobile. Conventional steel drive shafts have limitations of weight and low critical speed. To get the maximum efficiency for power transmission, weight reduction of the drive shaft is most important. Few researchers suggested the optimum stacking sequence & fiber orientation angles of the composite layer for manufacturing of composite shaft, which results in reduction of mass and increase in torque transmission capacity. The focus of this work is to study the effect of glass fiber on the properties of the composite formed by making a solid composite propeller shaft as the cost also impact on acceptance of the materials. This work represents the replacement of two piece conventional metallic propeller shaft with the single piece solid composite propeller shaft. Initially, design of shaft is done concentrating on natural frequency, buckling torque, and shear stress. Manufacturing of the composite propeller shaft is made by using composite of glass fiber & epoxy resin. Experimental testing is carried out on scaled model to find the torsion behavior & natural frequency of composite propeller shaft. Static analysis and dynamic analysis is done by using Ansys software. Analytical results of natural frequency are compared with the results of modal analysis on Ansys & FFT analyzer.***

Keywords - Composite material; Glass Fiber; Epoxy resin; FFT analyser; Torsion Testing Machine.

I. INTRODUCTION

Basically composite material is a combination of two or more number of materials. History of advance composites begin in 1970s in aerospace industries, but now a days after only four decades, it is developed in most of the industries. There is possibility that increase in composite material characteristics using the latest technology and various manufacturing methods have raised its application range. Along with progress in technology, metallic parts are replaced by composite materials in various industries. A Propeller shaft is the connection between the transmission and the rear axle of the vehicle. The entire driveline of the car is composed of several components, each with rotating mass. The two-piece steel drive shaft consists of three universal joints, a center supporting bearing and a bracket, which increases the total weight of an automotive vehicle and decreases fuel efficiency. The power is lost because it takes more energy to spin heavier parts.

This energy loss can be reduced by decreasing the amount of rotating mass. A one-piece composite shaft can be manufactured so as to reduce the weight & satisfy the vibration requirements. Lower rotating weight transmits more of available power. This eliminates all the assembly, connecting the two piece steel shafts and thus minimizes the overall weight, vibrations and the total cost. Due to the weight reduction, fuel consumption will be reduced. According to survey it is found that around 17-22% of total energy developed by the engine is lost due to weight of the vehicle. Due to this reason many researches are going on to reduce the weight of the vehicle by using light weight parts such as coupling, chassis, shaft with holes & composite materials parts.

This work is also related with the same concept to reduce the weight of the vehicle with the application of the lightweight materials such as glass fiber and Epoxy resin. Composite materials have high damping capacity and hence they produce less vibration and noise with the ability of good corrosion resistance. Composite structures have longer fatigue life than steel or aluminum shaft. Composite materials can be tailored to efficiently meet the design requirements of strength, stiffness and composite propeller shafts weight less than steel or aluminum. The focus of the work will be to reduce the weight of the propeller shaft by considering various constraints such as cost, torque transmission capacity, speed of rotation and space available i.e. diameter of shaft. According to previous researches many have done the various experiments to reduce the weight by changing the ply thickness, fiber orientation angle, number of plies but until now no one has studied the effect of glass fiber on the properties of the composite formed as the cost also impact on acceptance of the materials so the main aim of this work to minimize the cost and weight with the given working constraints.

II. PROBLEM STATEMENT

Almost all automobiles (at least those which correspond to design with rear wheel drive and front engine installation) have transmission shafts. The two-piece steel propeller shaft consists of three universal joints, a center supporting bearing and a bracket, which increases the total weight of an automotive vehicle and decreases fuel efficiency. The power is lost because it takes more energy to spin heavier parts. This energy loss can be reduced by decreasing the amount of rotating mass. The weight reduction of the shaft can have a certain role in the general weight reduction of the vehicle and is a highly desirable goal, if it can be achieve without increase in cost and decrease in quality and reliability. It is possible to achieve design of composite drive shaft with less weight to increase the first natural frequency of the shaft and to decrease the bending stresses. By doing the same, maximize the torque transmission and torsional buckling capabilities.

III. DESIGN OF CONVENTIONL STEEL PROPELLER SHAFT

The steel Propeller shaft should satisfy three design specifications such as torque transmission capability, buckling torque capability and bending natural frequency. The Propeller shaft outer diameter should not exceed 100 mm due to space limitations. Here the specifications of Mahindra Load King are considered for study having outer diameter of 72 mm.

Table No.1: Properties of Steel.

Mechanical Properties	Symbol	Units	Steel
Young's Modulus	E	GPa	207
Shear Modulus	G	Gpa	80

Poisson's Ratio	M	-	0.3
Density	P	Kg/m^3	7860
Yield Strength	Sy	MPa	370

Table No.2: Analytical Result for Steel Propeller Shaft.

Parameter of Shaft	Symbol	Units	Value
Outer Diameter	D0	mm	72
Inner Diameter	Di	mm	65.56
Length Of the Shaft	L	mm	1426
Thickness of the Shaft	t	mm	3.22
Applied Torque	T	N-m	1260
Di/D0	C	-	0.91
Torsional Buckling	Tb	N-m	35862.13
Natural Frequency	Fn	Hz	278.9
Critical Speed	N_{cr}	rpm	16494.6
Mass	m	Kg	7.5

IV. DESIGN OF COMPOSITE PROPELLER SHAFT

The specification of Composite propeller shaft for an automobile is same as of steel drive shaft. The high strength and high modulus Carbon/Epoxy materials are selected for composite propeller shaft. A glass fiber is a long, thin strand of material about 0.0002-0.0004 in (0.005-0.010 mm) in diameter and composed mostly of glass atoms. The crystal alignment makes the fiber incredibly strong for its size. Epoxy resin LY556 having low viscosity and high flexibility. The reactivity may easily be adjusted to demands through the combination of both hardeners. The long pot life of U972 facilitates the production of very large industrial parts. Glass fiber and matrix is used in this case is in the proportion of 70:30 volume fractions.

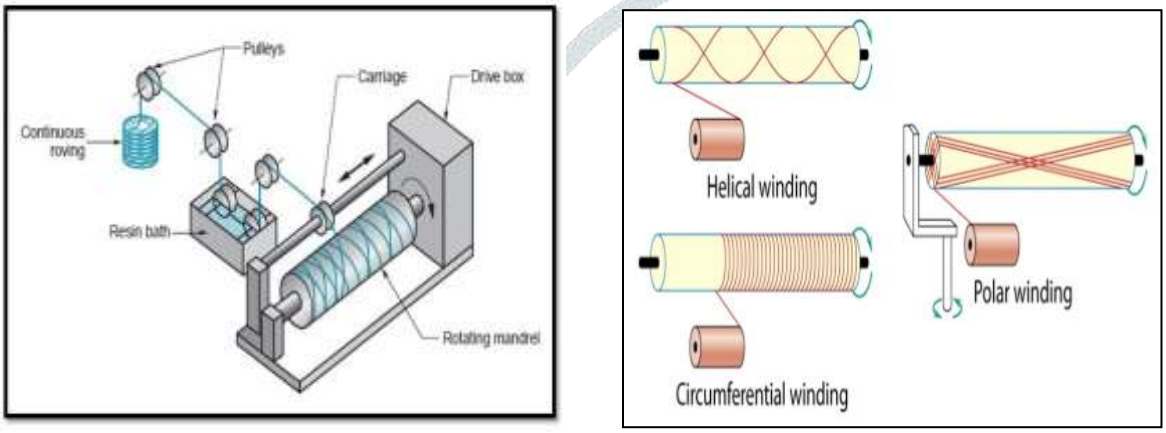
Table 3 Analytical results For Composite Propeller shaft

Parameter of Shaft	Symbol	Units	Value
Outer Diameter	D0	mm	60
Length Of the Shaft	L	mm	1426
Applied Torque	T	N-m	1260
Torsional Buckling	Tb	N-m	35862.13
Critical Speed	N_{cr}	rpm	14651.4
Mass	m	Kg	5.6

V. MANUFACTURING METHODOLOGY

Filament winding method is used for manufacturing of composite tube, because of its good advantages, such as it is a highly automated process, with typically low manufacturing costs, fiber orientation is controlled by the transverse speed of the fiber winding head, and the rotational speed of the mandrel and this process is that by controlling the winding tension on the fibers, they can be packed together very tightly to produce high fiber volume fractions.

The mandrel is fitted on to the cnc machine for filament winding where the mandrel rotates while a carriage moves horizontally, laying down fibers in the desired pattern. The filament used is glass fiber and are coated with synthetic resin LY556 as they are wound. The mandrel is completely covered with desired thickness as shown in figure 1.



(a) (b)

Fig.1. (a) (b) & (c) Filament Winding Process

VI. FINITE ELEMENT ANALYSIS

6.1 Static Analysis

A static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. A static analysis can however include steady inertia loads such as gravity, spinning and time varying loads. In static analysis loading and response conditions are assumed, that is the loads and the structure responses are assumed to vary slowly with respect to time.

6.2 Modal Analysis

Modal analysis is used to determine the vibration characteristics such as natural frequencies and mode shapes of a structure or a machine component while it is being designed. The natural frequency depends on the diameter of the shaft, thickness of the hollow shaft, specific stiffness and the length.

6.3 Boundary Conditions

The finite element model of composite shaft has one end is fixed and torque is applied at other end. The torque of 1260 N-m (for composite shaft and steel shaft) is applied at the other end which is free.

6.4 FEA Results

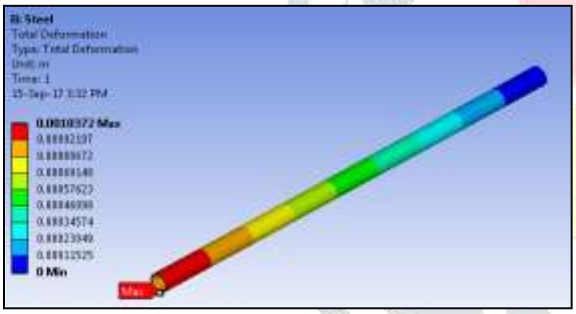


Fig.2-Total Deformation of Steel Shaft

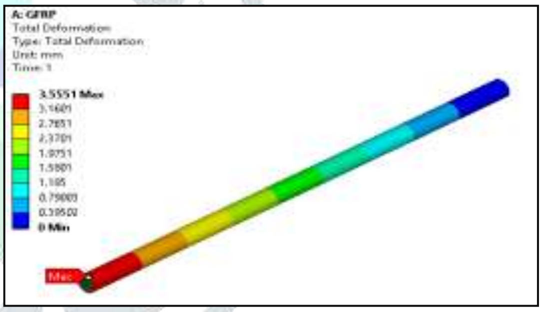
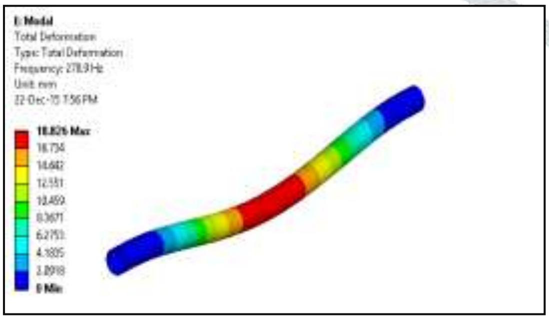


Fig.3-Total Deformation of GFRP Shaft



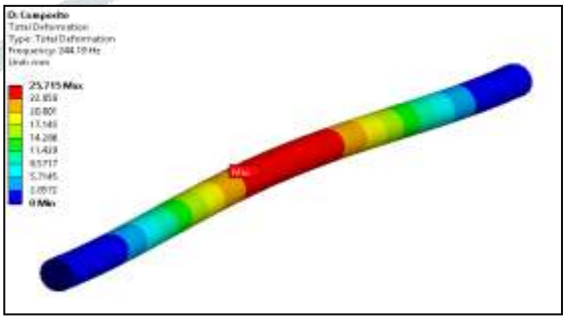


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Fig.3-Mode shape Plot for steel shaft.

Fig.4-Mode shape Plot for GFRP shaft.

VII. EXPERIMENTAL SET UP

7.1 FFT Analyzer Set-up

The FFT analyzer allows real-time, multi-channel FFT spectrum analysis, whether you want to perform mobility measurements, vibration diagnostics, or narrow-band analysis of acoustic signals. By using this experimental setup the fundamental natural frequency of composite propeller shaft is found.

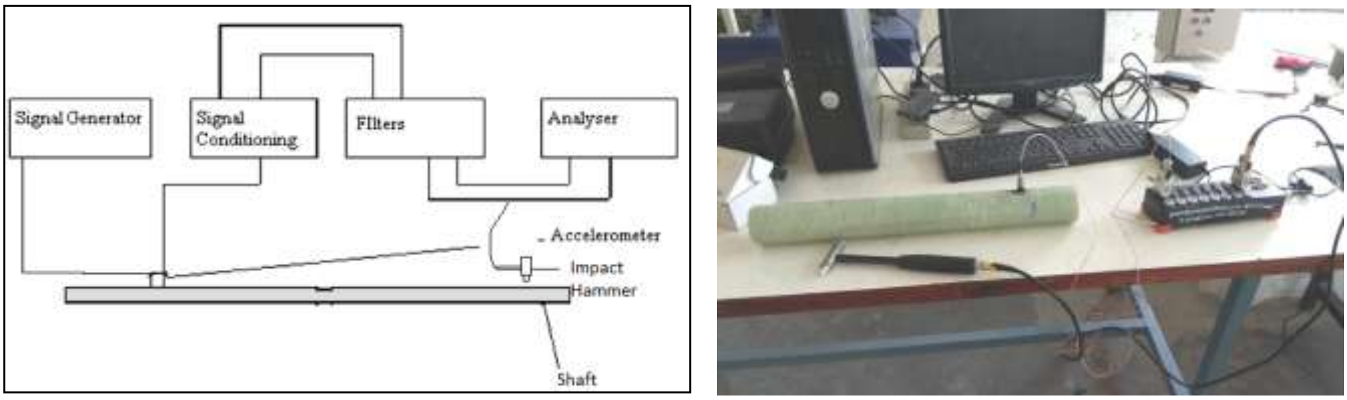


Fig. 5. FFT Analyzer experimental Setup

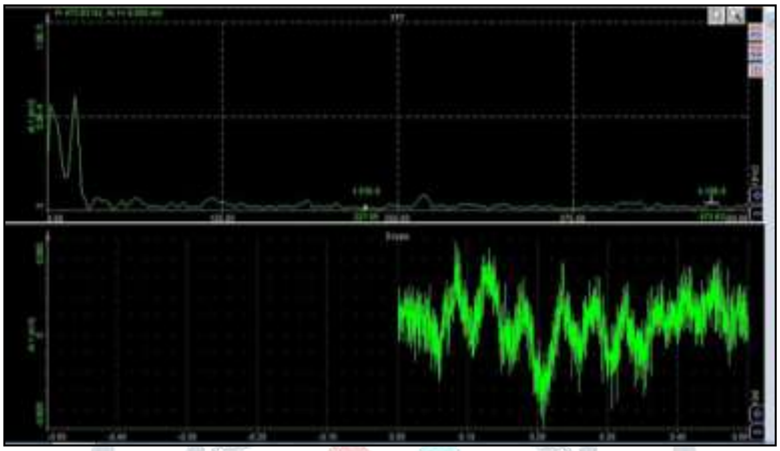


Fig. 6. FFT Analyzer Result

7.2 Experimental Procedure

1. Start the FFT analyzer.
2. Go to Run-up mode □ Set □ New set (Rename) □ OK.
3. Set the ranges of Force Amplitude, Frequency and Scale for Graphs.
4. A Force of amplitude measured by transducer in the hammer is applied on the bracket by the hammer which is provided with FFT analyzer and corresponding results (Natural frequencies) are obtained on FFT analyzer.

7.3 Procedure for determination of natural frequencies is as follows:

1. Select a peak value of vibration.
2. Check phase difference for that peak value, it is expected to be 180°. If this condition is satisfied then go for 3rd step and if not then select next pick and follow steps 1 and
3. Check coherence for that corresponding pick, it is expected to be one ideally (0.75 to 1 can also be chosen). If this condition is satisfied then corresponding peak will give first natural frequency and if not then select next peak and follow steps 1, 2 and 3 again. In this way we can get First natural frequencies by using FFT analyzer.

7.4 Torsion Test Set Up

Generally, torsion occurs when the twisting moment or torque is applied to a member. The torque is the product of tangential force multiplied by the radial distance from the twisting axis and measured in a unit of N-m. In torsion testing, relationship between applied torque and twisting angle is generally investigated.

Fig. 7. Torsion Testing Machine

7.5 Experimental Procedure

The first thing that was done in the lab was the measuring of the diameter of the specimen gage section using calipers, and to record that value for later calculations. After that, it was necessary to draw a straight longitudinal line on the specimen so that the angle of twist of the specimen can be observed during the test.

1. Measure initial diameter, initial length and initial gauge length of the specimen. Record these parameters on the table provided.
2. Draw a line using a permanent pen along the length of the test specimen. This line will help to notice the degree of rotation during applying the twisting moment.
3. Grip the test specimen on to the torsion testing machine using hexagonal sockets and make sure the specimens are firmly mounted. Fit both ends of the specimen to input and torque shafts and set reading on the torque meter to zero.
4. Start twisting the specimen at strain increment of 10 until failure occurs. Record the received data rotation in the table provided for the construction of torque and degree relationship.
5. Construct the relationship between shear stress and shear strain. Determine maximum shear stress, shear stress at proportional limit and modulus of rigidity.
6. Sketch fracture surfaces of failed specimens and described their natures in the table provided.

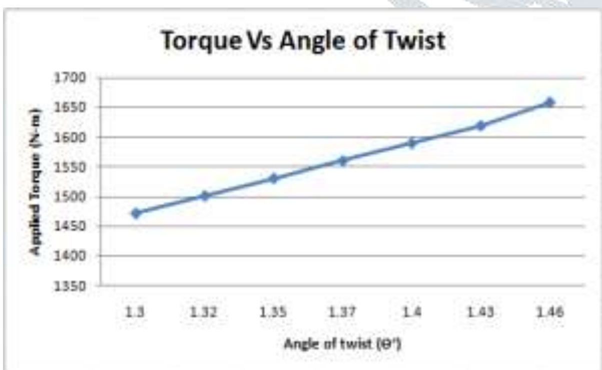
Discuss and conclude the obtained experimental results.

VIII. RESULTS AND DISCUSSION

The comparison is made between the analytical solutions of steel and composite propeller shaft for various parameters. The solid composite propeller shaft is having good results than the hollow steel propeller shaft. From the below comparison, it is observed that the results obtained from finite element modal are good agreement with the results obtained from experimental modal analysis. Also, the deviation between the frequencies obtained from finite element and experimental modal analysis is within the permissible range. So, the adopted process of analysis led design gives satisfactory results for Composite propeller shaft. Hence this design of Glass fiber/Epoxy Composite propeller shaft is accurate enough to work properly in working conditions.

Table 4.Comparison of Results for Steel and Composite Shaft

Factor		
Material Used	**Steel**	**GFRP**
Outer Diameter (Do) (mm)	72	60
Inner Diameter of hollow shaft (Di) mm	65.56	-
Torsion Shear Stress FEA (MPa)	109	140
Factor		
Material Used	**Steel**	**GFRP**
Angle of Deflection per meter (Torsion Rigidity)	1.36	1.45
Weight of the shaft (kg)	7.5	5.6
Weight Saved in %	-	28
FEA Maximum Stress (MPa)	107	145.35
First Natural Frequency FEA (Hz)	278.9	244.19
Critical Speed (N_{cr}) rpm	16494.6	14651.4
First Natural Frequency Testing (Hz)	-	239



Graph 1.Torque applied and angle of Twist

Graph 2.Weight comparison between Steel And Composite Shaft

IX. CONCLUSION

In this work, firstly the Design of Composite propeller shaft is to be done by using Classical lamination Theory. Then its analysis was carried out with help finite element software. After the manufacturing, its experimental modal analysis and Torsion Testing was performed. From above study, some conclusions can be made as:

1. A one–piece composite propeller shaft for rear wheel drive automobile has been designed optimally by using classical lamination theory with the objective of minimization of weight & cost of the shaft which was subjected to the constraints such as torque buckling capacities and natural bending frequency.
2. The weight of the composite propeller shaft is reduced by 28% as compared to steel propeller shaft.
3. The FEA predictions of natural frequency deviate by 2 % for solid composite propeller shaft that resulted from analytical solution which are within range of acceptance.

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REFERENCES

[1] John. W.et. al. Engineers Guide to Composite Materials, American Society for Metals, 1986.

[2] R. P. Kumar Rompicharla, Dr. K. Rambabu Sir C.R.R college of Engineering Department of Mechanical Eluru, India, International Journal of Engineering Research & Technology (IJERT) Vol. 1 Issue 7, September - 2012 ISSN: 2278-0181.Design and optimization of drive shaft with composite materials**.**

[3] Bhushan K. Suryawanshi, Prajitsen G. Damle, International Journal of Innovative Technology and Exploring Engineering (IJITEE), March 2013.Review of Design of Hybrid Aluminium/ Composite Drive Shaft for Automobile.

[4] Dai Gil Lee*,Hak Sung Kim, Jong Woon Kim and Jin Kook Kim Korea advanced institute of science and technology, south Korea. Design and manufacture of an automotive hybrid aluminium/composite drive shaft.

[5] A.R. Abu Talib, Aidy Ali*, Mohamed A. Badie, Nur Azida Che Lah, and A.F. Golestaneh, University Putra, Selangor, Malaysia. Developing a hybrid, carbon/glass fiber-reinforced, epoxy composite automotive drive shaft.

[6] R. Sino, T.N. Baranger*, E. Chatelet and G. Jacquet Laboratoire de Mecanique, University de Lyon, Villeurbanne, France. Dynamic analysis of a rotating composite shaft.

[7] M.A. Badie. Mahdi* and A.M.S. Hamouda Mechanical and Industrial engineering department, college of engineering, Qatar University, Doha, Qatar. An investigation into hybrid carbon/glass fiber reinforced epoxy composite automotive drive shaft

[8] M.R. Khoshravan, A. Paykan. Design of composite drive shaft and its coupling for automotive application.

[9] R. Srinivasa Moorthy, Yonas Mitiku & K. Sridhar School of Mechanical and Industrial Engineering, IoT, Bahir Dar University, Bahir Dar, Ethiopia. Design of Automobile Driveshaft using Carbon/Epoxy and Kevlar/Epoxy Composites.

[10] Parshuram D1, Sunil Mangsetty2. Pda College of Engineering Gulbarga. Design and Analysis of Composite/Hybrid Drive Shaft for Automotives.

[11] Rohan D. Hucche, S.Y. Gajjal, V.K. Kulloli, International Journal on Theoretical and Applied Research in Mechanical Engineering (IJTARME) V-5 No.2 ISSN (Print): 2319-3182. Design & Analysis of Composite Propeller Shaft.

[12] Prof. Bhirud Pankaj P., Prof. Sandip P. Chaudhari, Prof. Trinkle Y. Saindane, IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 3 Issue 2, February 2016. Natural Frequency & Mode Shape of Composite Drive Shaft.

[13] M. Pallavi, T. Joel Swaroop Raj, A. Syam Prasad, M. Madhavi, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 12, Issue 4 Ver. VI (Jul. - Aug. 2015), PP 01-07. Experimental Investigations on Static and Dynamic Parameters of Steel and Composite Propeller Shafts for Light Passenger Vehicle.