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# REVIEW ON DESIGN AND ANALYSIS OF HYBRID DRIVE SHAFT

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## ABSTRACT

Application of advanced composites has resulted in great success in many fields such as aviation, marine and automobile engineering, medicine, prosthetics and sports, in terms of improved fatigue and corrosion resistances, high specific strength and specific modulus and reduction in energy requirements ultimately resulting reduction in weight. So manufacturing of the automotive components from high strength, high stiffness FRP in order to reduce weight and fuel consumption has been under discussion. Automotive drive Shaft is a very important component of vehicle. The objective of this paper is to design and analyze a hybrid drive shaft for power transmission. This project deals with the replacement of conventional two-piece steel drive shafts with a hybrid material.

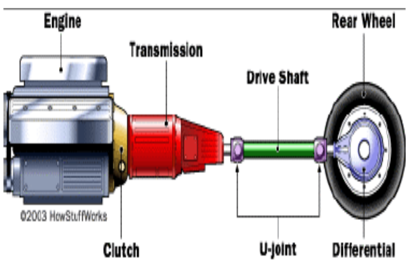
**Keywords:-** One-piece hybrid drive shaft, Static torque capability, buckling torque capability ,bending natural frequency, E-glass fiber ,Static Analysis , Modal Analysis

## 1. INTRODUCTION

### 1.1. INTRODUCTION TO DRIVE SHAFT

There are different names for shaft which varies according to application such as transmission shaft, axle, spindle, machine shaft etc. The term Drive shaft is used to refer to a shaft, which is used for the transfer of motion from one point to another. Drive shafts as power transmission element are used in many applications, including cooling towers, pumping sets, aerospace, trucks and automobiles. In metallic shaft design, knowing the torque and the allowable shear stress for the material, the size of the shaft's cross section can be determined. In case of an automobile, the drive shaft is connection between the transmission system and the rear axle of the car.

**Figure 1. One-Piece Composite Drive Shaft**




The propeller shaft is a longitudinal drive shaft used in vehicles where the engine is situated at the opposite end of the vehicle to the driven wheels. A propeller shaft is an assembly of one or more tubular shaft connected by universal, constant velocity or flexible joints.

### 1.2 INTRODUCTION TO COMPOSITES

Composites are formed by combining materials together to form an overall structure that is better than the sum of the individual components. A composite material (also called a composition material or shortened to composite) is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials.

The modern composite materials such as graphite, carbon, Kevlar and Glass with Suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/density). Advanced composite materials seem ideally suited for long, power driver shaft (propeller shaft) applications. Their elastic properties can be tailored to increase the torque they can carry as well as the rotational speed at which they operate. The automotive industry is exploiting composite material technology for structural components construction in order to obtain the reduction of the weight without decrease in vehicle quality and reliability. The main difference between composites, where as in alloys, constituent materials are soluble in each other and form a new material which has different properties from their constituents. But in case of composite constituents are combined at a macroscopic level and or not soluble in each other.

## 1.3 CLASSIFICATION OF COMPOSITE MATERIALS

Composite materials can be classified as

a) Polymer matrix composites
b) Metal matrix composites
c) Ceramic Matrix

Technologically, the most important composites are those in which the dispersed phase is in the form of a fiber. The Design of fiber-reinforced composites is based on the high strength is the ratio between strength and density. Specific modulus is the ratio between strength and density. Specific modulus is the ratio between modulus and density. Fiber length has a great influence on the mechanical characteristics of a material. The fibers can be either long or short. Long continuous fibers are easy to orient and process, while short fibers cannot be controlled fully for proper orientation.

## 1.4 PROPERTIES OF COMPOSITE MATERIALS

The physical properties of composite materials are generally not isotropic (independent of direction of applied force or load) in nature, but rather are typically orthotropic (depends on the direction of the applied force or load). For instance, the stiffness of a composite panel will often depend upon the orientation of the applied forces and/or moments. Panel stiffness is also dependent on the design of the panel. In contrast, isotropic materials (for example, aluminum or steel), in standard wrought forms, typically have the same stiffness regardless of the directional orientation of the applied forces and/or moments. While, composite materials exhibit different properties in different directions.

## 1.5 ADVANTAGES OF COMPOSITES OVER THE CONVENTIONAL MATERIALS

1) Better fatigue resistance
2) Improved corrosion resistance
3) High impact resistance
4) High stiffness to weight ratio
5) High strength to weight ratio
6) Good thermal conductivity
7) Low coefficient of thermal expansion. As a result, composite structures may exhibit a better dimensional stability over a wide temperature range.
8) High damping capacity.

## 1.6. LIMITATIONS OF COMPOSITES

1) Rework and repairing are difficult
2) The fabrication cost of composites is high
3) They do not necessarily give higher performance in all properties used for material Selection
4) The design of fiber reinforced structure is difficult compared to a metallic structure, mainly due to the difference in properties in directions
5) They do not have a high combination of strength and fracture toughness as compared to metals
6) Mechanical characterization of a composite structure is more complex than that of metallic structure

## 1.7. APPLICATIONS OF COMPOSITES

The common applications of composites are extending day by day. Nowadays they are used in medical applications too. The other fields of applications are,

| Field of application | Area of use |
|---|---|
| 1. Space | payload bay doors, remote manipulator arm, high gain antenna, antenna ribs and struts etc. |
| 2. Aviation and Aircrafts | Drive shafts, rudders, elevators, bearings, landing gear doors, panels and floorings of airplanes etc. |
| 3. Electrical & Electronics | Structures for overhead transmission lines for railways, Power line insulators, Lighting poles, Fiber optics tensile members etc |
| 4. Automotive | Drive shafts, clutch plates, engine blocks, push rods, frames, Valve guides, automotive racing brakes, filament–wound fuel tanks, fiber Glass/Epoxy leaf springs,suspension arms and bearings for steering system. |

## 2. PROBLEM STATEMENT

In the automobile transmission system drive shaft is most important part. To get the maximum efficiency for power transmission, weight reduction of the vehicle is most desirable goal. Some amount of weight reduction of vehicle is possible by reducing the weight of drive shaft without increase in cost and decrease in quality and reliability. It is possible to achieve design of hybrid drive shaft with less weight to increase the first natural frequency of the shaft.

## 3. SUGGESTED SOLUTION

a) Two-piece steel drive shaft can be replaced in single piece hybrid drive shaft by using hybrid material.
b) Design of hybrid drive shaft can be carry out by using macro mechanical and micro mechanical analysis.
c) Verification of the results is done by using software analysis.

## 4. LITERATURE REVIEW

Robert S. Salzaret. et al. [1], this paper demonstrates a logical step in the application of fiber-reinforced composites is to take advantage of their light-weight/high-strength potential and replace traditional monolithic shaft designs with composite materials. In the case of aircraft engine shafts where the high-temperature environment excludes the use of most traditional materials, a high-strength titanium alloy is recommended.

A. R. Abu Talibet. et.al. [2], In this paper it is mentioned that the study, a finite element analysis was used to design composite drive shafts incorporating carbon and glass fibers within an epoxy matrix. A configuration of one layer of carbon–epoxy and three layers of glass–epoxy with $0^0$, $45^0$ and $90^0$ was used. The developed layers of structure consist of four layers stacked as $[+45^0_{Glass}/-45^0_{glass}/0^0_{carbon}/90^0_{glass}]$.

O. Montagnier et al. [3], in this paper study deals with the optimization of hybrid composite drive shafts operating at subcritical or supercritical speeds, using a genetic algorithm. A formulation for the flexural vibrations of a composite drive shaft mounted on visco-elastic supports including shear effects is developed. In particular, an analytic stability criterion is developed to ensure the integrity of the system in the supercritical regime.

Mohammad Reza Khoshravan et al. [4] Studied design method and vibration analysis of composite propeller shafts. A propeller shaft is not limited to vehicles, but in many transmission applications can be used, but the aim is to replace a metallic drive shaft by a two-piece composite drive shaft.

Durk Hyun Cho et al. [5]The natural bending frequency of a torque transmission shaft can be increased without reducing the torque transmission capability, if the shaft is made using both carbon fiber composite and aluminum: the former increases the natural bending frequency and the latter sustains the applied torque. The high natural bending frequency of a shaft makes it possible to manufacture the drive shaft of passenger cars in one piece.

M.Arun, K.Somasundara Vinoth et al. [6] drive shaft, also known as a propeller shaft or cardan shaft, it is a mechanical part that transmits the torque generated by a vehicle's engine into usable motive force to propel the vehicle. Now a day's two piece steel shaft are mostly used as a drive shaft. This work deals with the replacement of conventional two piece steel drive shafts with a one piece Hybrid Aluminum E glass/epoxy composite drive shaft for an automotive application.

## 5. DESIGN OF CONVENTIONAL STEEL DRIVE SHAFT

| Mechanical properties | Symbol | Units | Steel |
|---|---|---|---|
| Young's Modulus | E | GPa | 210 |
| Shear modulus | G | GPa | 80 |
| Poisson's ratio | μ | - | 0.3 |
| Density | ρ | $Kg/m^3$ | 7800 |
| Yield Strength | $S_y$ | MPa | 370 |

**Table 1. Properties of steel (SM45c)**

The steel drive shaft should satisfy three design specifications such as torque transmission capability, buckling torque capability and bending natural frequency. Steel (SM45C) used for automotive drive shaft applications.

### 5.1 DESIGN OF STEEL DRIVE SHAFT

The steel drive shaft should satisfy three design specifications such as torque transmission capability, buckling torque capability and bending natural frequency.

a) Design of steel shaft based on Torsional Strength basis

$$\tau = \frac{16M_t}{\prod d_o^3(1-C^4)} ...............[1]$$

$$C = 0.8890$$

$$\text{we know} \quad C = \frac{d_i}{d_o}$$

$$d_i = 53.341\ mm$$

b) Design of steel shaft based on Rigidity basis

$$\theta = \frac{584 M_t L}{G d_o^4 (1-\mathrm{C}^4)} ..............................[2]$$

$$\theta = 3.594^0$$

c) Thickness of Steel Drive Shaft

$$t = \frac{d_o - d_i}{2} .............................................[3]$$

$$t = 3.33\ mm$$

5.2) Mass of steel drive shaft

$$m = \rho AL................................................[4]$$

$$m = \rho \times \frac{\pi}{4}(\mathrm{d}_o^2 - \mathrm{d}_i^2) \times L$$

$$m = 8.2774\ kg$$

The mass of spline-sleeve joint = 2.402 kg

$$m_{total} = 10.6794\ \mathrm{kg}$$

5.3) Torque buckling capacity of the drive shaft

$$T_b = (2\Pi r^2{}_m\ \mathrm{t})(0.272)(\mathrm{E})(\frac{t}{r_m})^{\frac{3}{2}} ..................................[6]$$

$$T_b = 38.658 \times 10^3\ N-m$$

5.4) Natural frequency can be found by using

$$f_{nt} = \frac{\pi P^2}{2L^2}\sqrt{\frac{EI_X}{m_1}} ................................[7]$$

$$(f_{nt})_1 = 177.569\ Hz$$

## 6.DESIGN OF HYBRID DRIVE SHAFT

1.2.1) Specification of Problem

The specification of hybrid drive shaft for an automobile is same as of steel drive shaft. Classical lamination theory was used for design of hybrid drive shaft. The material used for composite structure is epoxy resin and carbon fiber along with aluminum (T6-6063).

### 6.1. TORQUE TRANSMITTED BY THE HYBRID DRIVE SHAFT

The torque transmitted by the hybrid drive shaft, T is the sum of the torque transmitted by the aluminum tube, Tal and that by the composite layer, $T_{co}$

$$T = T_{al} + T_{co}$$

a) Torsional Capacity Composite tube

$$T_{(Buckling)co} = (2\Pi r^2{}_m\ \mathrm{t})(0.272)(\mathrm{E}_x\ E^3{}_h)^{\frac{1}{4}}(\frac{t}{r_m})^{\frac{3}{2}}$$

$$T_{(Buckling)co} = 70244.198\ N - m$$

Considering geometric compatibility and material properties of each material, the torque transmitted by the aluminum tube is calculated as follows:

b) Torsional Capacity of Aluminium tube

$$T_{(Buckling)al} = \frac{\pi\sqrt{2}E_{al}}{3\left(1-\upsilon_{avg}^2\right)^{0.75}}\sqrt{r_{avg} t_{al}^5}$$

$$T_{(Buckling)al} = 3857.3184\ N\text{-}m$$

Therefore,

$$T = T_{co} + T_{al}$$

$$T = 70244.198 + 3857.318$$

$$T = 74101.516\ N - m$$

This value is greater than the applied torque of 1472.45 N-m, thus the composite drive shaft is safe in buckling.

c) Fundamental bending natural frequencies of drive shafts

$$f_n = \frac{9.869}{L^2}\sqrt{\frac{E_{al}I_{al} + E_{co}I_{co}}{\rho_{al} + \rho_{co}}}$$

$$f_n = 569.12\ Hz$$

Because the minimum natural frequency is required to be 80 Hz, this requirement is also meet by the Hybrid shaft.

1.2.3) Mass Saving

1. Mass of steel drive shaft = 10.679 kg
2. Total mass of hybrid drive shaft: 5.4595 kg
3. Percentage of mass saving over steel is

$$= \frac{10.6794 - 5.4594}{10.6794} \times 100 = 48.878\%$$

| Parameter | Steel shaft | Hybrid shaft |
|---|---|---|
| Outer Diameter | 60 mm | 70.8 mm |
| Thickness | 3.33 mm | 8.4 mm |
| Torsional Buckling | 38658.23 N-m | 74101.516 N-m |
| Natural Frequency | 177.569 Hz | 379.54 Hz |
| Critical speed | 10654.113 rpm | 22772.46 rpm |
| mass (m) | 10.6794 kg | 5.4595 Kg |
| Percentage of mass saving | - | 48.878 % |

**Table 4. Comparison between steel and Hybrid drive shaft**

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