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Design And Dynamic Analysis Of Viscoelastic Structures For Propellar Shaft

DAVIDCLAUDE GOLLAPUDI[1]
Dept of Mechanical Engineering
Pursuing M.Tech in G.I.E.T
Rajahmundry

P.Veera Raju[2] Associate professor at
G.I.E.T in the Dept of Mechanical
Engineering, pursuing Ph.D in
(JNTUK) KAKINADA

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 effect of damping on the performance of isotropic (like Steel) and orthotropic (like Carbon Epoxy & E-Glass Epoxy) structures are analysed by using Finite Element Analysis. Damping factors, fundamental natural frequencies are increased for Steel Shaft, Carbon Epoxy Shaft and E- Glass Epoxy Shaft respectively, while embedding the rubber into the structure. The deflection value is decreased for same Shaft respectively, when rubber is embedded into the structure. The effect of damping on the performance of isotropic (steel) and orthotropic (Carbon Epoxy & E-Glass Epoxy) structures is to be analyzed by using Finite Element Analysis

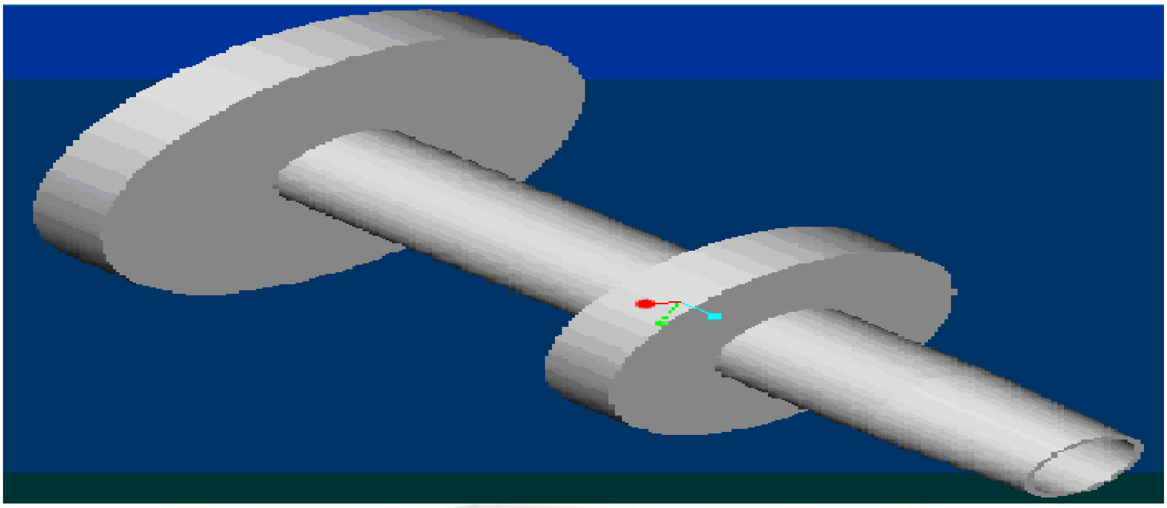
Keywords: laminated composite materials, damping factor, natural frequency, deflection using finite element analysis.

INTRODUCTION
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 for following specified design requirements as shown in Table. Due to space limitations the outer diameter of the shaft is restricted to 90.24 mm. 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 Problem Specification

Sl. No.	Parameter	Notation	Units	Value
1.	Torque	T	N-m	3500
2.	Max Speed	N	RPM	6500
3.	Length	L	m	1.250



Pictorial representation of shaft transmission system.

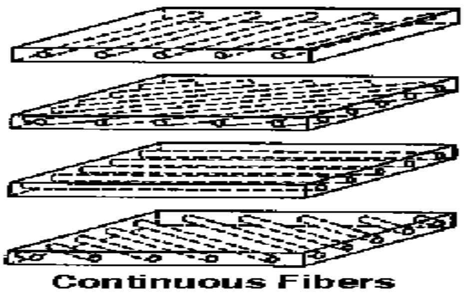
Material Properties

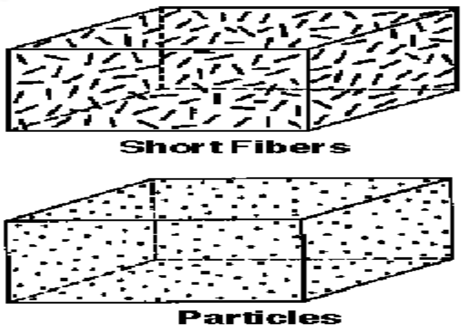
Sl. No.	Properties	Units	Steel	Carbon Epoxy	E-Glass Epoxy	Rubber
1	Young's Modulus E11	N/m^2	$2.068e^{11}$	$1.34\ e^{11}$	$50\ e^{9}$	$3.1027e^{6}$
2	Young's Modulus E22	N/m^2	$2.068e^{11}$	$7\ e^{9}$	$12\ e^{9}$	$3.1027e^{6}$
3	Density	kg/m^3	7830	1600	2000	2.466
4	Poisson Ratio	-	0.3	0.3	0.3	0.49
5	Shear Modulus G	N/m^2	$0.8e^{11}$	$5.8e^{9}$	$5.6e^{9}$	$1.379e^{11}$

COMPOSITE MATERIALS

Composite materials are those containing more than one bonded material, each with different material properties. The major advantages of composite materials are that they have a high ratio of stiffness to weight and strength to weight. A principal advantage of composite materials lies in the ability of the designer to tailor the material properties to the application.

The matrix material may be a plastic or rubber polymer, a metal or a ceramic. The most common form in which fiber reinforced composites are used in structural applications is called a laminate. It is obtained by stacking a number of thin layers of fibers and matrix consolidating them to the desired thickness. Fiber orientation in each layer as well as the stacking sequence of various layers can be controlled to generate a wide range of physical and mechanical properties for the composite laminate.



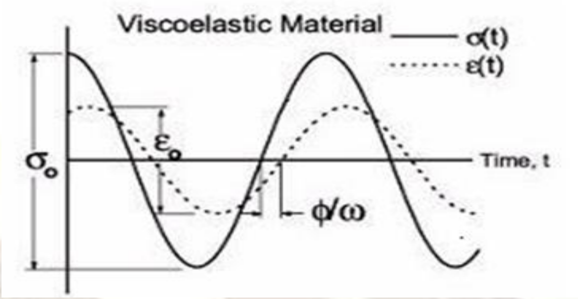


ADVANTAGES OF COMPOSITES

High strength to weight ratio, High stiffness, High impact resistance, Better fatigue resistance, Improved corrosion resistance, Good thermal conductivity

VISCOELASTIC MATERIAL

A Viscoelastic material sometimes is called material with memory. This implies that a Viscoelastic material's behavior depends not only on the current loading conditions, but also on the loading history. They are characterized by possessing both viscous and elastic behavior. A purely elastic material is one in which all the energy stored in the sample during loading is returned when the load is removed. As a result, the stress and strain curves for elastic materials move completely in phase. For elastic materials, Hooke's Law applies, where the stress is proportional to the strain, and the modulus is defined at the ratio of stress to strain.

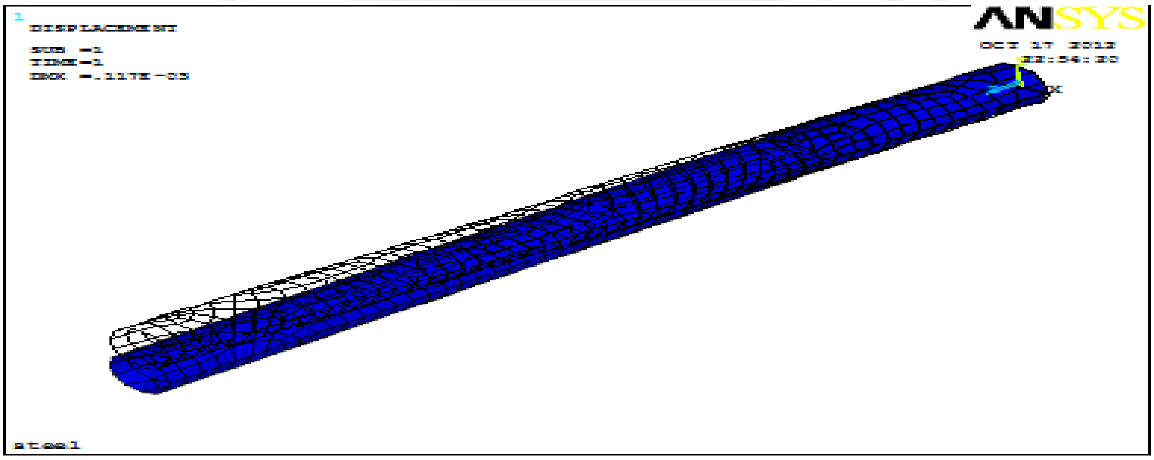


FEM

The Basic concept in FEA is that the body or structure may be divided into smaller elements of finite dimensions called "Finite Elements". The original body or the structure is then considered as an assemblage of these elements connected at a finite number of joints called "Nodes" or "Nodal Points". Simple functions are chosen to approximate the displacements over each finite element. Such assumed functions are called "shape functions". This will represent the displacement with in the element in terms of the displacement at the nodes of the element

7.1 table Specification for Steel Shaft

Sl. No.	Parameters	Values
1	Outer Diameter	0.09024 m
2	Thickness	2.1 e^{-3}



Deflection of Steel Shaft without Rubber

. STEEL SHAFT WITH DAMPING MATERIAL

In this type a damping material (i.e.) Rubber is inserted between the two layers of shaft and the deflection value is calculated using ANSYS. The specification of the shaft with damping material is shown in the Table.

Table Specifications for Steel Shaft with Rubber

Sl. No.	Parameters	Values
1	Outer Diameter	0.09024 m
2	Thickness of each layer	$1.05\ e^{-3}$ m
3	Number of layers	3
4	Damping Material	Rubber
5	Element	Shell 99

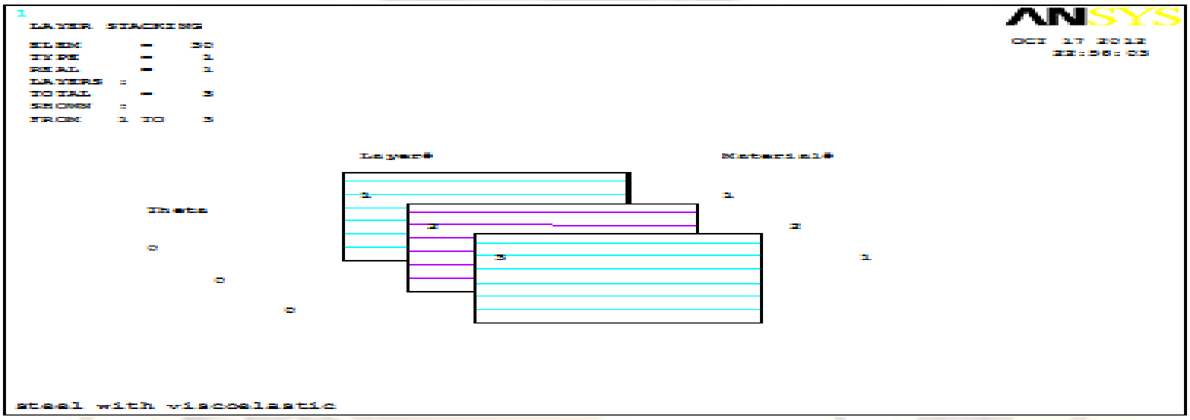
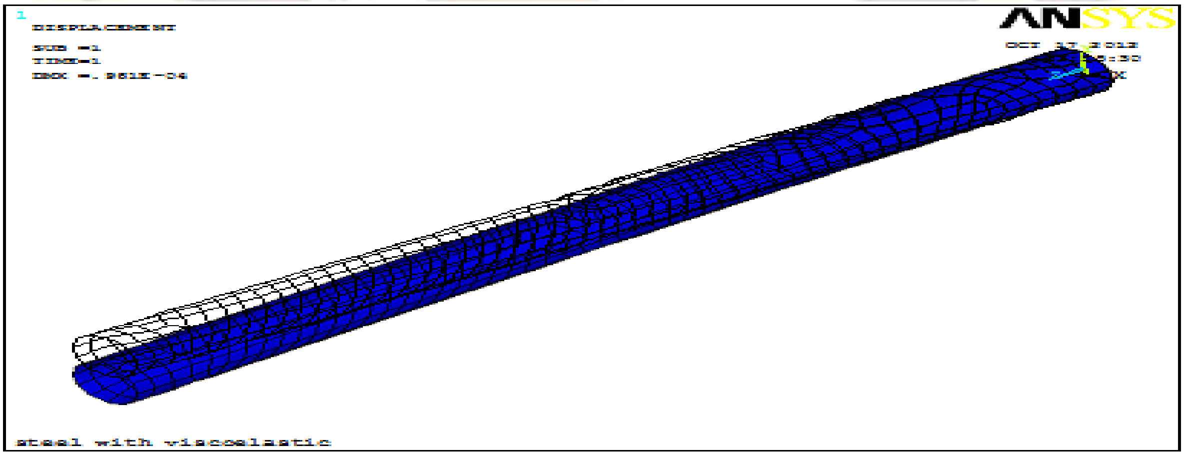


Fig Stacking Sequence for Steel Shaft with Rubber



CARBON EPOXY SHAFT WITHOUT DAMPING MATERIAL

In this case Carbon Epoxy shaft is modeled with 13 layers by considering the shell element. The specifications are shown in the Table .

Table Specification for Carbon Epoxy Shaft

Sl. No.	Parameters	Values
1	Outer Diameter	0.09024 m
2	Thickness of each layer	$1.5\ e^{-4}$ m

3	Number of layers	13
4	Element	Shell 99

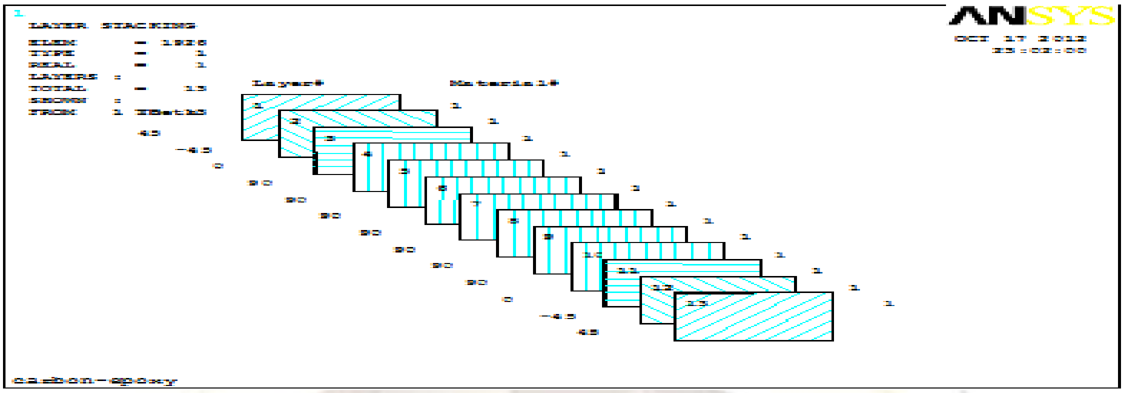


Fig Stacking Sequence for Carbon Epoxy Shaft

In fig the stacking sequence of the Carbon Epoxy shaft without damping material is shown. Using ANSYS 11.0 the deflection value is calculated. The value is 0.93 e $^{-4}$ m. The deformed shape of the shaft is shown in the Fig .. Fig Static Deflection for Carbon Epoxy Shaft

CARBON EPOXY SHAFT WITH DAMPING MATERIAL

In this case Carbon Epoxy shaft is modeled with damping material (Rubber) and it is incorporated in between the layers. The specification of the shaft is shown in the Table .

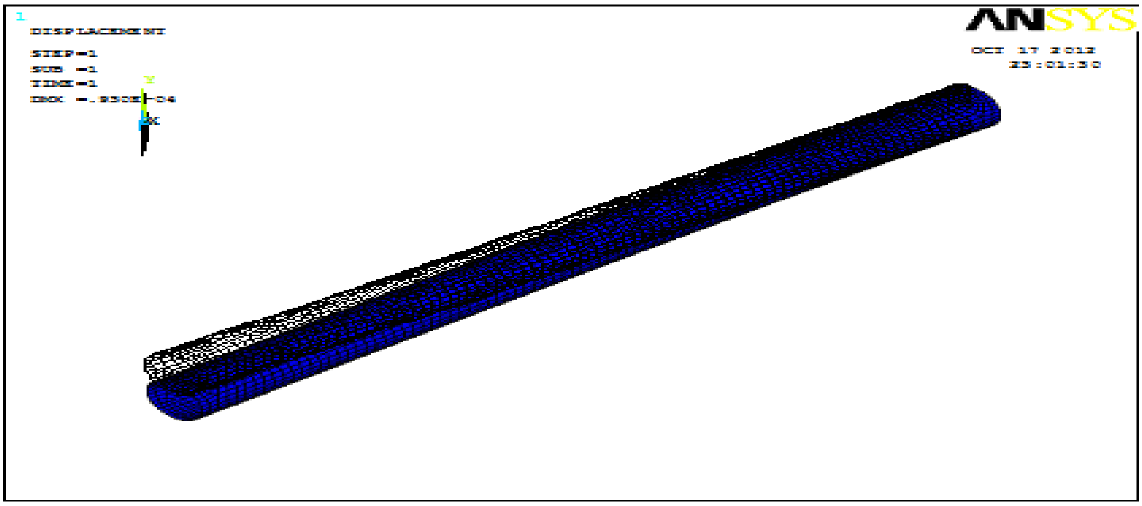


Table Specification for Carbon Epoxy Shaft with Rubber

Sl. No.	Parameters	Values
1	Outer Diameter	.09024 m
2	Thickness of each layer	1.5 e $^{-4}$ m
3	Number of layers	14
4	Damping Material	Rubber
5	Element	Shell 99

The stacking sequence of the Carbon Epoxy shaft with damping material (Rubber) is shown in the fig. Here the

8th layer is the rubber.

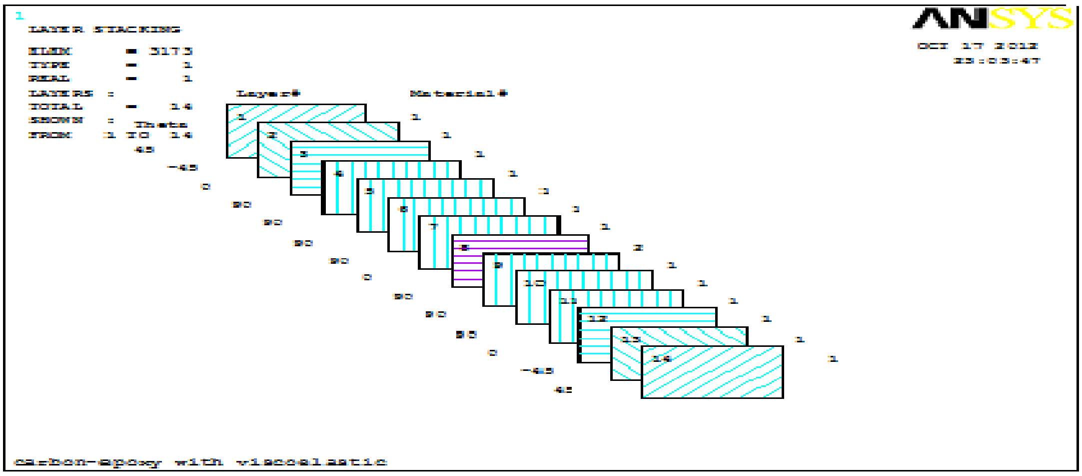


Fig Stacking Sequence for Carbon Epoxy Shaft

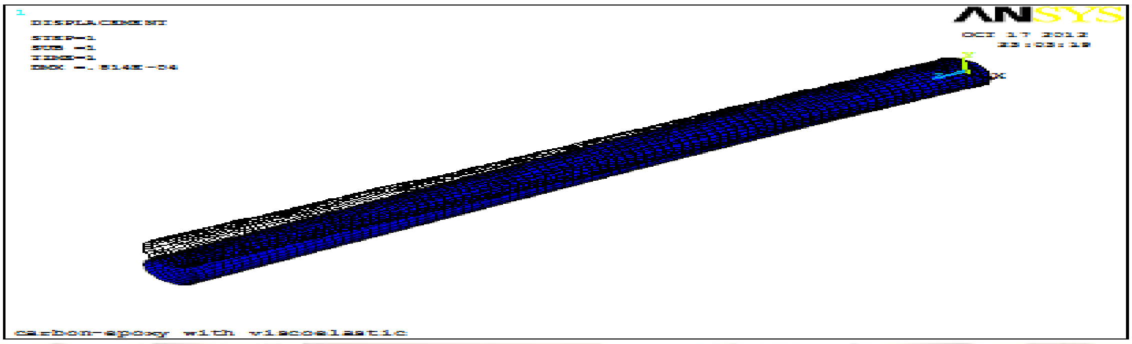


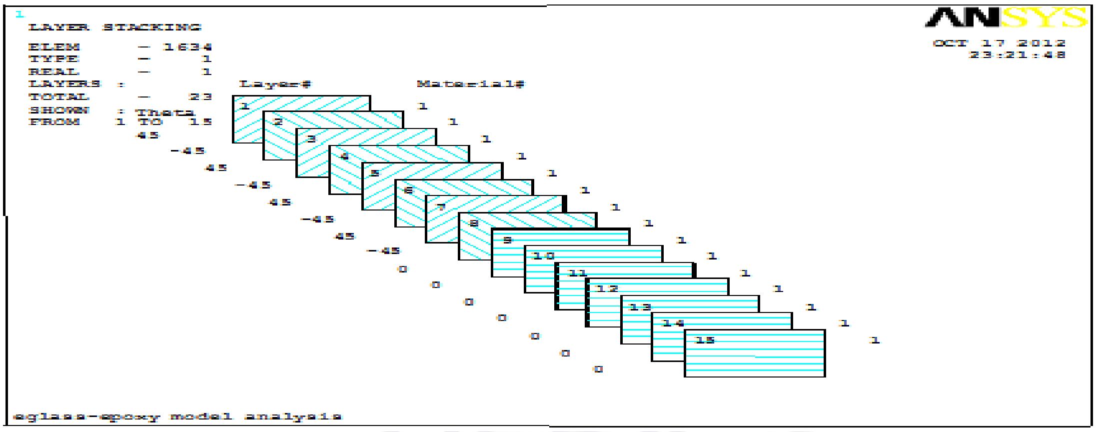
Fig Static Deflection for Carbon Epoxy Shaft with Rubber

Using ANSYS 11.0 the deflection value is calculated.The value is 0.930 e $^{-4}$ m. The deformed shape of the shaft is shown in the Fig .

E-GLASS EPOXY SHAFT WITHOUT DAMPING MATERIAL

In this case E-Glass Epoxy shaft is modeled with 23 layers by using the shell 99 element. The specifications are shown in the Table .Table Specification for E- Glass Epoxy Shaft

Sl. No.	Parameters	Values
1	Outer Diameter	.09024 m
2	Thickness of each layer	1.5 e $^{-4}$ m
3	Number of layers	23
4	Element	Shell 99



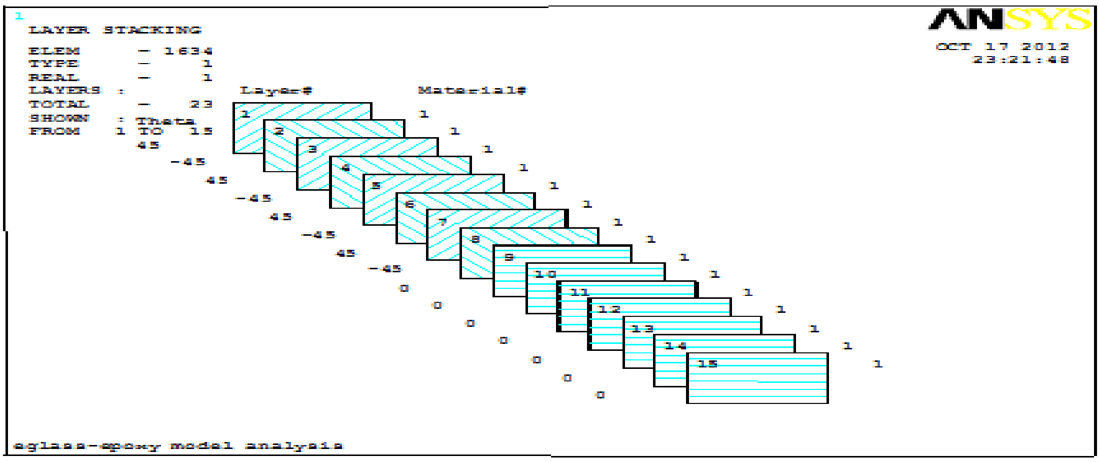


Fig Stacking Sequence Layers from 1 to 15

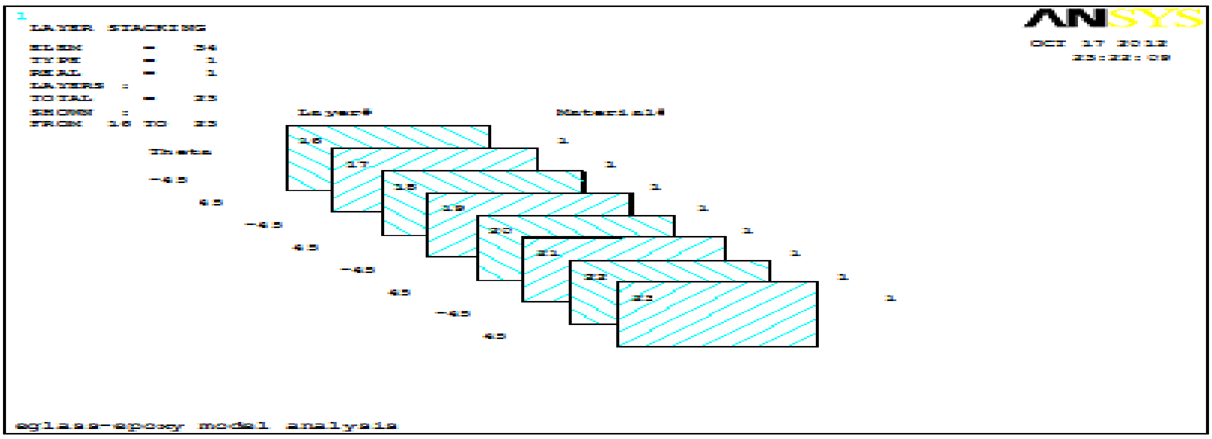


Fig Stacking Sequence Layers from 16 to 23

The stacking sequence of the Carbon Epoxy shaft without damping material is shown in fig .

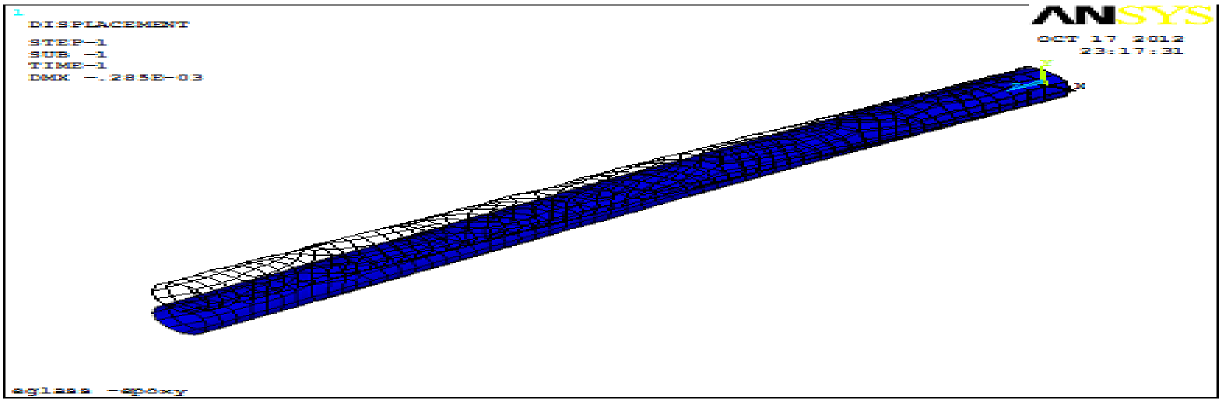


Fig Static Deflection for E-Glass Epoxy Shaft

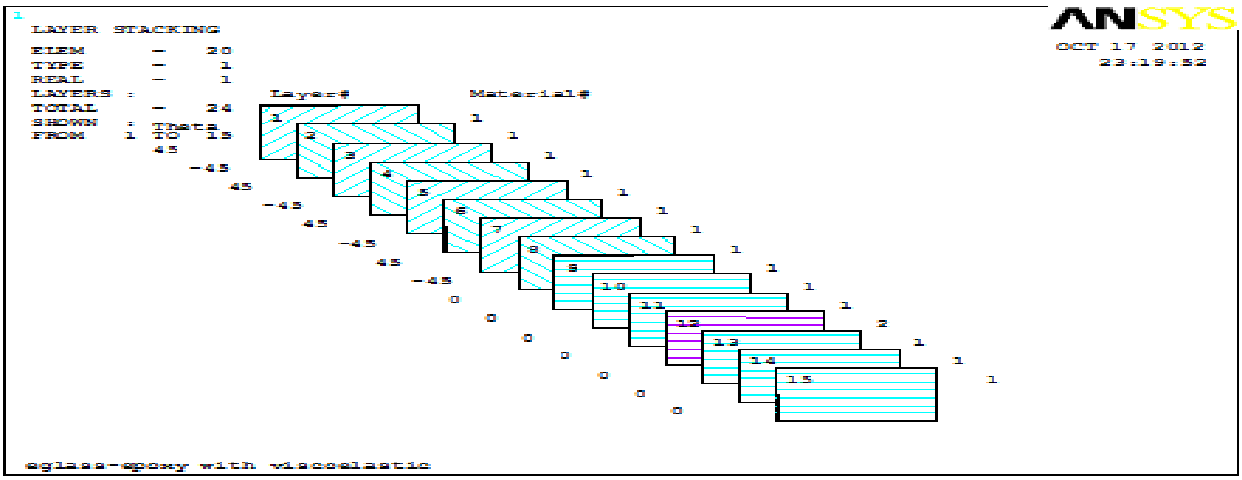
Using ANSYS 11.0 the deflection value is calculated. The value is 0.282 e $^{-3}$ m. The deformed shape of the shaft is shown in the Fign

E-GLASS EPOXY SHAFT WITH DAMPING MATERIAL

In this case E-Glass epoxy shaft is modeled with damping material (Rubber) and it is incorporated in between the layers. The specification of the shaft is shown in the Table .

Table Specification for E- Glass Epoxy Shaft with Rubber

Sl. No.	Parameters	Values
1	Outer Diameter	.09024 m
2	Thickness of each layer	1.5 e $^{-4}$ m
3	Number of layers	14
4	Damping Material	Rubber
5	Element	Shell 99



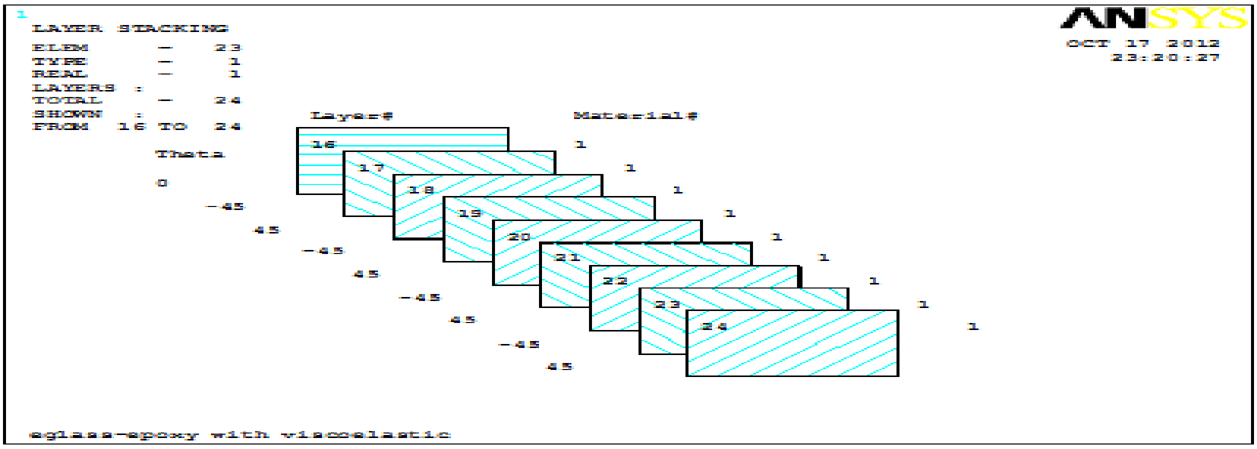


Fig Stacking Sequence Layers from 16 to 24 The stacking sequence of the E-Glass Epoxy shaft with damping material (Rubber) is shown in fig
Here the 12th layer is the rubber.

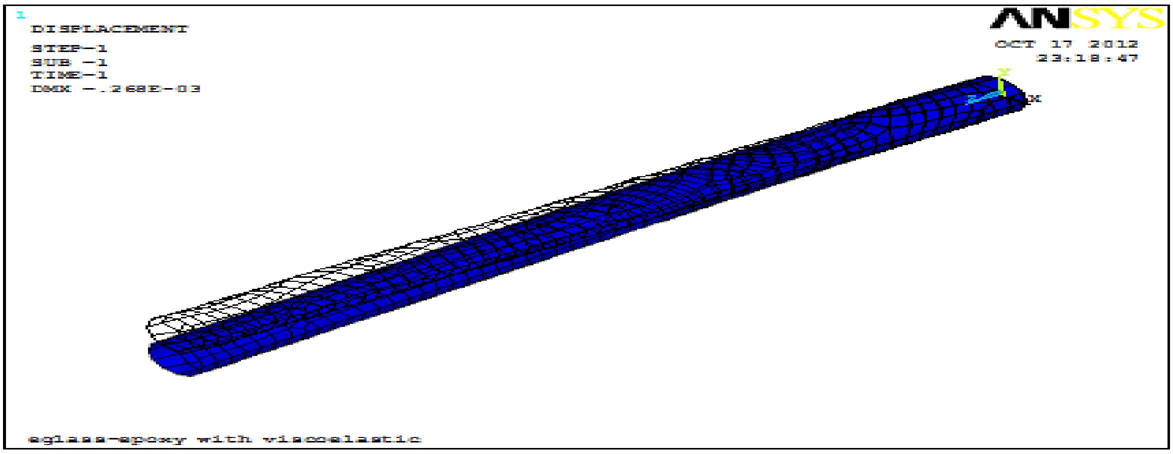


Fig Static Deflection for E-Glass Epoxy Shaft with Rubber
Using ANSYS 11.0 the deflection value is calculated. The value is 0.263 e^{-3} m. The deformed shape of the shaft is shown in the Fig .

RESULTS AND DISCUSSIONS DISCUSSIONS ON PROBLEM

In this case all the results of Static, Modal and Transient Dynamic Analysis of Steel Shaft, Carbon Epoxy Shaft and E-Glass Epoxy shaft with and without damping polymer are tabulated and compared

COMPARISON OF STEEL SHAFT WITH AND WITHOUT DAMPING MATERIAL

Comparison of Results for Steel Shaft

Type of the Shaft / Results	Steel without Viscoelastic Material	Steel with Viscoelastic Material	Deviation (%)
Static Deflection (in m)	0.117 e^{-3}	0.961 e^{-4}	17.86
Fundamental Natural Frequency (in Hz)	57.368	64.011	10.38
Damping Factor	0.04297	0.05037	14.69

From the above results shown in the Table

a. The damping value and the fundamental natural frequency of the steel shaft is increased to 14.69% and 10.38 % respectively, when the shaft is embedded with viscoelastic polymer.

b. The static deflection value of the steel shaft is decreased by 17.86% when the damping material is embedded.

COMPARISON OF CARBON EPOXY SHAFT WITH AND WITHOUT DAMPING MATERIAL

Comparison of Results for Carbon Epoxy Shaft

Type of the Shaft / Results	Carbon Epoxy without Damping Material	Carbon Epoxy with Damping Material	Deviation (%)
Static Deflection (in m)	$0.930\ e^{-4}$	$0.814\ e^{-4}$	12.47
Modal Frequency (in Hz)	64.049	68.568	6.59
Damping Factor	0.08268	0.08945	7.57

From the above results shown in the Table

a. The damping value and the fundamental natural frequency of the Carbon Epoxy shaft is increased to 7.57 % and 6.59 % respectively, when the shaft is embedded with viscoelastic polymer.

b. The static deflection value of the Carbon Epoxy shaft is decreased by 12.47 % when the damping material is embedded.

COMPARISON OF E-GLASS EPOXY SHAFT WITH AND WITHOUT DAMPING MATERIAL

Comparison of Results for E- Glass Epoxy Shaft

Type of the Shaft / Results	Glass Epoxy without Damping Material	Glass Epoxy with Damping Material	Deviation (%)
Static Deflection (in m)	$0.285\ e^{-3}$	$0.268\ e^{-3}$	5.96
Modal Frequency (in Hz)	32.9	33.50	1.8
Damping Factor	0.02702	0.02842	4.93

From the above results shown in the Table

a. The damping value and the fundamental natural frequency of the E- Glass Epoxy Shaft is increased to 4.93 % and 1.8 % respectively, when the shaft is embedded with viscoelastic polymer.

b. The static deflection value of the E- Glass Epoxy Shaft is decreased by 5.96 % when the damping material is embedded.

CONCLUSIONS

- The damping factor has been found out for Steel Shaft, Carbon Epoxy Shaft and E-Glass Epoxy Shaft with and without Viscoelastic polymer (Rubber).
- The Static, Modal and Transient Dynamic Analyses have been carried out using Finite Element Analysis.
- The following observations were made by embedding the Viscoelastic polymer (Rubber) into the structure.
  - ➢ Damping factor increased by 14.69%, 7.57% and 4.93% for Steel, Carbon Epoxy and E- Glass Epoxy Shafts respectively.
  - ➢ The fundamental natural frequency increased by 10.38%, 6.59% and 1.8% for Steel, Carbon Epoxy and E- Glass Epoxy Shafts respectively.
  - ➢ The deflection value decreased by 17.84%, 12.48% and 5.69% for Steel , Carbon Epoxy and E- Glass Epoxy Shafts respectively.
  - ➢ The increase in damping factor results in further suppression of vibrations and hence results in increased structural life.
- An optimal relation between design parameters such as the length, diameter, spacing, and Young's modulus of fibers and the shear modulus of viscoelastic matrix has been derived for achieving maximum damping performance. It has been found that for maximum damping performance, the characteristic value of the composite should be set to 0.75.

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