JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Modal Analysis of Hybrid Composite Propeller Shaft

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Abstract: *This paper deals with the modal analysis of hybrid composite propeller shaft made up of low carbon steel epoxy, s glass and T700 fiber. A one-piece hybrid composite propeller shaft and a conventional steel propeller shafts are designed and analyzed using ANSYS 14.5 software. By comparing the results, it is concluded that Hybrid Composite shaft have higher frequencies than Steel shaft, i.e. Hybrid Composite propeller shaft can rotate at higher frequencies than Steel propeller shaft. Hence, in order to reduce the weight of the shaft and increase the performance, conventional steel shaft can easily be replaced by hybrid composite shaft.*

Keywords: *Hybrid composite propeller shaft, Modal analysis, ANSYS 14.5*

1. INTRODUCTION

Propeller shaft is incorporated for transmission of power within the vehicle. They are exposed to heavy load and stress which ends up in gross misalignment of the wheels. Propeller shaft of vehicles are sufficiently long and operates at very high speed. Propeller shaft parts are designed to supply superior resistance to misalignment alongside efficiently absorbing undesired vibration.

Modal analysis is the process of determining the inherent dynamic characteristics of a system in forms of natural frequencies, damping factors and mode shapes, and using them to formulate a mathematical model for its dynamic behavior. Modal analysis helps to determine the vibration characteristics (natural frequencies and mode shapes) of a mechanical structure or component, showing the movement of different parts of the structure under dynamic loading conditions, such as those due to the lateral force generated by the electrostatic actuators.

The purpose of this study is to deal with the modal analysis of hybrid composite propeller shaft made up of low carbon steel epoxy, s glass and T700 fiber. A one-piece hybrid composite propeller shaft and a conventional steel propeller shafts are designed and analyzed using ANSYS 14.5 software. By comparing the results, it is concluded that Hybrid Composite shaft have higher frequencies than Steel shaft, i.e. Hybrid Composite propeller shaft can rotate at higher frequencies than Steel propeller shaft. Hence, in order to reduce the weight of the shaft and increase the performance, conventional steel shaft can easily be replaced by hybrid composite shaft.

2. LITERATURE REVIEW

Anamika, Anindya Bhar[1], In this study, the finite element analysis of design variables of composite materials orientation and stacking sequence provided an insight into their effects on drive shaft's, formulation results in natural frequencies that are reasonably close to test results when compared with previous studies. The formulation can be expanded to transversely isotropic and generally orthotropic materials. The study also did weight optimization of drive shaft. FEA results showed that the natural frequency increases with decreasing fiber orientation angles.

Silambarasan.M, Vinothraj.U.T.[2], attempted to evaluate the suitability of composite material such as E-Glass/Epoxy composite hollow shaft with grooves inclination for the purpose of automotive transmission applications. The glass/epoxy shaft was made flexible by introducing grooves. With this the torsional stiffness of the shaft reduces. The grooves inclined at 450 is first introduced in the shaft and checked for misalignments. This is followed by the introduction of perpendicular grooves.

M. Pallavi , T. Joel Swaroop Raj , A. Syam Prasad , M.Madhavi[3], have described static and dynamic analysis of steel propeller shaft and composite propeller shaft made of glass fiber reinforced polymer. Primary objective was to compare the torque bearing capacity, stiffness and weight savings of composite propeller shaft with that of steel propeller shaft. Composite propeller shaft had greater angle of twist, higher stiffness and higher natural frequency than that of existing steel propeller shaft. A weight reduction is achieved by using composite propeller shaft.

A.Sridhar, Dr. R. Mohan, R.Vinoth Kumar[4], aims to replace the conventional steel driveshaft of automobiles with an appropriate composite driveshaft. The design parameters were optimized with the objective of minimizing the weight of composite drive shaft. The replacement of composite materials resulted in considerable amount of weight reduction.

Srikanth Reddy [5], dealt with design and analysis of a drive shaft. Presently used materials in the market for manufacturing are cast iron, cast steel. The purpose of this paper was to design the drive shaft made of Ni-Cr steel and compare it with steel material. The design was done in Solid works software and analyzed using ANSYS.

Sheik A. N. S [6], conducted study to replace a forged steel drive shaft by a composite drive shaft with enhanced mechanical property with less weight. In this paper aluminum was chosen as matrix metal of composite, and reinforcement materials are aluminum oxide (Al_2O_3) and zirconium diboride (Z_rB_4) was fabricated.

G V Mahajan [7], in this paper design and vibration analysis of composites propeller shafts was undertaken. The aim was to replace a metallic drive shaft by a composite shaft. V. S. Bhajantri [8], also carried out a study in order to replace the steel shaft by composite shaft. In this work optimization of stacking sequence was done. Comparison was done for steel and composite shaft for max stress and deflection and concluded that the change in fiber orientation angle, varies the stress.

Bhirud Pankaj Prakash [9], studied that by using of composite material in shaft leads to significant saving in weight. In their work, weight reduction was carried out by using composite shaft to 2.7 kg from 10 kg of steel drive shaft. Sagar R Dharmadhikari [10], paper deals with the review of optimization of drive shaft using the genetic algorithm and ANSYS.

Shivanand & Dr. Shravankumar B. Kerur [11], conducted a study on exploration of hybrid materials for a propeller shaft in as aerospace applications. The results obtained from the Matlab are analyzed and the analysis determines that the hybrid material consisting of low carbon steel, epoxy, S glass and T 700 fibres is the best suitable for the propeller shaft to withstand maximum load with the least deflection. The orientation angle is considered to be 45 degrees.

Shivanand & Dr. Shravankumar B. Kerur [12], undertook a comprehensive study on failure and Thermal Examination of hybrid materials for a propeller shaft in aerospace applications. This study presents the failure analysis of the hybrid material in ANSYS software. The main aim of this study was to check the suitability of the composite material comprising of carbon steel + epoxy + S glass + T 700 fibers for the propeller shaft applications.

Dr.R.Ganapathi, Dr.B.Omprakash, J.Vinay Kumar [13], studied the modeling and analysis of composite drive shaft by replacing the conventional stainless steel with composite materials. They used composite materials in order to make a single long continuous shaft instead of conventional two piece steel drive shaft.

M. Pallavi et.al, [14], described the static and dynamic analysis of steel propeller shaft and composite propeller shaft made of glass fiber reinforced polymer. Primary objective was to match the torque bearing capacity, stiffness and weight savings of composite propeller shaft therewith of steel propeller shaft. The design constraints are angle of twist and natural frequency.

3. MATERIALS AND MODELING

In the present work, two propeller shafts one of conventional steel and another made up of hybrid composite are modeled. The Geometric considerations and design parameters for both the shafts are discussed and then the models are analyzed.

3.1 Modeling of steel propeller shaft

Propeller shafts are designed on the basis of torsional loading. The commonly used materials for manufacturing the propeller shaft is low carbon steel with 10-18 % Chromium and 5-8 % Nickel. The yield strength of the material should be of 370N/mm^2 used for manufacturing propeller shaft is: The geometry for the steel propeller shaft is taken from the literature survey. The geometric dimensions, 3D Model and Mechanical properties for steel shaft are shown below.

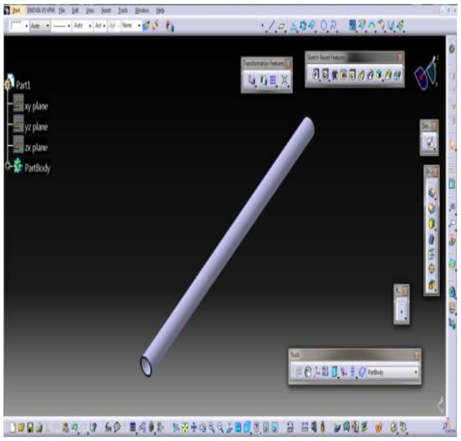


Fig 1: 3D Model of Steel Propeller Shaft

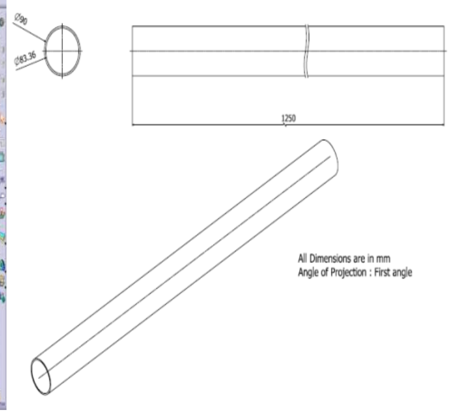


Fig 2: Geometric Dimension

Table 1: Properties of Steel

Young's Modulus	210 Gpa
Shear Modulus	80 Gpa
Poisson's Ratio	0.3
Density	7860 kg/m3
Yield Strength	370 Mpa

Modeling of the steel propeller shaft is done using CATIA V5 R21**.** The outer diameter of the Steel propeller shaft is 90mm, inner diameter is 83.36mm and length is 1250mm.

3.2 **Modeling of composite propeller shaft.**

The composite drive shaft should satisfy the design specifications such as static torque capability. The materials used for Hybrid Composite shaft in the present work are Low carbon Steel, S-Glass, Epoxy and T-700 fiber. The major role of Low carbon steel is to sustain the applied torque while the role of the carbon fiber epoxy composite is to increase bending strength. Modeling of the hybrid composite propeller shaft is done using ansys.

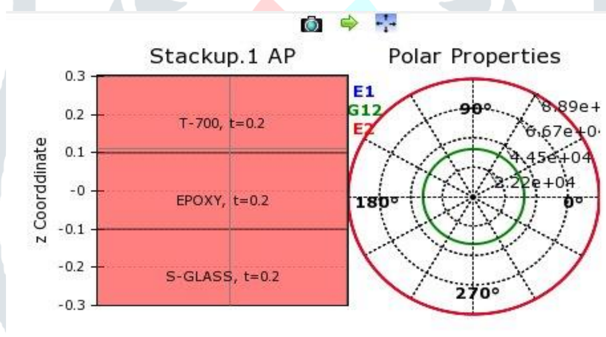


Fig 3: ACP post steps for adding layers

4. CODE VALIDATION

The problem is solved using Finite Element Analysis, the existing code is validated with the results of Mr. Swapnil Shinde[15]**,** for accuracy and correctness. For the modeling of Steel Propeller Shaft, the inner and outer diameters are considered along with that the length of the shaft also considered, for analysis static and modal analysis have been carried out and for the same parameters validation is carried out. It is found that it agrees well with the results of published works. The result comparison for code validation is shown below.

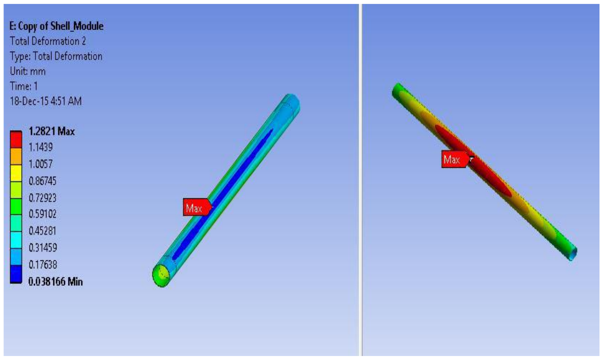


Fig. 4(a):Previous work model of Steel Propeller Shaft

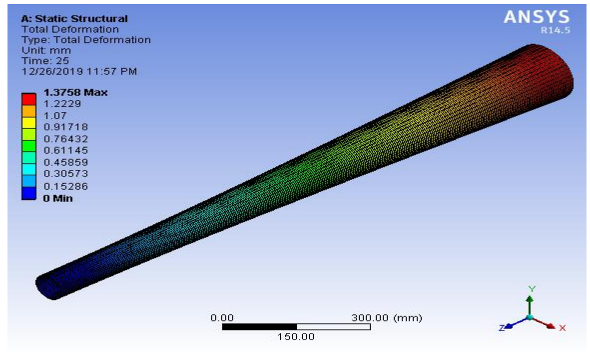


Fig.4(b): Present work model of Steel Propeller Shaft

Table 2: Result Comparison of Steel shaft for total Deformation

Work Done	Maximum deformation in mm	Difference in values in %
Previous	1.2821	93.18 % accuracy
Present	1.3758	

The present work values and boundary conditions are given same as that of previous work. Load of 2500 N-m is applied and we have made 25 iterations for the present work to get higher accuracy. By comparing the results of previous and present work the maximum and minimum deformations are similar i.e. 93% accuracy. So we can go ahead with the further analysis.

5. RESULTS AND DISCUSSIONS

When an elastic system free from external forces can disturbed from its equilibrium position and vibrates under the influence of inherent forces and is claimed to be within the state of free vibration. It'll vibrate at its natural frequency and its amplitude will gradually become smaller with time thanks to energy being dissipated by motion. The most parameters of interest in free vibration are natural frequency and therefore the amplitude. The natural frequencies and therefore the mode shapes are important parameters within the design of a structure for dynamic loading conditions. Modal analysis is employed to work out the vibration characteristics like natural frequencies and mode shapes of a structure or a machine component while it's being designed. Modal analysis is employed to work out the natural frequencies and mode shapes of a structure or a machine component. The natural frequency depends on the diameter of the shaft, thickness of the hollow shaft, specific stiffness and therefore the length.

5.1 Modal Analysis for Steel Propeller Shaft

In this analysis no major boundary conditions are applied, both the ends are fixed and no loads are applied, and the shaft is made to vibrate freely. Software will automatically generate different natural frequencies. In this analysis we have obtained 8 natural frequencies for both the shafts.

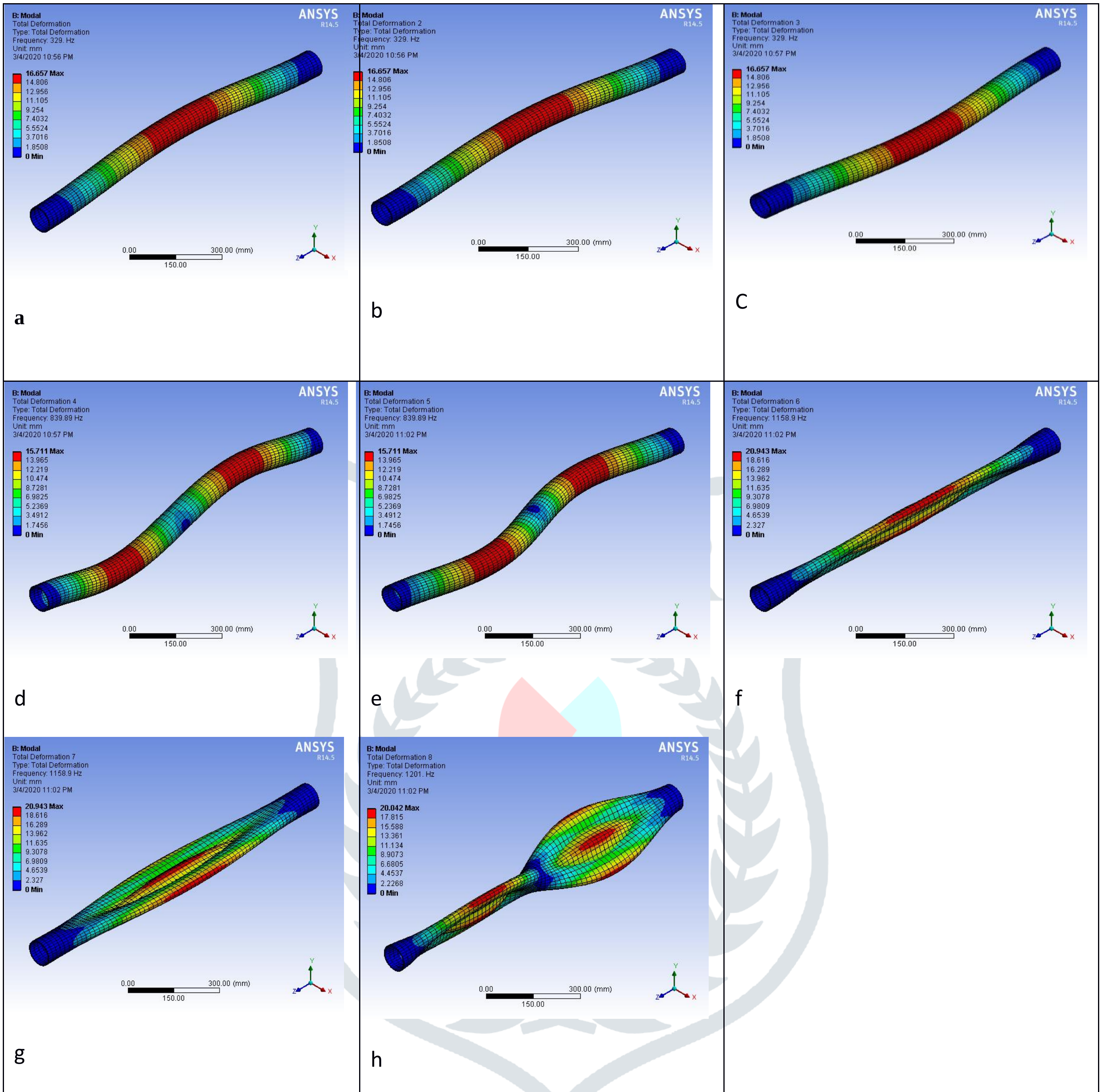


Fig. 5: a, b, c, d, e, f, g, h: Natural frequencies for steel shaft at first, second, third, fourth, fifth, sixth, seventh and eighth modes respectively.

5.2 Modal Analysis for Hybrid Composite Propeller Shaft

In this analysis both the ends are fixed and no loads are applied, the software will automatically generate different natural frequencies. In this analysis we have obtained 8 natural frequencies for both the shafts.

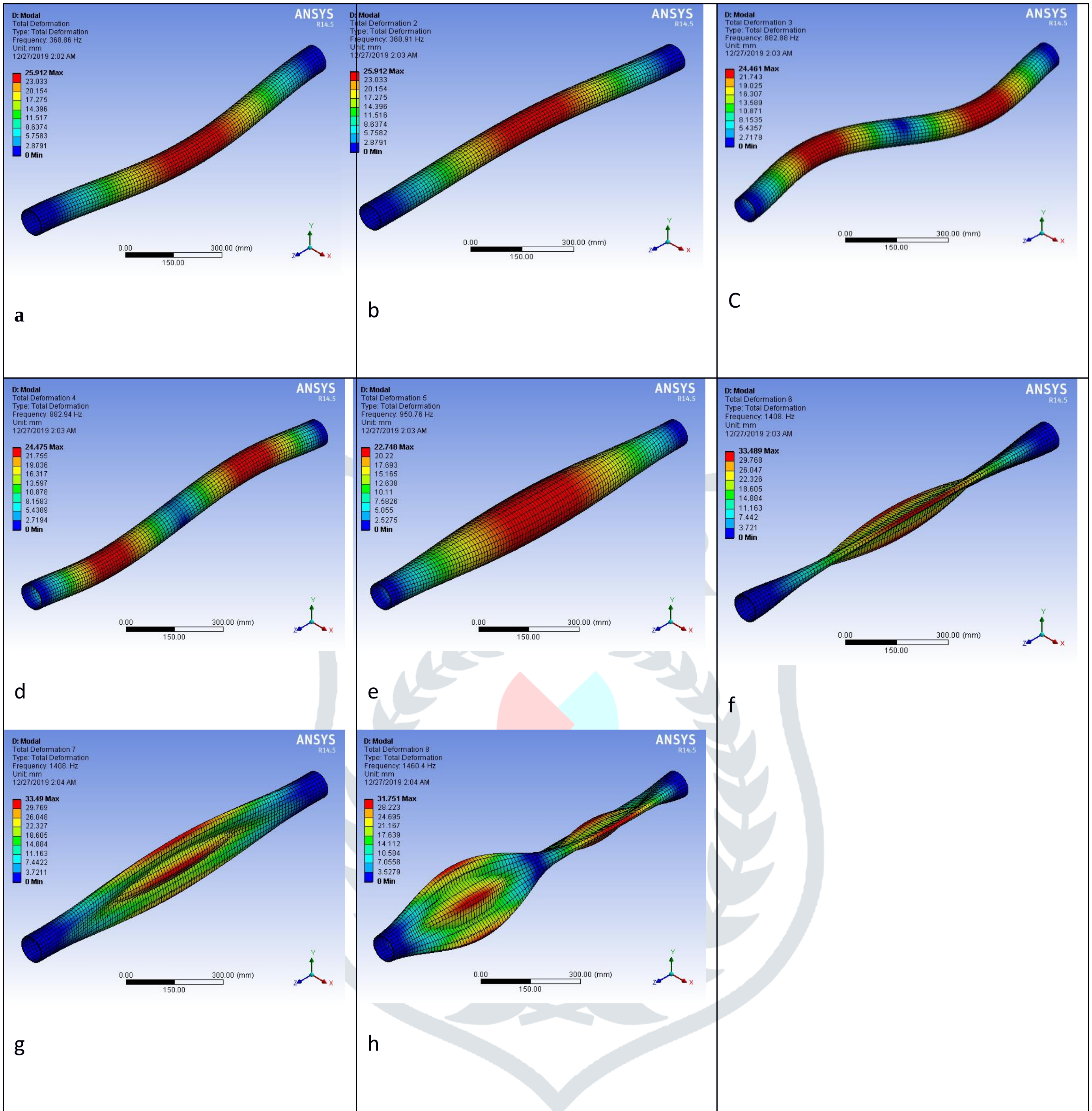
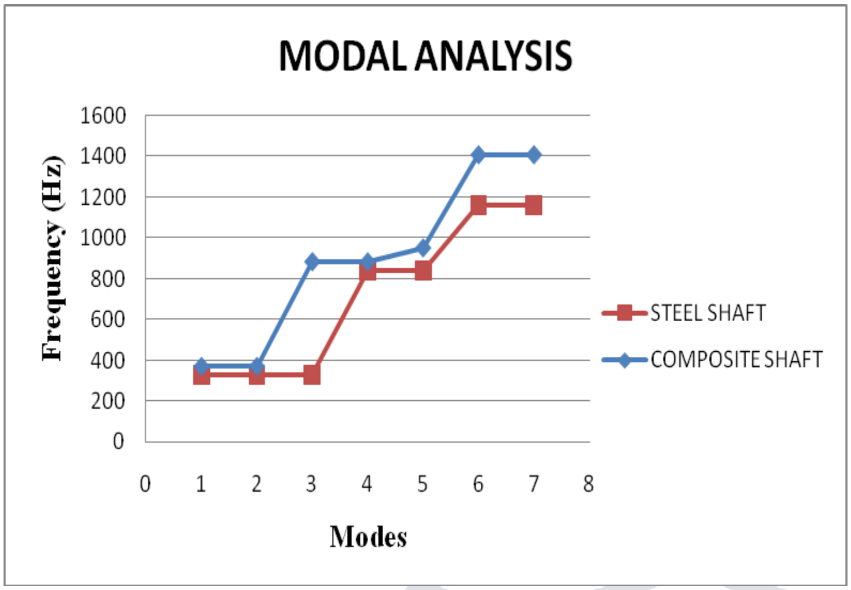


Fig. 6: a, b, c, d, e, f, g, h: Natural frequencies for hybrid composite shaft at first, second, third, fourth, fifth, sixth, seventh and eighth modes respectively.



Graph 1: Modal analysis of Natural frequencies

Table 3: Comparison of natural frequencies for Steel and Composite Shafts

Modes/Natural frequencies (Hz)	Steel Shaft	Hybrid Shaft
First	329	368.86
Second	329	368.91
Third	329	882.88
Fourth	839.89	882.94
Fifth	839.89	950.76
Sixth	1158.9	1408
Seventh	1158.9	1408
Eighth	1201	1460

Figure 5 shows the modal analysis results of steel propeller shaft and from Figure 6 shows the modal analysis results of Hybrid composite propeller shaft. The values extracted from the figure 5 and figure 6 are tabulated in table 3 and also shown in graph 1.

6. CONCLUSION

Minimum and maximum values of stress, strain, deformations are marked on the figurers itself which are obtained at two different ends. Comparison of frequencies for both steel and hybrid shaft show that the hybrid shaft has higher frequencies than the Steel propeller shaft which means that the Hybrid Composite propeller shaft can rotate at higher frequencies than Steel propeller shaft. Hence we can easily replace the conventional steel propeller shaft by hybrid composite propeller shaft which is lighter in weight and hence reducing the overall weight of the vehicle without affecting the performance.

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