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DESIGN & ANALYSIS OF COMPOSITE DRIVE SHAFT FOR AUTOMOBILE APPLICATIONS

Dr.S.Prabhakar, Mr. Gona Yarraiah, Mr. Mudassir, Mr. Mirza Shoeb Ahmed, Mr.Syed Salman
Department of Mechanical Engineering,Shadan College of Engineering and Technology HYD,T.S,INDIA

Abstract- The application of filament winding technology for the manufacturing of composite shaft is in widespread use in automobile & aerospace applications. These include composite drive shaft for car and composite rods for aircraft. Typically, composite drive shaftis designed using torque transmission capacity and torsional buckling capacity of the drive shaft.
In addition to that weight reduction taken as an objective function and the design variables such as Number of plies, thickness of ply and Stacking of sequence subjected to constraints namely Torque transmission of the capacity, Buckling torque capacity of the shaft. Since it is a single objective function with constraints is very difficult to optimize using conventional optimization techniques. Using FE Analysis Optimized the ply design and the results are calculated by using two different composite materials namely E-Glass /Epoxy, Carbon /Epoxy composite. 3D layered analyses of composite drive shaft have been performed to predict the behavior of the structure.It has been observed that the theoretical results are in close agreement with the finite element analysis results. Also, the design stresses were within safe limits.
Key words: Filament winding,Optimization, Composite drive shaft

1. INTRODUCTION

1.0 The advanced composite materials such as Graphite, Carbon, Kevlar and 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 thetorque they can carry as well as the rotational speed at which they operate. The drive shafts are used in automotive, aircraft and aerospace applications. The automotive industry is exploiting composite material technology for structural components construction in order to obtain the reduction of theweight without decrease in vehicle quality and reliability. It is known that energy conservation is one of the most important objectives in vehicle design and reduction of weight is one of the most effective measures toobtain this result. Actually, there is almost a direct proportionality betweenthe weightof a vehicle and its fuel consumption, particularly in city driving

1.1 Description of the Problem:

Almost all automobiles (at least those which correspond to design with rear wheel drive and front engine installation) have transmission shafts. The weight reduction of the drive shaft can have a certain role in the general weight reduction of the vehicle and is a highly desirable goal, if it can be achieved without increase in cost and decrease in quality and reliability It is possibleto achieve design of composite drive shaft with less weight to increase the first natural frequency of the shaft and to decrease the bending stresses using various stacking sequences. By doing the same, maximize thetorque transmission and torsional buckling capabilities are also maximized.

1.2Aim and Scope

This work deals with the replacement of a conventional steel drive shaft with E-Glass/ Epoxy, High Strength Carbon/Epoxy and High Modulus Carbon/Epoxy composite drive shafts for an automobile application.

CHAPTER-2

2. BACKGROUND

2.0 Composites consist of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. The constituents are combined at a macroscopic level and or not soluble in each other. The main difference between composite and an alloy are constituent materials which are insoluble in each other and the individual constituents retain those properties in the case of composites, where as in alloys, constituent materials are soluble in each other and forms a new material which has different properties from their constituents.

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2.1 Classification of Composites:

Composite materials can be classified as

- Polymer matrix composites.
- Metal matrix composites.
- 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 and stiffness on a weight basis. Specific strength 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. Long fibers provide many benefits over short fibers. These include impact resistance, low shrinkage, improved surface finish, and dimensional stability. However, short fibers provide low cost, are easy to work with, and have fast cycle time fabrication procedures. The characteristics of the fiber-reinforced composites depend not only on the properties of the fiber, but also on thedegree to which an applied load is transmitted to the fibers by the matrix phase. The principal fibers in commercial use are various types of glass, carbon, graphite and Kevlar.

All these fibers can be incorporated into a matrix either in continuous lengths or in discontinuous lengths as shown in the Fig.

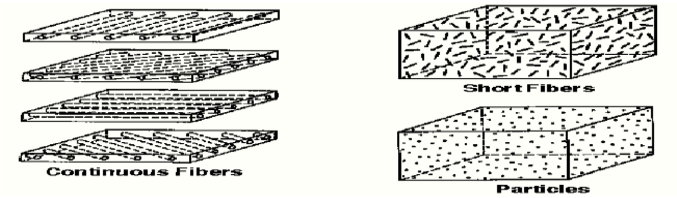

Figure 2.1 Types of fibers

2.2Advantages of Fiber Reinforced Composites:

The advantages of composites over the conventional materials are

- High strength to weight ratio
- High stiffness to weight ratio
- High impact resistance
- Better fatigue resistance
- Improved corrosion resistance
- Good thermal conductivity
- Low Coefficient of thermal expansion. As a result, composite
- structures may exhibit a better dimensional stability over a wide
- Temperature range.
- High damping capacity.

2.3 Limitations of composites:

The limitations of composites are Mechanical characterization of a composite structure is more

- complex than that of a metallic structure
- The design of fiber reinforced structure is difficult compared to ametallic structure, mainly due to the difference in properties indirections
- The fabrication cost of composites is high
- Rework and repairing are difficult
- They do not have a high combination of strength and fracture
- toughness as compared to metals
- They do not necessarily give higher performance in all propertiesused for material selection

2.4 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,

Automotive:

- Drive shafts,clutch plates, engine blocks, push rods,
- frames, Valve guides, automotive racing brakes, filament–wound fuel

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- tanks, fiber Glass/Epoxy leaf springs for heavy trucks and trailers,
- rocker arm covers, suspension arms and bearings for steering system,
- bumpers, body panels and doors

Aircraft:

- Drive shafts, rudders, elevators, bearings, landing gear doors,
- Panels and floorings of airplanes etc.

Space:

- payload bay doors, remote manipulator arm, high gain antenna,
- Antenna ribs and struts etc.

Marine:

- Propeller vanes, fans & blowers, gear cases, valves &strainers,

Condenser shells.

Chemical Industries:

- Composite vessels for liquid natural gas for
- alternative fuel vehicle, racked bottles for fire service, mountain
- Climbing, underground storage tanks, ducts and stacks etc.

Electrical & Electronics:

- Structures for overhead transmission lines
- for railways, Power line insulators, Lighting poles, Fiber optics tensile
- Members etc.

Sports Goods:

- Tennis rackets, Golf club shafts, Fishing rods, Bicycle
- Framework, Hockey sticks, Surfboards, Helmets and others.

2.5 Purpose of the Drive Shaft (or Propeller shaft):

The torque that is produced from the engine and transmission must be transferred to the rear wheels to push the vehicle forward and reverse. The drive shaft must provide a smooth, uninterrupted flow of power to the axles. The drive shaft and differential are used to transfer this torque.

2.6 Functions of the Drive Shaft

- First, it must transmit torque from the transmission to the differential gear box.
- During theoperation, it is necessary to transmit maximum low-gear torque developed by the engine. The drive shafts must also be capable of rotating at the very fast speedsrequired by the vehicle.
- The drive shaft must also operate through constantly changing angles between the transmission, the differential and the axles. As the rear wheels roll over bumps in the road, the differential and axles move up and down. This movement changes the angle between the transmission and the differential.
- The length of the drive shaft must also be capable of changing while transmitting torque. Length changes are caused by axle movement due to torque reaction, road deflections, braking loads and so on. A slip joint is used to compensate for thismotion. The slip joint is usually made of an internal and external spline. It is located on the front end of the drive shaft and is connected to the transmission.

2.7 Different Types of Shafts:

1. Transmission shaft:

These shafts transmit power between the source and the machines absorbing power. The counter shafts, line shafts, overhead shafts and all factory shafts are transmission shafts. Since these shafts carry machine parts such as pulleys, gears etc. Therefore they are subjected to bending moments in addition to twisting.

2. Machine Shaft:

Theseshafts form an integral part of the machine itself. For example, the crankshaft is an integral part of I.C.engines slider-crank mechanism.

3. Axle:

A shaft is called “an axle”, if it is a stationary machineelement and is used for the transmission of bending moment only. Itsimply acts as a support for rotating bodies.

Application: To support hoisting drum, a car wheel or a ropesheave.

4. Spindle:

A shaft is called “a spindle”, if it is a short shaft that imparts motion either to a cutting tool or to a work-piece.

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Applications:

- Drill press spindles-impart motion to cutting tool (i.e.) drill.
- Lathe spindles-impart motion to work-piece. Apart from, an axle and aspindle, shafts are used at so many places and almost everywhere wherever power transmission is required. Few of them are:

5. Automobile Drive Shaft:

Transmits power from main gearbox to differential gear box.

6. Ship Propeller Shaft:

Transmits power from gearbox to propellerattached on it.

7. Helicopter Tail Rotor Shaft:

Transmits power to rail rotor fan. This list has no end, since in every machine, gearboxes, automobiles etc. Shafts are there to transmit power from one end to other.

2.8 Drive Shaft Arrangement in a Car Model:

Conventional two-piece drive shaft arrangement for rear wheel vehicle driving system is shown in figure 2.2 below.

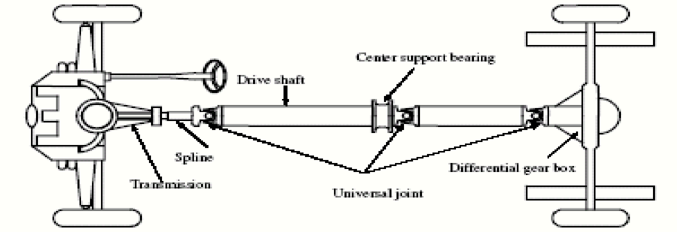

Figure 2.2 Conventional two-piece drive shaft arrangement for rear wheel vehicle driving system.

2.9 Part of Drive Shaft and Universal Joint:

Parts of drive shaft and universal joint are shown in fig.2.3.Parts of drive shaft anduniversal joints are,

1. U-bolt nut
2. U-bolt washers
3. U-bolt
4. Universal joint journal
5. Lubrication fitting
6. Snap ring.
7. Universal joint sleeve yoke
8. Spline seal
9. Dust cap
10. Drive shaft tube

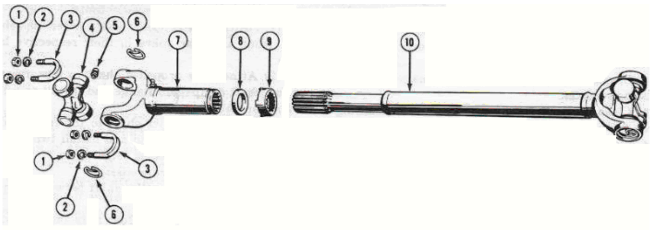

Fig 2.3 Parts of drive shaft and universal joint.

2.9.1Demerits of a Conventional Drive Shaft:

- They have less specific modulus and strength.
- Increased weight.
- Conventional 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. Therefore the steel drive shaft is made in two sections connected by a support structure, bearings and U-joints and hence over all weight of assembly will be more.
- Its corrosion resistance is less as compared with composite materials
- Steel drive shafts have less damping capacity.

2.9.2Merits of Composite Drive Shaft:

- They have high specific modulus and strength.
- Reduced weight.

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- The fundamental natural frequency of the carbon fiber composite drive shaft can be twice as high as that of steel or aluminum because the carbon fiber composite material has more than 4 times the specific stiffness of steel or aluminum, which makes it possible to manufacture the drive shaft of passenger cars in one piece. A one-piece composite shaft can be manufactured so as to satisfy the vibration requirements. 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.
- They have high damping capacity hence they produce less vibration and noise.
- They have good corrosion resistance.
- Greater torque capacity than steel or aluminum shaft.
- Longer fatigue life than steel or aluminum shaft.
- Lower rotating weight transmits more of available power.

CHAPTER-3

3. LITERATURE SURVEY

3.1 Composites:

The theoretical details of composite materials and composite structures areextensively reviewed. The Spicer U-Joint Division of Dana Corporationfor the Ford Econoline van models developed the first composite propellershaft in 1985. The General Motors pickup trucks, which adopted the Spicerproduct, enjoyed a demand three times that of projected sales in its firstyear. John. W. Weeton et al. briefly described the applicationpossibilities of composites in the field of automotive industry tomanufacture composite elliptic springs, drive shafts and leaf springs. Beardmore and Johnson discussed the potential for composites in structural automotive applications from a structural point of view. Pollard studied the possibility of the polymer Matrix composites usage in driveline applications. Faust et.al, described the considerable interest on the part of both the helicopter and automobile industries in the development of lightweight drive shafts. Procedure for finding the elastic moduli of anisotropic laminated composites is explained by Azzi.V.D et.al, Azzi.V.D .et.al, discussed about anisotropic strength of composites.

3.2 Torsional Buckling:

The problem of general instability under torsional load has been studied by many investigators. Greenhill obtained a solution for the torsional stability of a long shaft. The first analysis of buckling of thin-walled tubes under torsion made by Schwerin, but his analysis did not agree with his experimental data. However, all these papers were limited to isotropic materials. As far as orthotropic materials are concerned, general theories of orthotropic shells were developed by Ambartsumyan and Dong et al.Cheng and Ho analyzed more generally, the buckling problems of non-homogeneous anisotropic cylindrical shells under combined axial, radial and torsional loads with all four boundary conditions at each end of the cylinder.

CHAPTER-4

4. DESIGN OF DRIVE SHAFT

4.1 Design of steel drive shaft

The fundamental natural bending frequency for passenger cars, small trucks, and vans of the propeller shaft should be higher than 6,500 rpm to avoid whirling vibration and the torque transmission capability of the drive shaft should be larger than 3,500 Nm. The drive shaft outer diameter should not exceed 100 mm due to space limitations. Here outer diameter of the shaft is taken as 90 mm. The drive shaft of transmission system is to be designed optimally for following specified design requirements.

Steel (SM45C) used for automotive drive shaft applications. The material properties of the steel (SM45C) are given in Table4.2. The steel drive shaft should satisfy three design specifications such as torque transmission capability, buckling torque capability and bending natural frequency.

Mechanical properties	Symbol	Units	Steel
Young's Modulus	E	GPa	205.0
Shear modulus	G	GPa	80.0
Poisson's ratio	v	------	0.3

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Density	ρ	Kg/m	7600
Yield Strength	Sy	MPa	370
Shear Strength	Ss	MPa	-------

Table 4.1 Mechanical properties of Steel (SM45C)

4.1.2 Torque Transmission capacity of the Drive Shaft:

$$\mathbf{T} = S_s \frac{\pi (d_0^4 - d_i^4)}{16 d_0} \text{------ (4.1)}$$

4.1.3 Torsional Buckling Capacity of the Drive Shaft:

$$\text{If } \frac{1}{\sqrt{1-\nu^2}} \frac{L^2 t}{(2r)^3} > 5.5$$

It is as long shaft otherwise it is called Short & Medium Shaft.
For long shaft, the critical stress is given by

$$T_{cr} = (2\pi r^2 t)(0.272)\left(E_x E_y^3\right)^{0.25} \left(t/r\right)^{1.5} \text{----(4.2)}$$

For Short &Medium shaft, the critical stress is given by,

$$\tau_{cr} = \frac{4.39E}{(1-\nu^2)} \left(t/r\right)^2 \sqrt{1 + 0.0257(1-\nu^2)^{3/4} \frac{L^3}{(rt)^{1.3}}} \text{---- (4.3)}$$

The relation between the torsional buckling capacity and critical stress is given by,

$$T_{cr} = \tau_{cr} 2\pi r^2 t \text{ --------(4.4)}$$

4.1.4Lateral or Bending Vibration:

This shaft is consideredas simply supported beam under going transverse vibration orcan be idealized as pinned – pinned beam. Natural frequency can be can be found using the following two theories.

Natural frequency based on theBernolli –Euler beam theory is given by

$$f_{nb} = \frac{\pi p^2}{2L^2} \sqrt{\frac{EI}{m_1}} \text{--------- (4.5)}$$

Natural frequency based on theThimoshenko beam theory is given by

$$f_{nt} = K_s \frac{30\pi p^2}{L^2} \sqrt{\frac{Er^2}{2p}} \text{----------- (4.6)}$$

$$N_{crt} = 60 f_{nt} \text{-------(4.7)}$$

$$\frac{1}{K_s^2} = \frac{1 + n^2 \pi^2 r^2}{2L^2} \left[1 + \frac{f_s E}{G}\right] \text{---------------(4.8)}$$

f_s= 2 for hollow circular cross-section

4.2 Design of composite shaft

The specifications of the composite drive shaft of an automotivetransmission are same as that of the steel drive shaft for optimal design.

4.2.1Assumptions

- The shaft rotates at a constant speed about its longitudinal axis.
- The shaft has a uniform, circular cross section.
- The shaft is perfectly balanced, i.e., at every cross section, the mass center coincides with the geometric center.
- All damping and nonlinear effects are excluded.
- The stress-strain relationship for composite material is linear & elastic; hence, Hooke's law is applicable for composite materials.
- Acoustical fluid interactions are neglected, i.e., the shaft is assumed to be acting in a vacuum.
- Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane stress.

4.2.2Selection of Cross-Section

The drive shaft can be solid circular or hollow circular. Here hollow circular

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cross-section was 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.

4.2.3 Selection of Reinforcement Fiber:

Fibers are available with widely differing properties. Review of the design and performance requirements usually dictate the fiber/fibers to be used

Carbon/Graphite fibers:

Its advantages include high specificstrength and modulus, low coefficient of thermal expansion, andhigh fatigue strength. Graphite, when used alone has low impactresistance. Its drawbacks include high cost, low impact resistance,and high electrical conductivity.

CHAPTER-5

5. 5.1TORQUE TRANSMISSION CAPACITY OF THE SHAFT:

5.1.1 Stress-Strain Relationship for Unidirectional Lamina

The lamina is thin and if no out-of-plane loads are applied, it is consideredas the plane stress problem. Hence, it is possible to reduce the 3-D probleminto 2-D problem.

For unidirectional 2-D lamina, the stress-strain relationship is given by,

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix}$$

$$Q_{11} = \frac{E_{11}}{1 - \nu_{12}\nu_{21}} \qquad Q_{12} = \frac{\nu_{12}E_{22}}{1 - \nu_{12}\nu_{21}}$$

$$Q_{22} = \frac{E_{22}}{1 - \nu_{12}\nu_{21}} \qquad Q_{66} = G_{12} \qquad Q_{21} = Q_{12}$$

5.1.2 Stress-Strain Relationship for Angle-ply Lamina

The relation between material coordinate system and X-Y-Z coordinatesystem is shown in Fig 6.1.Coordinates 1, 2, 3 are principal materialdirections and coordinates X, Y, Z are transformed or laminate axes.

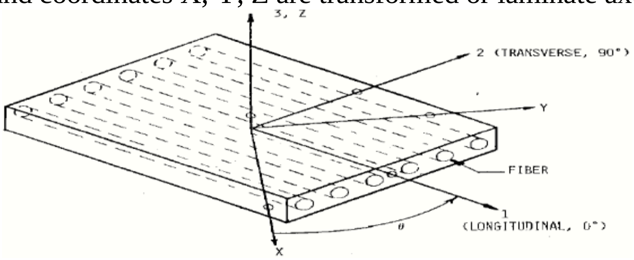

Figure 5.1 Relation between material coordinate system and X-YCoordinate system.

For an angle-ply lamina where fibers are oriented at an angle with thepositive X-axis Longitudinal axis of shaft), the effective elastic propertiesare given by,

$$\frac{1}{E_{xlamina}} = \frac{1}{E_{11}}C^4 + \left[\frac{1}{G_{12}} - \frac{2\nu_{12}}{E_{11}}\right]S^2C^2 + \frac{1}{E_{22}}S^4$$

$$\frac{1}{E_{ylamina}} = \frac{1}{E_{11}}S^4 + \left[\frac{1}{G_{12}} - \frac{2\nu_{12}}{E_{11}}\right]S^2C^2 + \frac{1}{E_{22}}C^4$$

$$\frac{1}{G_{xylamina}} = 2\left[\frac{2}{E_{11}} + \frac{2}{E_{22}} + \frac{2\nu_{12}}{E_{11}} - \frac{1}{G_{12}}\right]S^2C^2 + \frac{1}{G_{12}}\left[C^4 + S^4\right]$$

The variation of the Exlamina, Eylaminaand Gxylaminawith ply orientation is,

The stress strain relationship for an angle-ply lamina is given by,

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$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} \overline{Q_{11}} & \overline{Q_{12}} & \overline{Q_{16}} \\ \overline{Q_{12}} & \overline{Q_{22}} & \overline{Q_{26}} \\ \overline{Q_{16}} & \overline{Q_{26}} & \overline{Q_{66}} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix}$$

$$\overline{Q_{11}} = Q_{11}C^4 + Q_{22}S^4 + 2(Q_{12} + 2Q_{66})S^2C^2 \overline{Q_{12}} = (Q_{11} + Q_{22} - 4Q_{66})S^2C^2 + Q_{12}(C^4 + S^4) \text{--------5.1}$$

$$\overline{Q_{16}} = (Q_{11} - Q_{12} - 2Q_{66})C^3S - (Q_{22} - Q_{12} - 2Q_{66})CS^3$$

$$\overline{Q_{22}} = Q_{11}S^4 + Q_{22}S^4 + 2(Q_{11} + 2Q_{66})S^2C^2$$

$$\overline{Q_{26}} = (Q_{11} - Q_{12} - 2Q_{66})CS^3 - (Q_{22} - Q_{12} - 2Q_{66})C^3S$$

$$\overline{Q_{66}} = (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66})S^2C^2 + Q_{66}(S^4 + C^4)$$

SHEAR-EXTENSION COUPLINGBENDING-EXTENTION COUPLING

$$\begin{Bmatrix} N_x \\ N_Y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{Bmatrix} \epsilon_x^O \\ \epsilon_Y^O \\ \gamma_{xy}^O \end{Bmatrix} + \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{Bmatrix} K_x^O \\ K_Y^O \\ K_{xy}^O \end{Bmatrix} \text{----- (5.2)}$$

$$\begin{Bmatrix} M_x \\ M_Y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} B_{11} & B_{12} & B_{16} \\ B_{12} & B_{22} & B_{26} \\ B_{16} & B_{26} & B_{66} \end{bmatrix} \begin{Bmatrix} \epsilon_x^O \\ \epsilon_Y^O \\ \gamma_{xy}^O \end{Bmatrix} + \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} K_x^O \\ K_Y^O \\ K_{xy}^O \end{Bmatrix} \text{------ (5.3)}$$

BENDING-EXTENSION COUPLING BEND-TWIST COUPLING

$$A_{ij} = \sum_{k=1}^{n} \left((\overline{Q_{ij}})_k h_k - h_{k-1} \right)$$

$$A_{ij} = \sum_{k=1}^{n} \left((\overline{Q_{ij}})_k t_k \right)$$

$$B_{ij} = \frac{1}{2} \sum_{k=1}^{n} \left((\overline{Q_{ij}})_k h_k^2 - h_{k-1}^2 \right)$$

$$D_{ij} = \frac{1}{3} \sum_{k=1}^{n} \left((\overline{Q_{ij}})_k h_k^3 - h_{k-1}^3 \right)$$

Where I, j = 1,2,6.

[A], [B], [D] matrices are called the extensional, coupling, and bending stiffness matrices respectively.

By combiningthe equations 4.7&4.8

$$\begin{Bmatrix} N_x \\ N_Y \\ N_{xy} \\ M_x \\ M_Y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x^O \\ \varepsilon_Y^O \\ \varepsilon_{xy}^O \\ K_x^O \\ K_Y^O \\ K_{xy}^O \end{Bmatrix} \text{----(5.4)}$$

For symentric laminates, the B matrix vanishes and the in plane and bending stiffness are uncoupled. For a symmetric laminate.

$$\begin{Bmatrix} N_x \\ N_Y \\ N_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{Bmatrix} \epsilon_x^O \\ \epsilon_Y^O \\ \gamma_{xy}^O \end{Bmatrix} \text{------ (5.5)}$$

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$$\begin{Bmatrix} M_x \\ M_Y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} K_x^O \\ K_Y^O \\ K_{xy}^O \end{Bmatrix} \text{-------- (5.6)}$$

$$\begin{Bmatrix} \epsilon_x^O \\ \epsilon_Y^O \\ \gamma_{xy}^O \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{16} \\ a_{12} & a_{22} & a_{26} \\ a_{16} & a_{26} & a_{66} \end{bmatrix} \begin{Bmatrix} N_x \\ N_Y \\ N_{xy} \end{Bmatrix} \text{---------(5.7)}$$

$$\begin{Bmatrix} K_x^O \\ K_Y^O \\ K_{xy}^O \end{Bmatrix} = \begin{bmatrix} d_{11} & d_{12} & d_{16} \\ d_{12} & d_{22} & d_{26} \\ d_{16} & d_{26} & d_{66} \end{bmatrix} \begin{Bmatrix} M_x \\ M_Y \\ M_{xy} \end{Bmatrix} \text{----------(5.8)}$$

Where

$$\begin{bmatrix} a_{11} & a_{12} & a_{16} \\ a_{12} & a_{22} & a_{26} \\ a_{16} & a_{26} & a_{66} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix}^{-1} \text{------- (5.9)}$$

$$\begin{bmatrix} d_{11} & d_{12} & d_{16} \\ d_{12} & d_{22} & d_{26} \\ d_{16} & d_{26} & d_{66} \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{16} \\ D_{12} & D_{22} & D_{26} \\ D_{16} & D_{26} & D_{66} \end{bmatrix}^{-1} \text{-------- (5.10)}$$

$E_x = \frac{1}{a_{11}}\frac{1}{t}$ = young's Modulus of the shaft in axial direction

$E_y = \frac{1}{a_{22}}\frac{1}{t}$ = Young's Modulus of the shaft in hoop direction

$G_{xy} = \frac{1}{a_{66}}\frac{1}{t}$ = Rigidity Modulus of the shaft in xy direction

$$\begin{Bmatrix} \epsilon_x \\ \epsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} \epsilon_x^O \\ \epsilon_Y^O \\ \gamma_{xy}^O \end{Bmatrix} + h \begin{Bmatrix} K_x^O \\ K_Y^O \\ K_{xy}^O \end{Bmatrix} \text{------(5.11)}$$

When

Knowing the stresses in each ply, the failure of the laminate is determinedby using the First Ply Failure criteria. That is, the laminate is assumed to first ply fails. Here maximum stress theory is used to find the torque transmitting capacity.

CHAPTER-6

6. TORSIONAL BUCKLING CAPACITY (TCR):

Since long thin hollow shafts are vulnerable to torsional buckling, thepossibility of the torsional buckling of the composite shaft was checked bythe expression for the torsional buckling load Tcr of a thin walledorthotropictube, which was expressed below,

$$T_{cr} = (2\pi r^2 t)(0.272)(E_x E_y^3)^{0.25} (t/r)^{1.5}$$

This equation has been generated from the equation of isotropic cylindricalshell and has been used for the design of drive shafts. From the equationthe torsional buckling capability of composite shaft is strongly dependent on the thickness of composite shaft and the average modulus inthe hoop direction

CHAPTER-7

7. FINITE ELEMENT ANALYSIS

7.1Introduction

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behaviour of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behaviour and many other phenomena. It also can be used to analyze either small or large-scale deflection under loading or applied displacement.It uses a numerical technique called the finite element method (FEM). In finite element method, the actual continuum is represented by the finite elements. These elements are considered to be joined at specified joints called nodes or nodal points. As the actual variation of the field variable (like displacement, temperature and pressure or velocity) inside the continuum is not known, the variation of the field variable inside a finite element is approximated by a simple function. The approximating functions are also called as interpolation models and are defined in terms of field variable at the nodes. When the equilibrium equations for the whole continuum are known,

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the unknowns will be the nodal values of the field variable. In this project finite element analysis was carried out using the FEA software ANSYS. The primary unknowns in this structural analysis are displacements and other quantities, such as strains, stresses, and reaction forces, are then derived from the nodal displacements.

7.2 FE analysis of steel shaft

The finite element model of steel shaft (2.5mm thickness) is shown in Figure 6.2. One end is fixed and torque is applied at other end. The FE results are given in Fig.6.3 to 6.4. The total torque applied is 7000 N-m at free end.

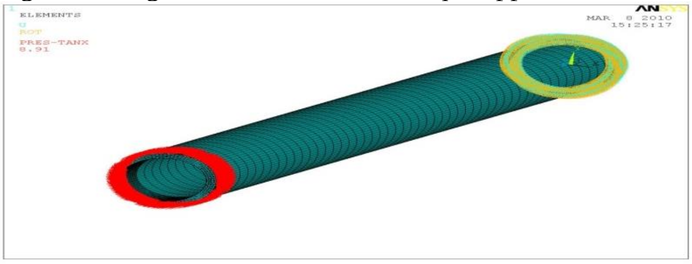

Figure 7.1 FE Model

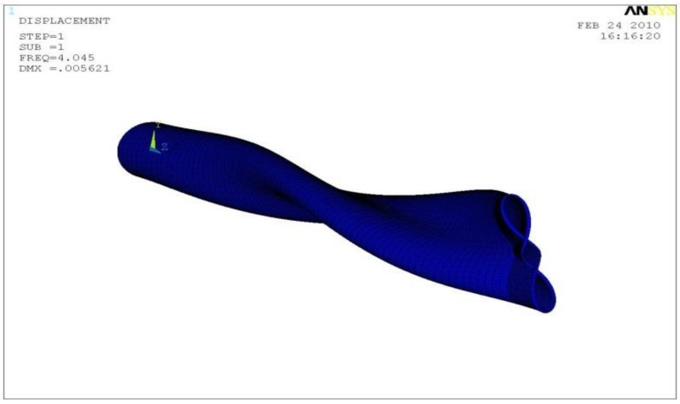

Fig.7.2 Mode shape

. Chapter-8

8. RESULTS AND DISCUSSIONS

8.1 Results:

A one-piece composite drive shaft for rear wheel drive automobile wasdesigned optimally by using genetic Algorithm for E-Glass/ Epoxy, HighStrength Carbon/Epoxy and High Modulus Carbon/Epoxy composites withthe objective of minimization of weight of the shaft which is subjected tothe constraints such as torque transmission, torsional buckling capacitiesand natural bending frequency.

8.1.1Composite Drive Shaft shear in XY-plan:

- Element type: Solid 45
- Torque is applied as normal pressure

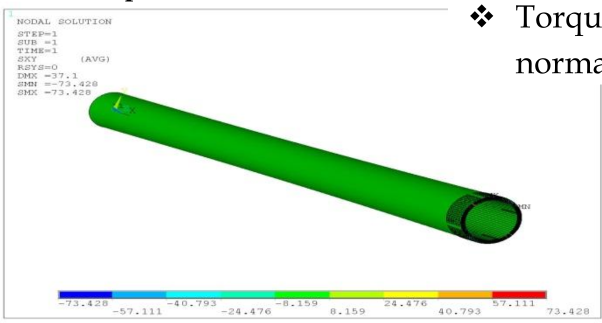

Fig. 8.1 Composite Drive Shaft shear in XY-plan

8.1.2 Composite Drive Shaft shear in XZ-plan:

CHAPTER-9

9. CONCLUSIONS:

The following conclusions are drawn from the present work.

- The E-Glass/ Epoxy, High Strength Carbon/Epoxy and High Modulus Carbon/Epoxy composite drive shafts have been designed to replace the steel drive shaft of an automobile.

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❖ A one-piece composite drive shaft for rear wheel drive automobile has been designed optimally by using Genetic Algorithm for E-Glass/Epoxy, High Strength Carbon/Epoxy and High Modulus Carbon/Epoxy composites with the objective of minimization of weight of the shaft which was subjected to the constraints such as torque transmission, torsional buckling capacities and natural bending frequency.

❖ The weight savings of the E-Glass/ Epoxy, High Strength Carbon/Epoxy and High Modulus Carbon/Epoxy shafts were equal to 48.36%, 86.90% and 86.90% of the weight of steel shaft respectively.

❖ The optimum stacking sequence of E-Glass/ Epoxy, High Strength Carbon/Epoxy and High Modulus Carbon/Epoxy shafts are shown in

Table 9.0 Optimum Stacking Sequence

Material	**stacking sequence**
E-Glass/Epoxy	[46/64/-15/-13/39/-84/-28/20/-$\overline{27}$]
HS Corban/ Epoxy	[-56/-51/74/-8467/70/13/-44/-$\overline{75}$]
HM Corban/ Epoxy	[-65/2568/-63/36/40/-39/74/-$\overline{39}$]

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