Structural and Modal Analysis of Composite Material Shaft with Damping Material

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Abstract

High-technology structures often have stringent requirements for structural dynamics. Suppressing vibrations is crucial to their performance. Passive damping is used to suppress vibrations by reducing peak resonant response. Viscoelastic damping materials add passive damping to structures by dissipating vibration strain energy in the form of heat energy. The incorporation of damping materials in advanced composite materials offers the possibility of highly damped, light-weight structural components that are vibration-resistant. The aim of the project is to analyze the shaft without damping material and with damping material. The present used material for shaft is steel. In this thesis, the composite materials considered are E – Glass Epoxy and S2 Glass Epoxy. The material for damping is rubber. The structural analysis will be done to verify the strength of the shaft and compare the results for three materials. Modal analysis will also be done on the shaft to determine mode shapes. Analysis will be done in Ansys.

Keywords: E – Glass Epoxy, Damping Material, S-2 GLASS

I. INTRODUCTION

A driveshaft is a rotating shaft that transmits power from the engine to the differential gear of a rear wheel drive vehicles. Driveshaft must operate through constantly changing angles between the transmission and axle. High quality steel (Steel SM45) 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 driveshaft weight less than steel or aluminum of similar strength. It is possible to manufacture one piece of 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. As a result, when torque peaks occur in the driveline, the driveshaft can act as a shock absorber and decrease stress on part of the drive train extending life. Many researchers have been investigating about hybrid drive shafts and joining methods of the hybrid shafts to the yokes of universal the drive shaft is generally composed by the main gear box, differential, wheels, transmission and drive shaft shell. Its role is cardan transmission power coming folded over an angle of 90° to change the direction of transmission of force by the main reducer to reduce the speed, to increase the torque, after differential assigned to the left and right axle and drive round.

Function The end of a drive shaft in the powertrain, basic functions: (1) the universal transmission from the engine torque transmitted to the drive wheels, through the main gear box, differential, axle deceleration torque increases pass through the the main reducer bevel gear Deputy change torque direction; (2) through differential differential action on both sides of the wheel, guarantee outer wheels turning at different speeds; (4) through the shaft housing and the wheel bearer The Chuan force. Drive shaft can be divided into non-disconnect disconnected two categories. The form of the structure, the drive shaft can be divided into central single reduction drive shaft, the central double reduction drive shaft, single-stage central hub reduction drive shaft.

II. DESIGN OF COMPOSITE DRIVE SHAFT

A. Specification of the Problem

The fundamental natural bending frequency for passenger’s cars, small trucks and vans of the propeller shaft should be higher than 2,400 rpm to avoid whirling vibration and the torque transmission capability of the drive shaft should be larger than 154 Nm. The drive shaft outer diameter should not exceed 100 mm due to space limitations. The torque transmission capability of the drive shaft is taken as 151 N.m the length and the outer diameter here are considered as 1.5 meters and outer diameter of the
shaft is 0.072, respectively. The drive shaft of transmission system was designed optimally to meet the specified design requirements.

B. Assumptions
The shaft rotates at a constant speed about its longitudinal axis. The shaft has a uniform, circular cross section. The shaft is perfectly balanced, all damping and nonlinear effects are excluded. The stress-strain relationship for composite material is linear and elastic; hence, Hook’s law is applicable for composite materials. Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane stress.

C. Merits of Composite Drive Shaft
1) They have high specific modulus and strength.
2) Reduced weight.
3) Due to the weight reduction, fuel consumption will be reduced.
4) They have high damping capacity hence they produce less vibration and noise.
5) They have good corrosion resistance.
6) Greater torque capacity than steel or aluminum shaft.
7) Longer fatigue life than steel or aluminum shaft

Shafts form the important elements of machines. They are the elements that support rotating parts like gears and pulleys and in turn are themselves supported by bearings resting in the rigid machine housings. The shafts perform the function of transmitting power from one rotating member to another supported by it or connected to it. Thus, they are subjected to torque due to power transmission and bending moment due to reactions on the members that are supported by them. Shafts are to be distinguished from axles which also support rotating members but do not transmit power. Axles are thus subjected to only bending loads and not to the torque. Shafts are always made to have circular cross-section and could be either solid or hollow. The shafts are classified as straight, cranked, flexible or articulated. Straight shafts are commonest to be used for power transmission. Such shafts are commonly designed as stepped cylindrical bars, that is, they have various diameters along their length, although constant diameter shafts would be easy to produce. The stepped shafts correspond to the magnitude of stress which varies along the length. Moreover, the uniform diameter shafts are not compatible with assembly, disassembly and maintenance. Such shafts would complicate the fastening of the parts fitted to them, particularly the bearings, which have to be restricted against sliding in axial direction. While determining the form of a stepped shaft it is borne in mind that the diameter of each cross-section should be such that each part fitted on to the shaft has convenient access to its seat. The parts carried by axle or shaft are fastened to them by means of keys or splines and for this purpose the shaft and axle are provided with key ways or splines. The bearings that support the shafts or axle may be of sliding contact or rolling contact type. In the former case the journal of the shaft rotates freely on thin lubricant layer between itself and bearing, while in the latter case the inner race of the bearing is force fitted on the journal of the shaft and rotates with the shaft while outer race is supported in the housing and remains stationary. A shaft is joined with another in different ways and configurations. The coaxial shafts are connected through couplings which may be rigid or flexible. 166 Machine Design Objectives After studying this unit, you should be able to • describe types of shafts, • estimate shaft diameters in different segments along length, and • design couplings for shafts.

D. Types of Shaft
The types of shaft are mentioned in introduction. Figure 7.1(a) shows a stepped shaft with three seats for supported parts which can be pulleys, gears or coupling. Two seats for bearings are also indicated. These bearings will be rolling contact type. Figure 7.1(b)

E. Drive Shafts and Universal Joints
1) Function
The purpose of the drive shaft and universal joints is to transmit the drive from the gearbox to the back axle with a smooth transmission of torque even though the gearbox and pinion shaft are never in exact alignment.
2) Construction
The shaft is a hollow tubular steel unit with a hook joint at each end. The joint consists of two u shaped ‘yokes’ which are connected at 90° to each other by a four-legged cross or ‘spider’. Needle roller bearing may be used to support the spider legs in the yokes.
Fig. 1: Hotchkiss Drive layout

Fig. 2: Universal Joint

Fig. 3: Sliding Joint

Fig. 4: Two universal joints connected in series

Shows a single crank shaft. The crank may be connected to another element like connecting rod which may have a combined rotary and reciprocating motion. The connection is through a bearing often called crank pin. The straight part of the shaft may support a pulley or a gear. The connection will be through a key. Multiple crank shaft is shown in Figure 7.1(c). Each crank pin would carry a connecting rod and each crank pin will be between the supporting bearings. The other shaft types are explanatory.

3) Operating Principle
When universal joints are used to connect two units (e.g. gearbox and back axle) the driven shaft does not rotate with uniform velocity i.e. it does not turn at the same speed during each part of a revolution. In one revolution the driven shaft is accelerated twice and decelerated twice. This effect being increases as the angularity is increased. These velocity differences can be cancelled in the propeller shaft by the use of two correctly aligned joints, the acceleration of one being neutralised by the deceleration of the second. A sliding joint is used to allow the drive shaft to change its length as it rotates, to compensate for the small backward and forward movement of the rear axle caused by the action of the suspension system. It is simply a splined tubular portion built onto the forward universal joint and it slides in splines on the gearbox mainshaft.
F. Propeller-Shaft Vibration

Due to the high speeds the drive shaft reaches, in top gear its R.P.M. is the same as the engine, the shaft must be balanced to avoid vibration. If vibrations occur in the drive shaft it may be due to worn or broken needle rollers in the universal joint. This may be checked by turning the drive shaft by hand to check for free play, a seized joint may not be detected this way so removal of the shaft may be necessary for further checks.

Small cars and short vans and trucks are able to use a single propeller shaft with a slip-joint at the front end without experiencing any undue vibration. However, with vehicles of longer wheelbase, the longer propeller shaft required would tend to sag and under certain operating conditions would tend to whirl and then set up sympathetic resonant vibrations in the body of the vehicle - that is, cause the body to ‘drum’ or vibrate as the shaft whirls.

![Fig. 5: Simple one-piece propeller shaft with one slip-joint and two universal joints](image)

G. Divided Propeller Shafts and Their Support

Two-piece drive-lines, with two shafts and an intermediate support bearing are generally used on trucks with wheel bases from 3.4 to 4.8 m, but there is some overlap depending on the vehicle’s work role.

![Fig. 6: Two-piece drive-line with single intermediate support bearing](image)

The two-piece propeller shaft has three universal joints, and the primary propeller shaft is of the fixed-joints-and-tube-assembly type, but the secondary propeller shaft has a slip-joint at the support-bearing end to accommodate any elongation due to suspension movement. Usually the primary shaft is in line with the gearbox mainshaft axis, but the secondary propeller shaft is inclined slightly so that it intersects the rear-axle final-drive pinion shaft.

![Fig. 7: Three-piece drive-line with two intermediate support bearings](image)

For vehicles with wheelbases over 4.8 m, a three-piece drive-line with two intermediate support bearings may be necessary. There are four universal-joints, and it can be seen that the intermediate shaft lies parallel to the output shaft of the gearbox. Again only the rear propeller shaft incorporates a slip-joint to compensate for shaft length change.

Now days all automobiles (which are having front engine rear wheel drive) have the transmission shaft as shown in fig.1 [3]. The reduction in weight of the drive system has the advantageous in overall weight reduction of automobiles which is a highly desirable goal of design engineer.

![Fig. 8: Two Piece Drive Shaft Arrangement for Rear Wheel Vehicle Driving System](image)
Composite material Composite consist of two or more material phase that are combine to produce a material that has superior properties to these of its individual constituent. Technologically the most important composite are those in which the dispersed phase is in the form of fibre. The composite materials can be classified on the basis of micro structures, multi phases, reinforcements, manner of packing of fibers layered compositions, method of compositions, matrix system, processing methods, etc. [5] Composite materials can be classified as: 1) Polymer Matrix Composites. 2) Metal Matrix Composites. 3) Ceramic Composites.

A drive shaft, driveshaft, driving shaft, propeller shaft (prop shaft), or Cardan shaft is a mechanical component for transmitting torque and rotation, usually used to connect other components of a drive train that cannot be connected directly because of distance or the need to allow for relative movement between them.

As torque carriers, drive shafts are subject to torsion and shear stress, equivalent to the difference between the input torque and the load. They must therefore be strong enough to bear the stress, whilst avoiding too much additional weight as that would in turn increase their inertia. To allow for variations in the alignment and distance between the driving and driven components, drive shafts frequently incorporate one or more universal joints, jaw couplings, or rag joints, and sometimes a splined joint or prismatic joint. The term drive shaft first appeared during the mid-19th century. In Storer's 1861 patent reissue for a planing and matching machine, the term is used to refer to the belt-driven shaft by which the machine is driven. [11] The term is not used in his original patent. [12] Another early use of the term occurs in the 1861 patent reissue for the Watkins and Bryson horse-drawn mowing machine. [3] Here, the term refers to the shaft transmitting power from the machine's wheels to the gear train that works the cutting mechanism.

In the 1890s, the term began to be used in a manner closer to the modern sense. In 1891, for example, Battles referred to the shaft between the transmission and driving truck of his Climax locomotive as the drive shaft. [4] and Stillman referred to the shaft linking the crankshaft to the rear axle of his shaft-driven bicycle as a drive shaft. [5] In 1899, Bukey used the term to describe the shaft transmitting power from the wheel to the driven machinery by a universal joint in his Horse-Power. [6] In the same year, Clark described his Marine Velocipede using the term to refer to the gear-driven shaft transmitting power through a universal joint to the propeller shaft. [7] Crompton used the term to refer to the shaft between the transmission of his steam-powered Motor Vehicle of 1903 and the driven axle.

An automobile may use a longitudinal shaft to deliver power from an engine/transmission to the other end of the vehicle before it goes to the wheels. A pair of short drive shafts is commonly used to send power from a central differential, transmission, or transaxle to the wheels.

III. PROBLEM FORMULATION

A. Introduction to Propulsion Shaft
The torque transmission capability of the propeller shaft for ship should be larger than 3,500 Nm and fundamental natural bending frequency of the propeller shaft should be higher than 6,500 rpm to avoid whirling vibration. The outer diameter of the propeller shaft should not exceed 100 mm due to space limitations. The propeller shaft of transmission system is shown in figure 4, for following specified design requirements as shown in Table 1. The description of shaft is given in fig. Due to space limitations the outer diameter of the shaft is restricted to 90.24 mm.

![Fig. 9: Pictorial representation of shaft transmission system](image)

B. Problem Description
The one-piece hollow composite drive shaft should satisfy three design specifications, such as static torque transmission capability, torsional buckling capacity and the fundamental natural bending frequency. For given specification, the damping...
factor for Steel, carbon Epoxy and E-Glass Epoxy are to be calculated and compared with and without damping material (Rubber).

<table>
<thead>
<tr>
<th>Problem Specification S. No</th>
<th>Parameter</th>
<th>Notation</th>
<th>Units</th>
<th>Value</th>
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<tr>
<td>1.</td>
<td>Torque</td>
<td>T</td>
<td>N-m</td>
<td>3500</td>
</tr>
<tr>
<td>2.</td>
<td>Max Speed</td>
<td>N</td>
<td>RPM</td>
<td>6500</td>
</tr>
<tr>
<td>3.</td>
<td>Length</td>
<td>L</td>
<td>m</td>
<td>1.250</td>
</tr>
</tbody>
</table>

C. Composites
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, whereas in alloys, constituent materials are soluble in each other and forms a new material which has different properties from their constituents.

D. 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 the degree 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.

The matrix material may be a plastic or rubber polymer, metal or 11

Fig. 10: Types of fibers

E. Advantages of Fiber Reinforced Composites
The advantages of composites over the conventional materials are [1, 2]
- 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.

**F. Limitations of Composites**
The limitations of composites are [1, 2],
- 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 a metallic structure, mainly due to the difference in properties in directions
- 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 properties used for material selection

**G. 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,
1) **Automotive**
Drive shafts, clutch plates, engine blocks, push rods, frames, Valve guides, automotive racing brakes, filament–wound fuel 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
2) **Aircraft**
Drive shafts, rudders, elevators, bearings, landing gear doors, panels and floorings of airplanes etc.
3) **Space**
Payload bay doors, remote manipulator arm, high gain antenna, antenna ribs and struts etc.
4) **Marine**
Propeller vanes, fans & blowers, gear cases, valves &strainers, condenser shells.
5) **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.
6) **Electrical & Electronics**
Structures for overhead transmission lines for railways, Power line insulators, Lighting poles, Fiber optics tensile members etc.
7) **Sports Goods**
Tennis rackets, Golf club shafts, Fishing rods, Bicycle framework, Hockey sticks, Surfboards, Helmets and others

**H. 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.
1) **Functions of the Drive Shaft**
1) First, it must transmit torque from the transmission to the differential gear box.
2) During the operation, it is necessary to transmit maximum low-gear torque developed by the engine.
3) The drive shafts must also be capable of rotating at the very fast speeds required by the vehicle.
4) 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.
5) 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 this motion. 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.

**I. 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 14 twisting.
2) **Machine Shaft**
These shafts form an integral part of the machine itself. For example, the crankshaft is an integral part of I.C.enines slider-crank mechanism.
3) **Axle:**
A shaft is called “an axle”, if it is a stationary machine element and is used for the transmission of bending moment only. It simply acts as a support for rotating bodies.

4) **Application**
To support hoisting drum, a car wheel or a rope sheave.

5) **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.

6) **Applications**
1) Drill press spindles impart motion to cutting tool (i.e.) drill.
2) Lathe spindles impart motion to work-piece.

Apart from an axle and a spindle, shafts are used at so many places and almost everywhere wherever power transmission is required. Few of them are:

1) **Automobile Drive Shaft:** Transmits power from main gearbox to differential gear box.
2) **Ship Propeller Shaft:** Transmits power from gearbox to propeller attached on it.
3) **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.

**J. Drive Shaft Arrangement in a Car Model**
Conventional two-piece drive shaft arrangement for rear wheel vehicle driving system is shown in figure 3.2 below.

![Fig. 11: Conventional Two-piece Drive Shaft Arrangement for rear Wheel](image)

**K. Part of Drive Shaft and Universal Joint**
Parts of drive shaft and universal joint are shown in fig.3.3. Parts of drive shaft and universal 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. 11: Parts of Drive Shaft and universal joint](image)
L. **Demerits of a Conventional Drive Shaft**
1) They have less specific modulus and strength [3].
2) Increased weight [3].
3) 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 [4].
4) Its corrosion resistance is less as compared with composite materials [4].
5) Steel drive shafts have less damping capacity

M. **Merits of Composite Drive Shaft**
1) They have high specific modulus and strength.
2) Reduced weight.
3) The fundamental natural frequency of the carbon fiber composite drive shaft can be twice as high as that of steel or aluminium because the carbon fiber composite material has more than 4 times the specific stiffness of steel or aluminium, 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 [4].
4) Due to the weight reduction, fuel consumption will be reduced [3].
5) They have high damping capacity hence they produce less vibration and noise [4].
6) They have good corrosion resistance [3].
7) Greater torque capacity than steel or aluminium shaft [5].
8) Longer fatigue life than steel or aluminium shaft [5].

Lower rotating weight transmits more of available power

N. **Structural Analysis of Composite Material Shaft with Damping Material**

1) **Case 1:** Material – E-Glass Epoxy

Save Pro-E Model as .iges format

→→Ansys → Workbench → Select analysis system → static structural → double click

→→Select geometry → right click → import geometry → select browse → open part → ok

→→Select mesh on work bench → right click → edit

![Image](https://via.placeholder.com/150)

**Fig. 12:** Double click on geometry → select MSBR → edit material →

O. **Material Properties of E-Glass Epoxy**

Density : \( 0.00000254 \text{kg/mm}^3 \)

Young’s modulus : \( 73000 \text{Mpa} \)
Passions ratio : 0.19
Select mesh on left side part tree → right click → generate mesh →

Select static structural right click → insert → select pressure and displacement →
Select displacement → select required area → click on apply → put X,Y,Z component zero → Select pressure → select required area → click on apply → enter pressure value 2.79Mpa →
Select solution right click → solve →
Solution right click → insert → deformation → total → Solution right click → insert → strain → equivant (von-mises) →
Solution right click → insert → stress → equivant (von-mises) →
Right click on deformation → evaluate all result

P. Result Table

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<td>S2 GLASS</td>
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Q. Model Analysis

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<td>d.o.f</td>
<td>51.88</td>
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| Modal2 | E GLASS | S2 GLASS |
| frequency | 66.204 | 2.347e+006 |
| d.o.f | 51.88 | 1.656 |

| Modal3 | E GLASS | S2 GLASS |
| frequency | 392.53 | 1.3904e+007 |
| d.o.f | 50.935 | 1.625 |

| Modal4 | E GLASS | S2 GLASS |
| frequency | 392.53 | 1.3904e+007 |
| d.o.f | 50.935 | 1.625 |

| Modal5 | E GLASS | S2 GLASS |
| frequency | 420.21 | 1.5028e+007 |
| d.o.f | 64.354 | 2.070 |

R. Shell Element without Damping Results

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S. Shell Element with Damping Results

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<tr>
<td>S2GLASS</td>
<td>6.370</td>
<td>76.961</td>
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IV. CONCLUSIONS

A driveshaft is a rotating shaft that transmits power from the engine to the differential gear of a rear wheel drive vehicles we have designed a shaft used in an engine, 2d drawing is created and modeling of shaft is done using Pro/Engineer. We have done structural, modal shell analysis on shaft using two materials E-GLASS and S-2 GLASS to validate our design.

By observing the results, for all the materials the stress values are less than their respective permissible yield stress values. So our design is safe. We have also done modal analysis for number of modes to see the displacement of shaft for number of frequencies.

By comparing the results for two materials, the stress value for S-2 GLASS is less than that of E-GLASS. By comparing the shell element results for two materials, the stress value for S-2 GLASS is less than that of E-GLASS.

So we conclude that for our design, s-2 glass is better material for shaft.

REFERENCES