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WHIRLING ANALYSIS OF FIBER REINFORCED PLASTIC SHAFTS

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ABSTRACT

Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and strength of composite materials. This work deals with the replacement of conventional steel propeller shaft with CFRP composite propeller shaft for an automotive application. The fundamental bending natural frequency should be higher than the critical speed to avoid whirling vibration. The fundamental bending natural frequency of a one-piece drive shafts made of steel or aluminum is normally lower than the critical speed. 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 composite drive shaft with less weight to increase the first natural frequency of the shaft. The composite drive shaft has many benefits such as less noise and vibration and increases fuel efficiency and also increases the torque transmission and torsional buckling capabilities.

Hence in this work, the whirling analysis of CFRP composite propeller shaft and steel shaft at the critical speed and their comparison is proposed to be done. Modeling and analysis of CFRP composite propeller shaft and conventional steel propeller shaft by using finite element analysis software ANSYS is also planned. The properties to be analyzed are fundamental natural frequency and torsional buckling capacity of the shaft.

Introduction

DRIVE SHAFT

A driveshaft is a rotating shaft that transmits power from the gearbox to the differential gear of a rear wheel drive for the vehicles. High quality steel is a common material for construction. Steel drive shafts are usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft is inversely proportional to the square of beam length and proportional to the square root of specific modulus. The two piece steel drive shaft consists of three universal joints, a center supporting bearing and a bracket, which increase the total weight of a vehicle. Power transmission can be improved through the reduction of inertial mass and light weight. Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and higher specific strength of composite materials. Composite materials can be tailored to efficiently meet the design requirements of strength, stiffness and composite drive shafts weight less than steel or aluminium of similar strength. It is possible to manufacture one piece composite drive shaft to eliminate all of the assembly connecting two piece steel drive shaft. Also, composite materials typically have a lower modulus of elasticity. The weight reduction of the drive shaft with have a certain role in the general weight reduction of the vehicle and it is a

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highly desirable goal. It has to be achieved without much 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 natural frequency of the shaft and to decrease the bending stress. By doing this, the torque transmission and torsion buckling capabilities are maximized.

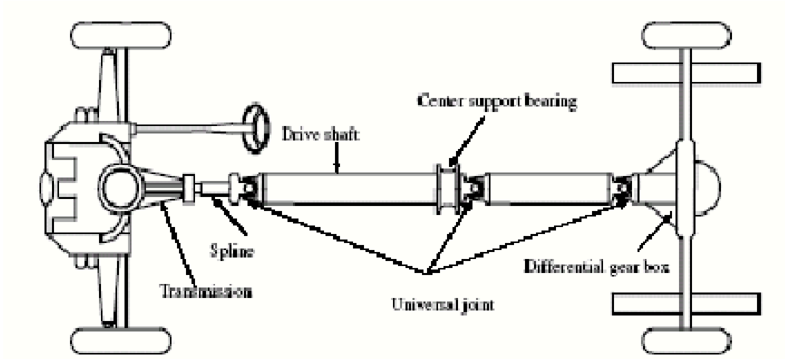

Figure 1 Drive shaft assembly

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1.1 ProblemStatement

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 torque capability of the drive shaft for passenger cars should be larger than 3500 Nm and the fundamental bending natural frequency should be higher than the critical speed to avoid whirling vibration. The composite drive shaft has many benefits such as reduced weight and less noise and vibration and increases fuel efficiency. So it is proposed to prepare a propeller shaft by a **CFRP** composite material and to perform static, modal and buckling analysis by using **ANSYS** software.

1.2 Objective

To prepare a **Carbon/epoxy** composite propeller shaft and compare its properties with conventional steel shaft and validation of the same with the Modeling and Analysis using **ANSYS** software. The properties to be analyzed are fundamental natural frequency and torsional buckling capacity.

1.3 Scopeoftheproject

In this work, the whirling analysis of **CFRP** composite propeller shaft and steel shaft at the critical speed and their comparison is proposed to be done. Modeling and analysis of **CFRP** composite propeller shaft and conventional steel propeller shaft by using finite element analysis software **ANSYS** is also planned. The properties to be analyzed are fundamental natural frequency and torsional buckling capacity of the shaft.

1.4 Toolsused forsimulation

The Modeling and Analysis using **ANSYS** software

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1. LITERATURESURVEY

Sunil Mangsetty (2013), "Design and Analysis of Composite/Hybrid Drive Shaft for Automotives"

The main concept of our project is to reduce the weight of automotive drive shaft with the utilization of composite material. Composite materials have been used in automotive components because of their properties such as low weight, high specific stiffness, corrosion free, and ability to produce complex shapes, high specific strength and high impact energy absorption. He found that the usage of composite materials has resulted in considerable amount of weight saving in the range of 81% to 72% when compared to conventional steel drive shaft.

Ravikan et al (2013), "Modal analysis of drive shaft using FEA"

In the present work the modal analysis of a drive shaft has been carried out the inherent frequencies and vibration mode shapes with their respective deformation. They found that the frequency goes on increasing from first mode shape to last mode shape. The simulation results it is clear that maximum deformation occurs at the free end.

Dr. SuhasDeshmukh (2012), "Static and Modal Analysis of Composite Drive Shaft and Development of Regression Equations"

In the present work an attempt is made to evaluate the suitability of composite material such as Carbon/Epoxy for drive shaft in automotive transmission. ANSYS FEM solver is used for evaluation of shaft properties (such as maximum stress, maximum deformation) with variation in fiber orientation in each layer. He found that Shear stress in that layer increases up to 45 degree orientation, then decreases till 90 degree orientation angle.

Dr.K.Rambabu (2012), "Design and analysis of drive shaft with composite materials"

The objective of this paper is to design and analyze a composite drive shaft for power transmission. In this work attempt has been made for design optimization of drive shaft with composite materials, the one piece drive shaft is designed to replace conventional steel drive shaft of an automobile using composite Materials. He found that the usage of composite material has resulted to inconsiderable amount of weight saving in the range of 28% when compared to conventional steel shaft.

Thahar Ali Syed etal (2012), "Design and Analysis of Propeller shaft By Using KEVLOR/EPOXY Composite"

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The project aims to reduce the weight of the drive shaft assembly by using advanced composite materials. For this project work, the drive shaft of a Toyota Qualis was chosen. The modelling of the drive shaft assembly was done using CATIA V5R16. A shaft has to be designed to meet the stringent design requirements for automobiles. They found that the drive shaft of the Toyota Qualis car was chosen for determining the dimensions, which were then used for creating a model in CATIA V5R16. A total of five materials were chosen for the comparative analysis, including steel, which was used for reference. The usage of composite materials has resulted in considerable amount of weight saving in the range of 65% to 54% when compared to conventional steel shaft.

AsmamawGebresilassie (2012), "Design and analysis of Composite Drive Shaft for Rear-Wheel Drive Engine"

In this project work an attempt is made to evaluate the suitability of composite material such as E-Glass/Epoxy for the purpose of automotive drive shaft application. A one-piece composite shaft is optimally analyzed using Finite Element Analysis Software. He found that Composite shaft made from E-Glass/ Epoxy is investigated theoretically and numerically by taking torsion load. To analyse the shaft using FEA the composite shaft is fixed from one end and the torque is applied to the other end. The result shows there is a linear relationship between torque and deflection, between torque and stress, also between torque and strain.

V.N.Mujbaile (2012), "Design Optimization of Drive Shaft"

This work deals with the replacement of conventional two-piece steel drive shaft with a single-piece e-glass /epoxy, high strength carbon/ epoxy composite drive shaft for an automotive application. The design parameters were optimized with the help of Genetic Algorithm (GA) with the objective of minimizing the weight of composite drive shaft. He found that a one piece composite drive shaft for rear wheel drive automobiles has been design optimally by using Genetic Algorithm (GA) for high strength carbon/epoxy composites with the objective of minimization of weight of shaft.

3. MATERIALSANDMETHODS

3.1 SELECTIONOFREINFORCEMENT FIBERSAND RESIN

Carbon fiber:

Carbon fiber, alternatively graphite fiber, carbon graphite or CF, is a material consisting of fibers about 5–10 μm in diameter and composed mostly of carbon atoms. The carbon atoms are

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bonded together in crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment gives the fiber high strength-to-volume ratio (makes it strong for its size). Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric. Carbon fibres are created when polyacrylonitrile fibres (PAN), Pitch resins, or Rayon are carbonized (through oxidation and thermal pyrolysis) at high temperatures. Through further processes of graphitizing or stretching the fibres strength or elasticity can be enhanced respectively. Carbon fibers are usually combined with other materials to form a composite.

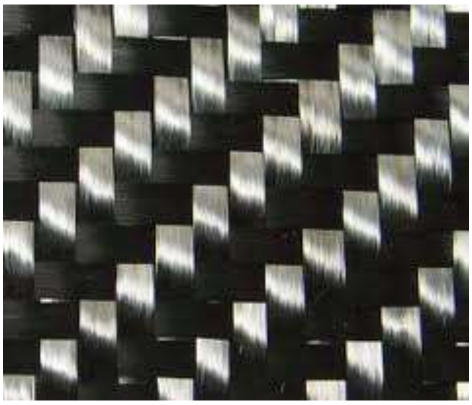

Figure 2 carbon fibers

Glass fiber:

Each individual glass fibre is very fine with a small diameter, and they are woven to form a flexible fabric. The fabric is normally placed in a mould, for instance a mould for a canoe and polyester resin is added, followed by a catalyst (to speed up the reaction). The process is repeated so that there are many layers of fibre glass and resin and allowed to dry/cure. The resulting material is strong and light. Glass Reinforced Plastic can be sanded for a smooth finish and painted.Three samples of different weaves of fibreglass are seen below. The pattern of weave determines the strength and weight of the Glass Reinforced Plastic, after resin has been added. Different weaves have been developed for different practical applications.The disadvantages are low elastic modulus, poor adhesion to polymers, low fatigue strength and high density, which increase shaft size and weight.

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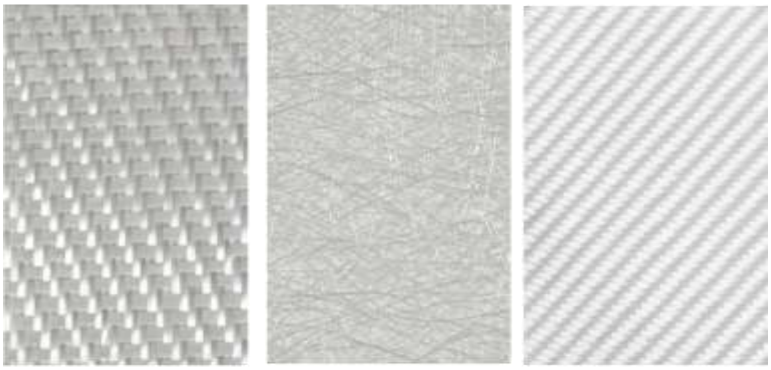

Figure 3 Glass fibers

Epoxy Resin

Epoxy resins have a wide range of properties. They can be rigid or flexible with different temperature resistance, with some able to withstand continuous use up to 250°C. Advantages of epoxy resins over polyester and vinyl ester resins include lower mould shrinkage, low volatility during curing, good environmental and solvent resistance, and very good adhesion to most reinforcement materials. They are widely used in structural aerospace applications.

Figure 4 Liquid epoxy resins

3.2 METHODOLOGY

3.2.1 FILAMENT WINDING METHOD:

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Figure 4 filament winding process

Filament winding is a very fast and efficient method of laying down resin and reinforcements to create strong, lightweight composite products. Windings are limited to the size of the machine and the rotating mandrel. Continuous strands of resin-impregnated glass fibre, carbon fibre or other reinforcements are wound under tension onto the mandrel in precise geometric patterns to build up the part. Once the desired winding thickness is achieved, the winder stops, the part is allowed to cure, and the mandrel is removed using an extractor.

CFRP SHAFTS:

Figure 5CFRP shaft

GFRP SHAFTS:

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Figure 6 GFRP shaft

4. SIMULATIONS

4.1. ANALYSIS

Modeling of the high strength **Carbon/Epoxy** composite drive shaft using **ANSYS** software.
Modal and Buckling analysis are to be carried out on finite element model of the high strength **Carbon/Epoxy** composite drive shaft using **ANSYS**.

4.1.1 MODAL ANALYSIS

When elastic free from external force is disturbed from its equilibrium position it vibrates under the influence of inherent force and is said to be in the state of free vibration. It will vibrate at its natural frequency and its amplitude will gradually become smaller with time due to energy being dissipated by motion. The main parameters of interest in free vibration are natural frequency and the amplitude. The natural frequencies and the mode shapes are important parameters in the design of a structure for dynamic loading conditions. Modal analysis is used to determine the vibration characteristics such as natural frequencies and mode shapes of a structure or a machine component. The rotational speed must be lower than the first natural bending frequency of the shaft. The natural frequency depends on the diameter of the shaft, thickness of the hollow shaft, specific stiffness and length of the shaft.

4.1.2 BUCKLING ANALYSIS

Buckling analysis is a technique used to determine buckling loads (critical loads) at which a structure becomes unstable and buckled mode shapes. The drive shaft system improved lateral stability characteristics must be achieved together with improved torque carrying capabilities. The dominant failure mode, torsional buckling is strongly dependent on fiber orientation angles and ply stacking sequence.

5. RESULTS AND DISCUSSION

5.1. Modal Analysis of CFRP Shaft and GFRP Shaft

Meshing Model of Shaft:

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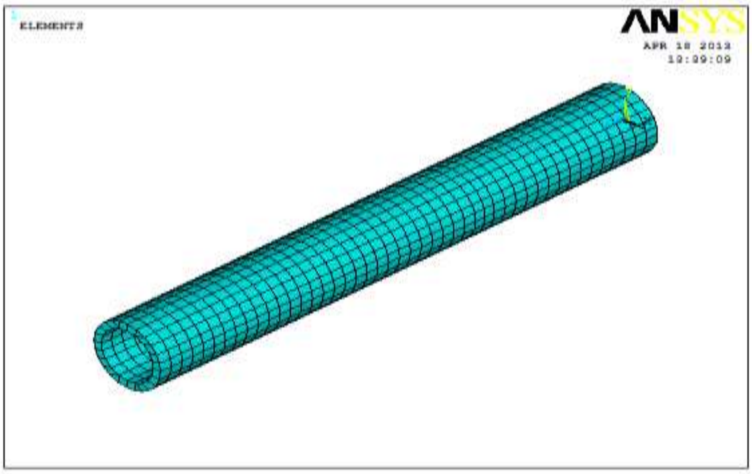
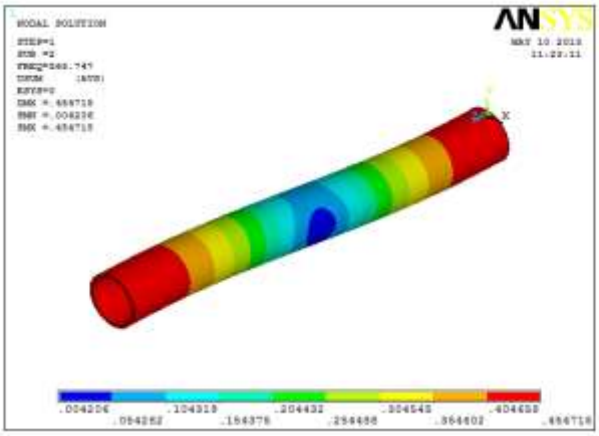


Deformed Shapes of Steel Shafts:
First Mode for Steel Shaft:



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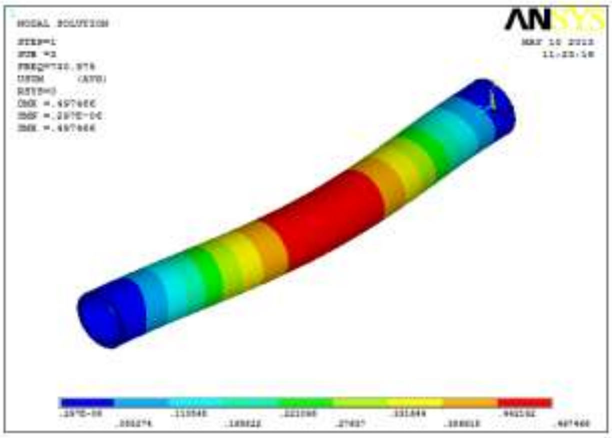
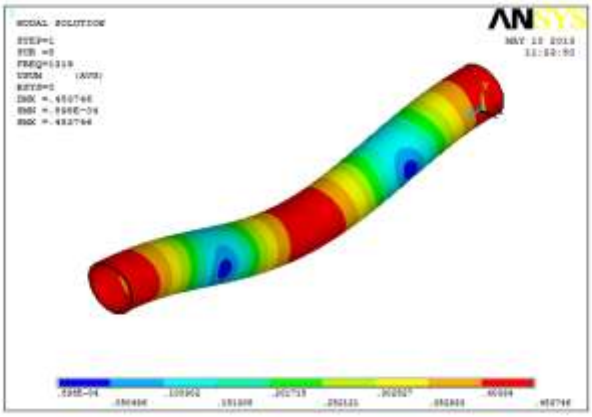
Second Mode for Steel Shaft:



Third Mode for Steel Shaft:



NATURAL FREQUENCIES OF STEEL SHAFT:

Table 1 Natural frequencies of steel shaft

Natural frequency (Hz)	1	2	3	4
STEEL(Hz)	365.75	730.98	1231	1319.3

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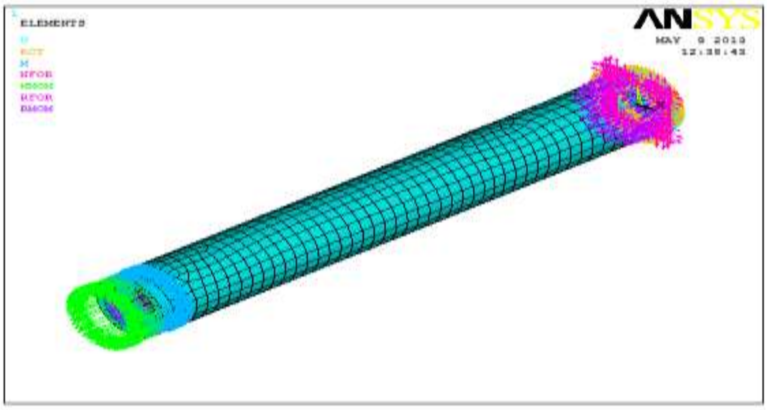
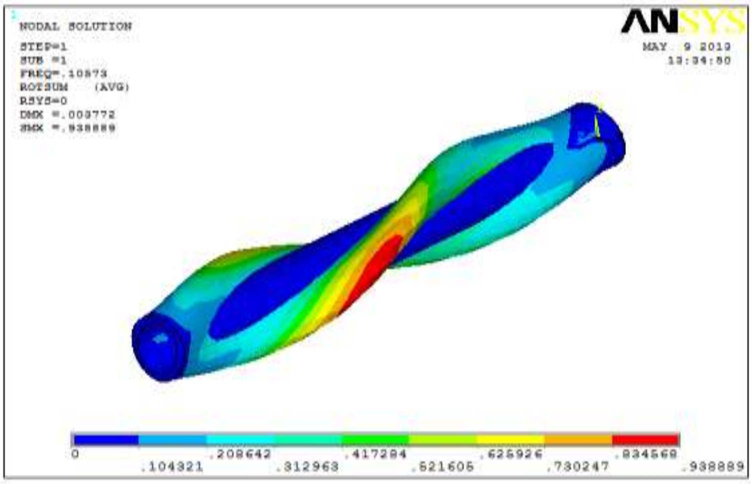
5.2. Buckling Analysis:

Buckling analysis is a technique used to determine buckling loads (critical loads) at which a structure becomes unstable, and buckled mode shapes. Torsional buckling is strongly dependent on fiber orientation angle.

Boundary Conditions:



Buckling Analysis of CFRP Shaft:



Torsional Buckling Capacity of Drive Shaft:

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Table 2 Torsional buckling capacity of the shaft

DRIVE SHAFT	CRITICAL LOADS	UNITS
STEEL	4500	Nm
CFRP	4200	Nm

5.3 EXPERIMENTAL TESTING:

VIBRATION TESTING SETUP:

The shaft is fixed as a one end clamped and other end free condition on a hard non-vibrating device. A piezoelectric accelerometer is mounted on the shaft. Rap test is conducted and the accelerometer signal through charge amplifier is fed into the real-time FFT analyser to find the natural frequency of the shaft.

Figure 7 Vibration testing setup

EXPERIMENTAL TEST RESULTS:

Table 3 Vibration test results

Natural frequency(Hz)	1	2	3	4
CFRP SHAFT	584	1207	1983	2128

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CONLUSION

In this present work, the shafts have been prepared from carbon/epoxy composite materials. The natural frequency of CFRP shaft is increased with 66% when compared to steel shaft. Modal and Buckling analyses have been performed using **ANSYS** software. Natural frequency and critical buckling load are calculated.The shaft was fabricated using filament winding process. Vibration test is conducted for the CFRP shaft and the natural frequencies of the shaft are also calculated experimentally and the experimental and analysis results are compared.

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