Design & Analysis of Composite Propeller Shaft

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Abstract— A Propeller Shaft is the connection between the transmission and the rear axle of the vehicles. The function of propeller shaft is to transmit the power from engine to the rear wheel in case of front engine drive vehicle. High quality steel (Steel SM45) is most commonly used material. The steel drive shaft consists of three universal joints, a center supporting bearing and a bracket, which increase the total weight of a system. The Power transmission can be improved through reducing its weight. 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 on the properties of the composite formed by changing volume fraction of carbon fiber & epoxy resin. The focus of this work will be to investigate either replacing steel structure of propeller shaft by composite structure such as carbon fiber & epoxy resin to minimize the cost and weight, also to check the suitability of composite structures by experimental method and software testing.

Key words: Composite Material, Carbon Fiber, Epoxy Resin, Propeller Shaft

I. INTRODUCTION

The drive shaft is the most important component to any power transmission application; automotive drive shaft is one of this. However the drive shaft of the automobile is also referred to as the propeller shaft because apart from transmitting the rotary motion from the front end to the rear end of the vehicle, these shafts also propel the vehicle forward. A driveshaft is the connection between the transmission and the rear axle of the vehicles. The function of propeller shaft is to transmit the power from engine to the rear wheel in case of front engine drive vehicle. Conventional steel propeller shaft is made in two pieces to increase its fundamental natural frequency and bending strength. The use of two piece shaft increases the total weight of the vehicle due to use of bearings and coupling at the center to support the shaft.

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 is 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 carbon 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 drive 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 carbon 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

A driveshaft 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.

III. METHODOLOGY

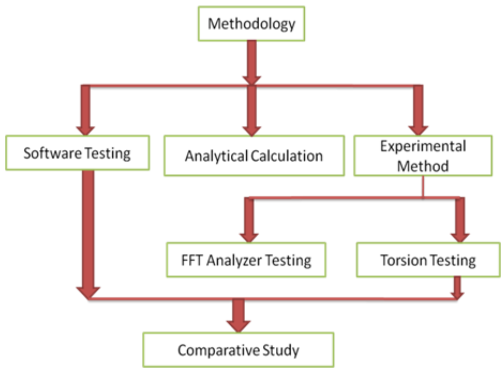

Fig. 1: Methodology

In the present study, it is very important and necessary to develop proper composite shaft specimen by fabrication method. There are lots of fabrication methods to develop composite shaft. It is essential for the reader to know how these materials are made. The selection of a fabrication process obviously depends on the constituent materials in the composite, with the matrix material being the key. The name of fabrication processes given below.

- Hand lay-up.
- Spray-up.
- Automated lay-up.
- Pultrusion process.

- Filament winding.
- Resin transfer molding.

Filament winding method is used to fabricate composite shaft.

A. Fabrication Method

The most common materials are glass/carbon fiber and epoxy resin, although higher performance materials can also be used. In general, composite fiber winding machines are developed due to technological advances in various industries including aerospace, marine, electrical, chemical, transportation, as well as piping system.

Filament winding is a fabrication technique mainly used for manufacturing open (cylinders) or closed end structures (pressure vessels or tanks). The process involves winding filaments under tension over a male mandrel. The mandrel rotates while a wind eye on a carriage moves horizontally, laying down fibers in the desired pattern. The most common filaments are carbon or glass fiber and are coated with synthetic resin as they are wound. Once the mandrel is completely covered to the desired thickness, the resin is cured; often the mandrel is placed in an oven to achieve this, though sometimes radiant heaters are used with the mandrel still turning in the machine. Once the resin has cured, the mandrel is removed, leaving the hollow final product. For some products such as gas bottles the 'mandrel' is a permanent part of the finished product forming a liner to prevent gas leakage or as a barrier to protect the composite from the fluid to be stored.

Filament winding is well suited to automation, and there are many applications, such as pipe and small pressure vessel that are wound and cured without any human intervention. The controlled variables for winding are fiber type, resin content, wind angle, tow or bandwidth and thickness of the fiber bundle. The angle at which the fiber has wound effects on the properties of the final product.

The percentage of fiber and matrix was 50:50 in weight at first, which will vary afterwards according to experiments. Fiber orientation also changes to study the different orientations of fibers on vibration. Below figure shows the filament winding techniques.

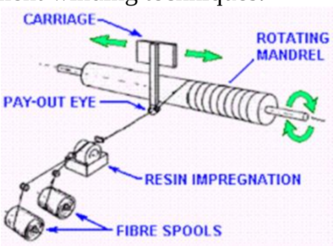

Fig. 2: Filament Winding Process

IV. EXPERIMENTATION

A. FFT Analyzer Testing:

FFT analyzer is used to analyze vibration, to know the natural frequencies of the test specimen.

1) Test Setup

Following apparatus will be used to perform the experiment:

- Impact Hammer.
- Accelerometer.
- Multi-channel Vibration Analyzer (At least two-channel).
- A PC or a Laptop loaded with software for modal analysis.
- Test-specimen (A composite shaft).
- Power supply for the PC and vibration analyzer, connecting cables for the impact hammer and accelerometer, fasteners and spanner to fix the specimen in the fixture, and adhesive/wax to fix the accelerometer).

The connections of all the instruments are done as per the guidance manual. The specimen was excited by impact hammer.

2) Test Procedure

- Prepare the Specimen: Fix the test specimen made of composite material in fixture and divide the whole length of it into equal number of parts. Fix the accelerometer to the specimen at one of the node.
- Connect the wires and cables.
- Switch on the power supply. Open the software of vibration analysis and experimental modal analysis installed on the PC/laptop. Provide necessary inputs and make necessary settings in the software. Ensure that there is proper supply and communication between the devices connected.
- Now we shall provide impacts by the impact hammer on the nodes marked on the test specimen one by one. Signals from the impact hammer and the accelerometer will be received by the vibration analyzer for each impact provided one by one and will be compared and analyzed by the software. Curve known as Frequency Response Function (FRF) will be generated by the software that is used to find the natural frequencies of the plate.
- Observe the curve and read frequencies that correspond to peaks of the FRF.

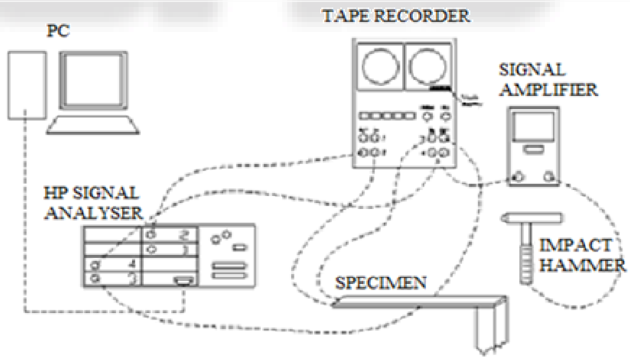

Fig. 3: Experimental Setup

B. Torsion Testing

Torsion testing of the specimen is carried out to study the torque applied versus angle of twist behavior of the drive shaft & determine the mechanical properties, e.g., Modulus of rigidity, Shear strength, and shear strain in torsion.

1) Test setup

Following apparatus will be used to carry out the torsion testing

- Test specimens
- Micrometer or venire caliper
- Permanent pen
- Torsion testing machine

2) *Test Procedure*

- Measure initial diameter, initial length and initial gauge length of the specimen. Record these parameters on the table provided.
- 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.
- 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.
- 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.
- Construct the relationship between shear stress and shear strain. Determine maximum shear stress, shear stress at proportional limit and modulus of rigidity.
- Sketch fracture surfaces of failed specimens and described their natures in the table provided.
- Discuss and conclude the obtained experimental results.

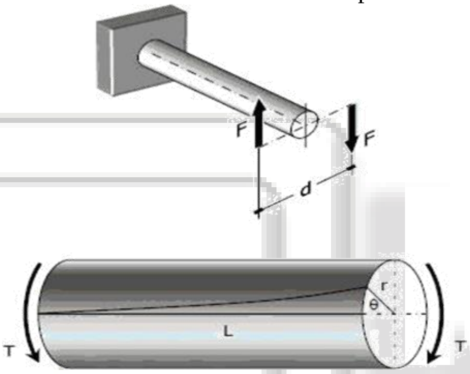

Fig. 4: Torsion Twisting of Bar

V. SOFTWARE TESTING

Finite element analysis is a computer based analysis technique for calculating the strength and behavior of structures. In the FEM the structure is represented as finite elements. These elements are joined at particular points which are called as nodes. The FEA is used to calculate the deflection, stresses, strains temperature, buckling behavior of the member. FEA involves three stages of activity. The finite element analysis methods provide results of stress distribution, displacements and reaction loads at supports etc. for the model.

General procedure of FEA can be described shortly as follows.

- Select suitable field variables and the elements.
- Discretization of continua.
- Select interpolation functions.
- Find the element properties.
- Assemble element properties to get global properties.
- Impose the boundary conditions.
- Solve the system equations to get the nodal unknowns.
- Make the additional calculations to get the required values.

VI. DESIGN OF PROPELLER SHAFT

A. *Selection of Cross-Section*

The drive shaft can be solid circular or hollow circular. Here hollow circular cross-section is chosen because:

- The hollow circular shafts are stronger in per kg weight than solid circular.
- The stress distribution in case of solid shaft is zero at the center and maximum at the outer surface while in hollow shaft stress variation is smaller. In solid shafts the material close to the center are not fully utilized.

Parameter of shaft	Symbol	Value	Unit
Outer Diameter	d_0	68	mm
Inner Diameter	d_i	63	mm
Length of the Shaft	L	1300	mm
Thickness of Shaft	T	2.4	mm

Table 1: Design Parameters For Steel Drive Shaft

Mechanical Properties	Symbol	Value	Units
Young's Modulus	E	207	Gpa
Shear Modulus	G	80	Gpa
Poisson's ratio	μ	0.3	-
Density	ρ	7800	Kg/m^3
Shear Strength	Ss	370	MPa

Table 2: Mechanical Properties Steel Shaft

B. *Mass of the Steel Drive Shaft*

"m = ρAL"
= ρ×Π/4×(d02 - di2) × L"
= 7800 × 3.14/4 × (0.0682– 0.0632) × 1.3
m= 5.10kg.

Property	Carbon / epoxy	Unit
E_{11}	47.05	GPa
E_{22}	58.64	GPa
G_{12}	5.6	GPa
μ_{12}	0.3	-
$\sigma^T_1 = \sigma^C_1$	2910.0	MPa
$\sigma^T_2 = \sigma^C_2$	40.0	MPa
τ_{12}	72.0	MPa
ρ	1550.5	kg/m^3
V_f	0.6	-

Table 3: Mechanical Properties of E-Glass / Epoxy

A. *Mass of Composite Drive Shaft*

"m = ρAL"
= $\rho \times \Pi/4 \times (d_0^2 - d_i^2) \times L$
= $1550.5 \times 3.14/4 \times (0.0334^2 – 0.027^2) \times 1.3$
m= 2.44 kg

VII. CONCLUSION

The composite propeller shaft can be designed to replace the conventional steel propeller shaft of an automobile. The mass of the propeller shaft can be reduced by using composite material. Near about 50% to 60% of weight reduction can be obtained using composite material.

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