Design and Analysis of Propeller Shaft

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Abstract – *In current scenario, the most important in automobile power transmission application is the drive shaft. Drive shaft is a mechanical component used to connect the drive train components which are not connected due to the distance between them. Drive shaft are used for transmitting torque and power which subjects the drive shaft to high torsional and shear stress. This work deal with the study of replacement of conventional two-piece steel drive shaft with one-piece composite drive shaft. Automobile industries exploring composite materials in order to obtain reduction of weight without significant decrease in vehicle quality and reliability, this is due to fact that the reduction of weight of a vehicle directly impacts its fuel consumption. Hence design, analysis and comparison are done among material to obtain the most optimized and efficient material for drive shaft.*

Key Words: Drive shaft, composite material, design and analysis.

1. INTRODUCTION

A driveshaft in automobile is a rotating shaft used to transmit power from engine to differential gear of a rear-wheel-drive vehicles. Driveshaft must operate through constantly changing angles between the transmission and axle. The conventional materials used for ordinary shaft are steel, generally 35C8, 45C8, 55C8 etc. When high strength is required alloy steel such as nickel, nickel-chromium or chrome Vanadium steel is used. High quality steel (Steel SM45) is a common material for construction. The steel drive shaft is 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 increases the total weight of an automotive vehicle and decreases fuel efficiency.

1.1 Composite Material

Composite materials can be defined as a macroscopic combination of two or more materials having a recognizable interface between them. Composite materials typically have a fiber or particle phase that is stiffer and stronger than the continuous phase. Now a day's people are using composite materials for many numbers of application in various fields, some of them are aerospace, automotive, construction etc. In the case of automotive application people are using the composite materials for the car door panels, bonnet construction. Drive shafts must be exceptionally tough and light to improve the overall performance of the vehicle, hence automobile industries are exploring composite materials in order to obtain reduction of weight without significant decrease in vehicle quality and reliability. It is possible to manufacture one piece of composite drive shaft to eliminate all of the assembly connecting two-piece steel drive shaft. Composite materials typically have SCOE, B. E. (Mechanical) 2015 Course, Project Stage II, 2018-19 2 a lower modulus of elasticity. As a result, when torque peaks occur in the driveline, the driveshaft can act as a shock absorber, decrease stress on part of the drive train extending life and resonates at a higher rotational speed and keeping a higher margin of safety. The composite drive shaft has other benefits such as reduced weight and less noise and vibration. Hollow circular shafts are commonly used because they are stronger in specific weight than solid circular. In case of solid shafts, the stress distribution is zero at the Centre and maximum at the outer surface, while in hollow circular shafts stress variation is small. The material which is close to the Centre is not completely utilized in solid shafts, so hollow circular shafts are considered over the solid circular shafts. The advanced composite materials such as Graphite, Carbon, Kevlar and Glass with suitable resins are widely used because of their high specific strength/density and high specific modulus/density. Advanced composite materials seem ideally suited for long, power driver shaft (propeller shaft) applications. Their elastic properties can be tailored to increase the torque they can carry as well as the rotational speed at which they operate. 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 to obtain this result. A propeller shaft is an assembly of one or more tubular shaft connected by universal, constant velocity or flexible joints. The number of tubular pieces and the joints depends on the distance between the gearbox and the axle. In some four wheelers one propeller shaft is used to power the rear wheels as with rear wheel drive and a second propeller shaft is used to power the front wheels. In this case the second propeller shaft is replaced between a transfer gear box and the front axle. Hence, it can be observed that a drive shaft is one of the most important components, which is responsible for the actual movement of the vehicle once the motion is produced in the engine. The designing of such a critical component is usually stringent, as any fracture in this part could lead to as catastrophic failure of the vehicle when it is in motion [2].

1.2 Fibers

Fibers are the principal constituent in a fiber-reinforced composite material. They occupy the largest volume fraction in a composite laminate and share the major portion of the load acting on a composite structure. Proper selection of the type, amount and orientation of fibers is very important, because it influences the following characteristics of a composite laminate. a. Specific gravity b. Tensile strength and modulus c. Compressive strength and modulus d. Fatigue strength and fatigue failure mechanisms e. Electric and thermal conductivities f. Cost. The various types of fibers currently in use area. Glass Fibers b. Carbon Fibers c. Aramid Fibers d. Boron Fibers e. Silicon Carbide Fibers.

1.3 Matrix

In a composite material the fibers are surrounded by a thin layer of matrix material that holds the fibers permanently in the desired orientation and distributes an applied load among all the fibers. The matrix also plays a strong role in determining the environmental stability of the composite article as well as mechanical factors such as toughness and shear strength. SCOE, B. E. (Mechanical) 2015 Course, Project Stage II, 2018-19 4 The matrix binds the fibers together, holding them aligned in the important stressed directions. The matrix must also isolate the fibers from each other so that they can act as separate entities. The matrix should protect the reinforcing filaments from mechanical damage (e.g., abrasion) and from environmental attack. A ductile matrix will provide a means of slowing down or stopping cracks that might have originated at broken fibers; conversely, a brittle matrix may depend upon the fibers to act as matrix crack stoppers. Through the quality of its “grip” on the fibers (the interfacial bond strength), the matrix can also be an important means of increasing the toughness of the composite. Because the reinforcing fibers can be oriented during fabrication of item, composites can be tailored to meet increased load demands in specific directions. The combined fiber matrix system is an engineered material designed to maximize mechanical and environmental performance [3].

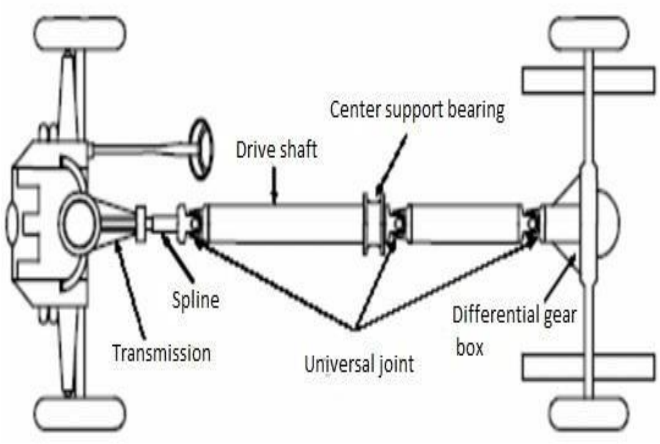

Fig -1.1: Conventional Two-Piece Propeller Shaft [4]

1.4 Need

Shaft must transmit torque from the transmission to the differential gear box. It must also be capable of rotating at the very fast speed required by the vehicle. The drives shaft must also operate through constantly changing the angles between the transmission, the differential and the axle. The length of the drive shaft must also be capable of changing while transmitting torque. 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. This study provides the analysis of the design in many aspects. The composite materials such as Boron, Kevlar, Carbon and Glass with suitable resins are used because they have high specific strength/density and modulus/density respectively. Advanced composite materials seem ideally suited for long, power driver shaft (propeller shaft) applications. Their elastic properties can be tailored to increase the torque they can carry as well as the rotational speed at which they operate. The drive shafts are used in automobile, aircrafts and aerospace applications. 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 to obtain this result [5].

1.5 Problem Statement

The torque transmission capability for passenger cars, small trucks, and vans of the propeller shaft should be higher than 3,500 Nm and the fundamental bending natural frequency of the drive shaft should be larger than 9,200 rpm to avoid whirling vibration. 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 SCOE, B. E. (Mechanical) 2015 Course, Project Stage II, 2018-19 6 be designed optimally for following specified design requirements as shown in Table 1.1 [2].

Table 1.1: Design requirement and Specifications

Sr.No	Name	Notation	unit	value
1	Ultimate Torque	T_{max}	T_{max}	T_{max}
2	Maximum Speed of Shaft	N_{max}	N_{max}	N_{max}
3	Length of Shaft	L	L	L
4	Outer Diameter	Do	Do	Do
5	Thickness	t	t	t

1.6 Aim and Objective

1.6.1 Aim

Aim of this project is to design, analyze and simulate a
propeller shaft which is optimized with respect to weight, strength and reliability.

1.6.2 Objective

The objectives of this project are: • Design of propeller shaft for reduction in weight. • Computer Aided Design of propeller shaft in Solidworks software. • Analysis of a composite drive shaft by using ANSYS software. • Simulation of propeller shaft by using MATLAB software. SCOE, B. E. (Mechanical) 2015 Course, Project Stage II, 2018-19 7 • To compare the results of conventional steel and other composite materials for drive shaft.

1.7 Future scope and limitations

This study leaves wide scope for future investigations. It can be extended to newer composites using other reinforcing phases. The reduction in weight gives further advantage in the increase in the fuel economy of vehicle. The main limitation in this whole process is cost of composite materials [6].

2. METHODOLOGY

The solution for the problem is performed in the following six stages –Defining dimensions, Material Selection, Theoretical Analysis, Creating a Solid Model, Finite Element Analysis and Comparative study. • Defining dimensions: - Taking all the dimensions of pre-existing propeller shaft of the car and using them for further calculation and analysis. • Material Selection: - Selecting the feasible material for Propeller Drive Shaft for a car considering the required parameters. These includes conventional as well as different composite materials. • Theoretical Design: - Theoretical design is performed by using the basic concepts of Strength of Materials. • Creating a Solid Model: - A three-dimensional solid model of shaft is created on the computer using SOLIDWORKS software. This 3D Model is exported to ANSYS software for performing Finite Element Analysis. • Finite Element Analysis: - There are three main steps, namely: pre-processing, solution and post processing. In pre-processing (model definition) includes: define the geometric domain of the problem, the element type(s) to be used, the material properties of the elements, the geometric properties of the elements (length, area, and the like), the element connectivity (mesh the model), the physical constraints (boundary conditions) and the loadings. In solution phase, the governing algebraic equations in matrix form are assembled and the unknown values of the primary field variable(s) are computed. Static analyses are to be carried out on the finite element model of the High strength Carbon/Epoxy composite drive shaft using ANSYS Software. Comparative study: - Weight reduced due to use of composite driveshaft compared to steel shafts and also suggesting different possible materials depending upon the comparison of composites.

2.1 Design and Analysis

The design procedure was carried out by considering the values stated in problem statement which has been mentioned in the first chapter of the report.

2.2 Theoretical Design

2.2.1 Mass of the shaft

The mass m, of the hollow shaft is given by:

$$m = \rho \times A \times L \qquad (3.1)$$

$$m = \rho \times \pi\ 4\ (Do2 - Di2) \times L \qquad (3.2)$$

2.2.2 Torque transmission capacity of shaft

Torque transmission capacity 'Tcr' of a steel drive shaft is given by:

$$T = Ss\ \pi\ (Do4 - Di\ 4)\ /16Do \qquad (3.3)$$

Where, Ss is the shear strength, Do and Di represent outside and inside diameter of the steel shaft.

2.2.3 Torsional Buckling capacity of shaft

If $(1 * L^2 t)\ /(\sqrt{(1-\mu^2)} * (2r)^3) > 5.5$, it is called as long shaft otherwise it is called as short & medium shaft [6]. For a long shaft, the critical stress τ_{cr} is given by:

$$\tau_{cr} = (E\ (t/r)\ \hat{}\ (3/2))\ /(3\sqrt{2}(1-\mu 2)\ \hat{}\ (3/4)) \qquad (3.4)$$

Where, E and μ represent steel properties. L, t and r are the length, thickness and mean radius of the shaft respectively. The relation between the torsional buckling capacity τ_{cr} and critical stress is given by:

$$T_{cr} = \tau_{cr} 2\pi r^2 t \qquad (3.5)$$

2.2.4 Fundamental bending natural frequency

The expression for the lowest natural frequency 'fn' is given as follows:

$$fn = (\pi/\ 2)\ \sqrt{(gEI\ /wL^4)} \qquad (3.6)$$

Where, g, E, I, w and L are the gravitational acceleration, Young's modulus, polar moment of inertia, weight and length respectively.

2.2.5 Torsional Deflection of shaft

The expression for the torsional deflection of the shaft 'θ' is given as follows:

$$\theta = (L \times T)/\ (G \times J) \qquad (3.7)$$

$$\theta = 32 \times L \times T\ /\ (G\pi\ (Do\hat{}4 - Di\hat{}4)) \qquad (3.8)$$

Where, T and G are the torque transmitted and shear modulus of rigidity respectively [5]

2.3 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, 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 [1].

2.4 Dimensions of the Propeller Shaft

By using the theoretical design formula, all the dimensions were obtained which satisfies the given conditions in the problem statement. Further using data analysis, following dimensions were considered to obtain accurate results with minimum weight. Dimensions for shaft are as follows:
Length of the Shaft: 1250 mm
Outer Diameter of the Shaft: 90mm
Inner Diameter of the Shaft: 80mm
Thickness: 10mm

2.5 Material Selection

2.5.1 Materials for Steel drive shaft

Steel is a material mostly used for conventional drive shaft. The steel material which are used for conventional drive shaft must satisfy the specifications such as capacity of torque transmission, bending natural frequency and capability of buckling torque. The properties of all the materials are shown in Table 2.1

2.5.2 Composite Materials for drive shaft

2.5.2.1 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 specific strength and modulus, low coefficient of thermal expansion, and high fatigue strength. Graphite, when used alone has low impact resistance. Its drawbacks include high cost, low impact resistance, and high electrical conductivity. Glass fibers: Its advantages include its low cost, high strength, high chemical resistance, and good insulating properties. The disadvantages are low elastic modulus, poor adhesion to polymers, low fatigue strength, and high density, which increase shaft size and weight. Also crack detection becomes difficult.

2.5.2.2 Selection of Resin System

The important considerations in selecting resin are cost, temperature capability, elongation to failure and resistance to impact (a function of modulus of elongation). The resins selected for most of the drive shafts are either epoxies or vinyl esters. Here, epoxy resin SCOE, B. E. (Mechanical) 2015 Course, Project Stage II, 2018-19 17 was selected due to its high strength, good wetting of fibers, lower curing shrinkage, and better dimensional stability.

2.5.2.3 Selection of Cross-Section

The drive shaft can be solid circular or hollow circular. Here hollow circular 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 [2]

2.6 Material Properties

In the process of material selection, materials were decided upon analyzing and comparing four composite materials with conventional steel, which are Carbon/Epoxy, Glass/Epoxy, Kevlar/Epoxy and Boron/Epoxy. The material properties of all the materials is given bellow in Table 2.1.

Table 2.1: Mechanical Properties of all the materials [4]

	Young's Modulus GPa	Shear Modulus GPa	Poisson's Ratio	Density Kg/m^3	Yield Strength MPa	Shear Strength MPa
Steel (SM45)	207.0	80.0	0.3	7600	370	275
Carbon/Epoxy	190	4.2	0.36	1600	870	97
Glass/Epoxy	50	5.6	0.3	1350	800	72
Kevlar/Epoxy	154	2.9	0.34	2000	1410	80
Boron/Epoxy	204	5.59	0.3	2000	870	67

2.7 Computer Aided Design (CAD Model)

Computer-aided design (CAD) is the use of system (or workstation) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase SCOE, B. E. (Mechanical) 2015 Course, Project Stage II, 2018-19 19 productivity of designer, improve the quality of design, improve communication through documentation, and to create data base for manufacturing. The technical and engineering drawings and image must convey information such as material, processes, dimensions and tolerances according to application-specific conventions. CAD may be used to design curve and figures in two-dimensional (2D) space or curve, surface and solid in threedimensional (3D) space. CAD software for mechanical design uses either vector-based graphics to depict the object of traditional drafting, or may also produce raster graphics showing the overall appearance of designed object. However, it involves more than just shapes. As in the manual drafting of technical and engineering drawings, the output of CAD conveys information, such as material, processes, dimensions and tolerances, according to application-specific convection. Computer Aided Design of the propeller shaft was prepared on CAD software called SOLIDWORKS 18.1.

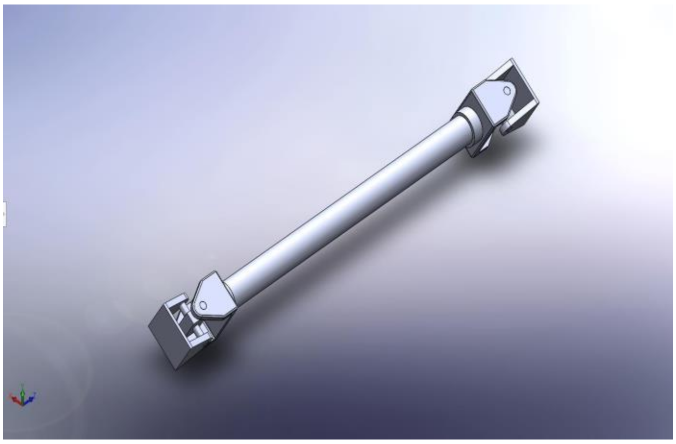

Fig -2.2: 3D Model

2.8 Finite Element Analysis (FEA)

Finite element analysis is a computer-based analysis technique for calculating the strength and behavior of structures. 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 is carried out by using the ANSYS 18.1. Initially the displacement and other quantities like strains, stresses were unknown. which were then calculated from nodal displacement.

2.8.1 Boundary Conditions

As the figure 2.3 shows, one end of the propeller shaft is fixed to a shaft, which is connected to gearbox. Hence all the degrees of freedom at that end are arrested. Another end of the shaft is connected to the differential gear shaft. As the

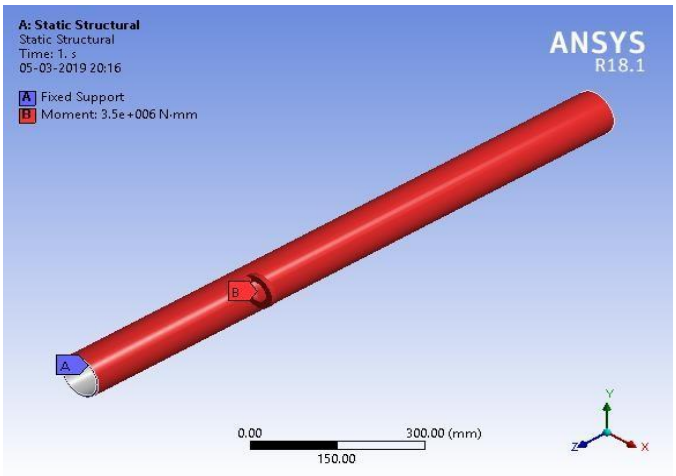

Fig -2.3: Boundary Condition

propeller shaft is subjected to the twisting moment, a moment is applied about x-axis as shown in the figure.

2.8.2 Meshing

The mesh size opt was 2 mm with fine mesh type. For greater control over sizing functions relevance center was selected as fine. Also, to improve element quality medium smoothing was done.

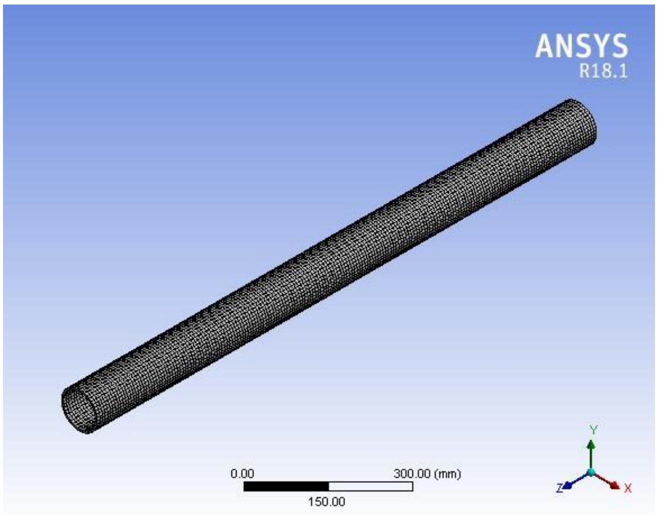

Fig -2.4: Component Meshing

2.8.3 Stacking Sequence

Twenty layers were used for stacking sequence. Ply thickness was obtained as 0.5mm from CAD geometry. Angle of orientation for stacking sequence [0/45/-45/0] [5].

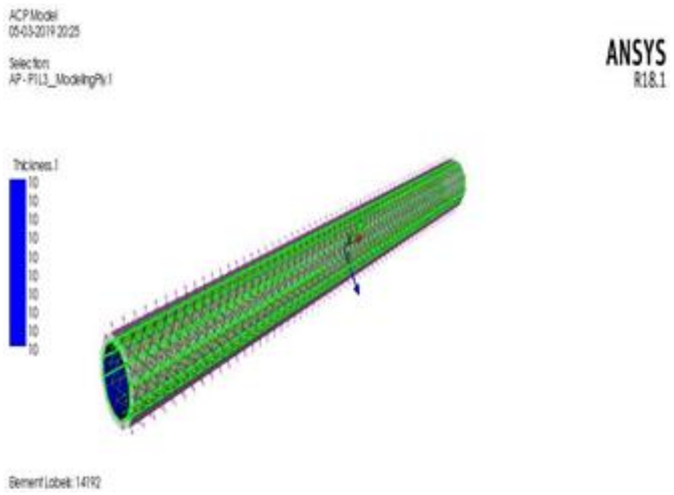

Fig -2.5: Stacking Sequence

2.8.4 Static Structural Analysis

A static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. A static analysis can however include steady inertia loads such as gravity, spinning and time varying loads. In static analysis loading and response conditions are assumed, that is the loads and the structure responses are assumed to vary slowly with respect to time. The kinds of loading that can be applied in static analysis includes, externally applied forces, moments and pressures Steady state inertial forces such as gravity and spinning Imposed non-zero displacements. If the stress values obtained in this analysis crosses the allowable values it will result in the failure of the structure in the static condition itself. To avoid such a failure, this analysis is necessary.

2.8.4.1 FEA Results

1. **Steel**

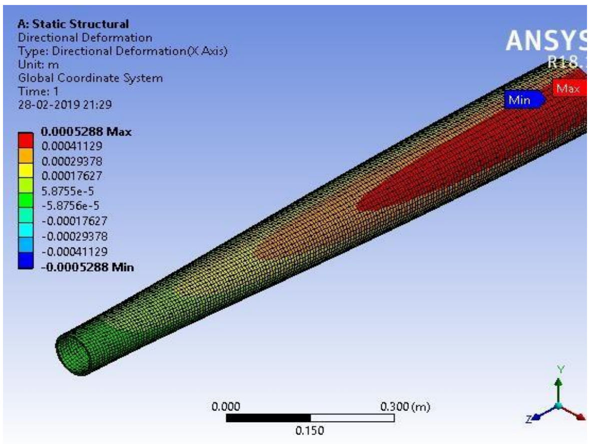

Fig -2.6: Directional Deformation Steel

- Maximum Directional Deformation = 5.288 mm
- Minimum Directional Deformation = -5.288 mm

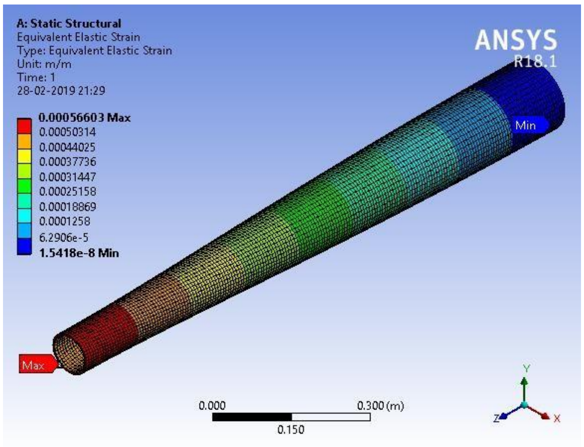

Fig -2.7: Equivalent Elastic Strain Steel

- Maximum Equivalent Elastic Strain = 0.56603 mm/mm
- Minimum Equivalent Elastic Strain = 1.5418e-5 mm/mm

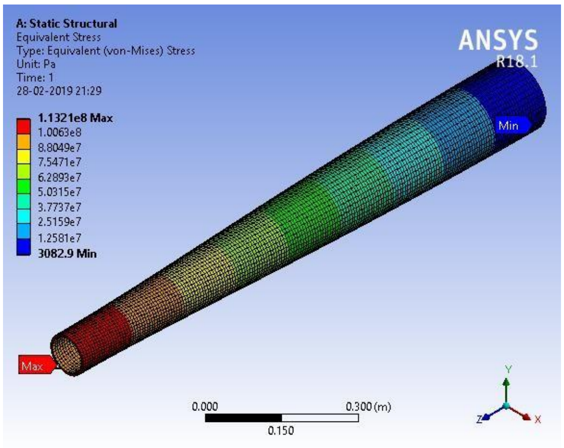

Fig -2.8: Equivalent (von-Mises) Stress Steel

- Maximum Equivalent (von-Mises) Strain = 113 MPa
- Minimum Equivalent (von-Mises) Strain = 0.0030829 MPa

2. Carbon/Epoxy

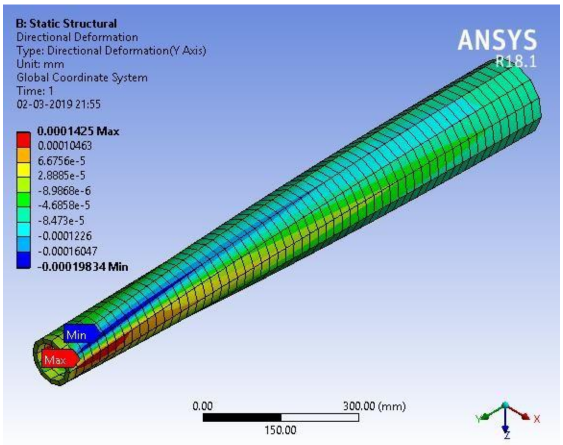

Fig -2.9: Directional Deformation Carbon/Epoxy

- Maximum Directional Deformation=0.0001425 mm
- Minimum Directional Deformation =-0.0019834 mm

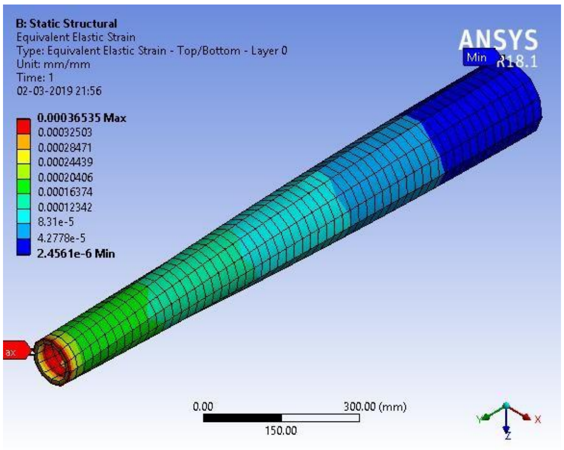

Fig -2.10: Equivalent Elastic Strain Carbon/Epoxy

- Maximum Equivalent Elastic Strain = 0.00036535 mm/mm
- Minimum Equivalent Elastic Strain = 2.456e-6 mm/mm

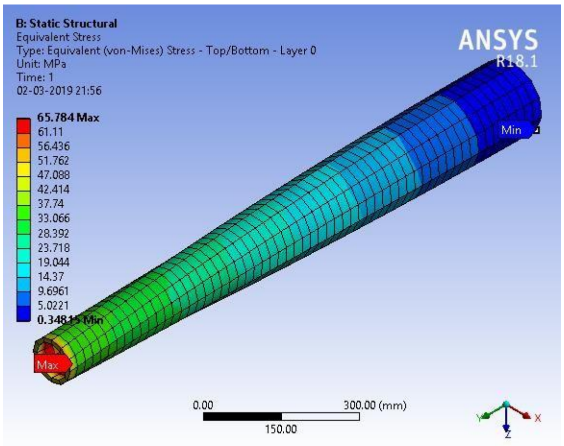

Fig -2.11: Equivalent (von-Mises) Stress Carbon/Epoxy

- Maximum Equivalent (von-Mises) Stress = 65.784

- MPa Minimum Equivalent(von-Mises) Stress = 0.34815 MPa

3. Glass/Epoxy

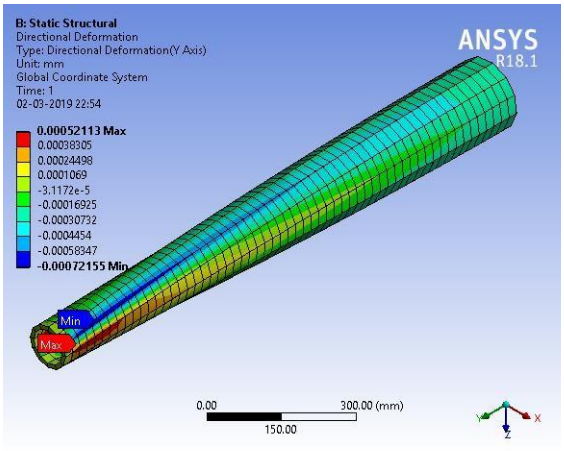

Fig -2.12: Directional Deformation Glass/Epoxy

- Maximum Directional Deformation = 0.00052113 mm
- Minimum Directional Deformation = -0.00072155 mm

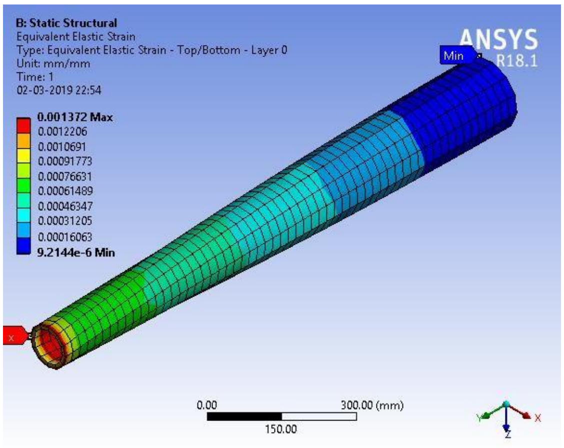

Fig -2.13: Equivalent Elastic Strain Glass/Epoxy

- Maximum Equivalent Elastic Strain = 0.001372 mm/mm
- Minimum Equivalent Elastic Strain = 9.2144e-6 mm/mm

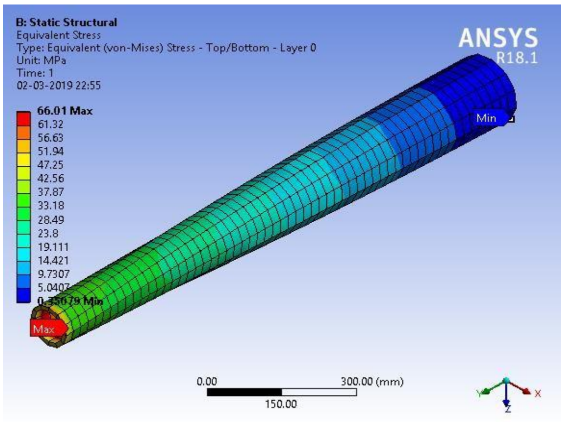

Fig -2.14: Equivalent(von-Mises) Stress Glass/Epoxy

- Maximum Equivalent(von-Mises) Stress = 66.01 MPa
- Minimum Equivalent(von-Mises) Stress = 0.35079 MPa

4. Kevlar/Epoxy

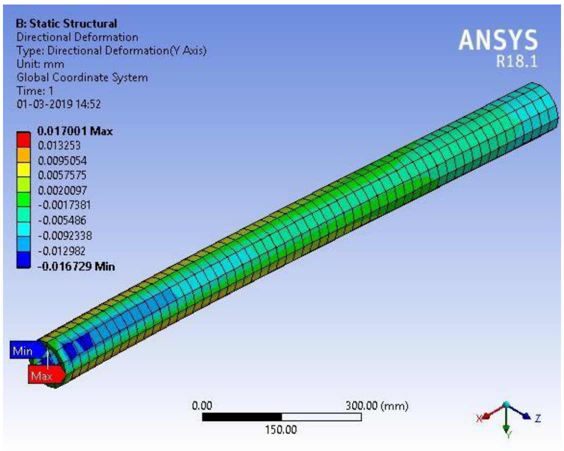

Fig -2.15: Directional Deformation Kevlar/Epoxy

- Maximum Directional Deformation = 0.017001 mm
- Minimum Directional Deformation = -0.016729 mm

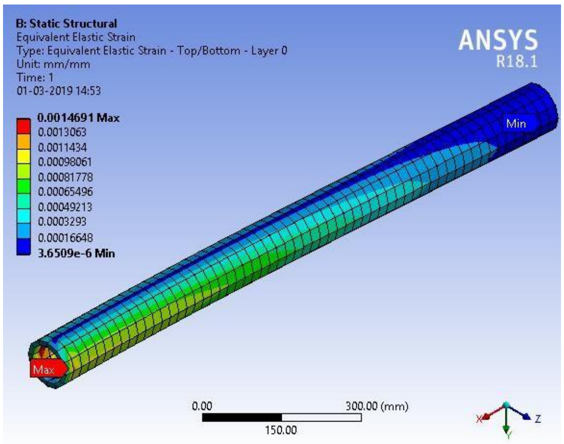

Fig -2.16: Equivalent Elastic Strain Kevlar/Epoxy

- Maximum Equivalent Elastic Strain = 0.0014691 mm/mm
- Minimum Equivalent Elastic Strain = 3.6509e-6 mm/mm

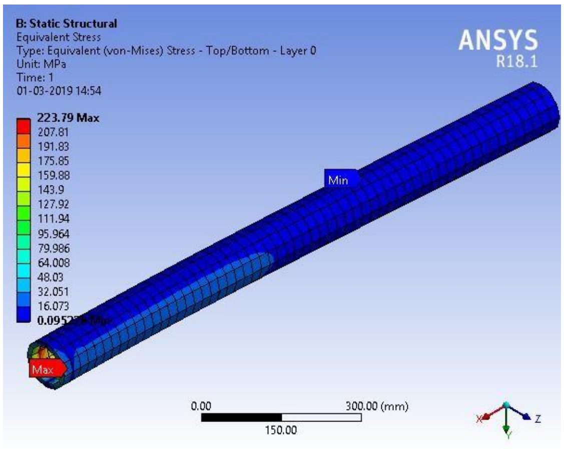

Fig -2.17: Equivalent (von-Mises) Stress Kevlar/Epoxy

- Maximum Equivalent (von-Mises) Stress = 223.79 MPa
- Minimum Equivalent (von-Mises) Stress = 0.0953 MPa

5. Boron/Epoxy

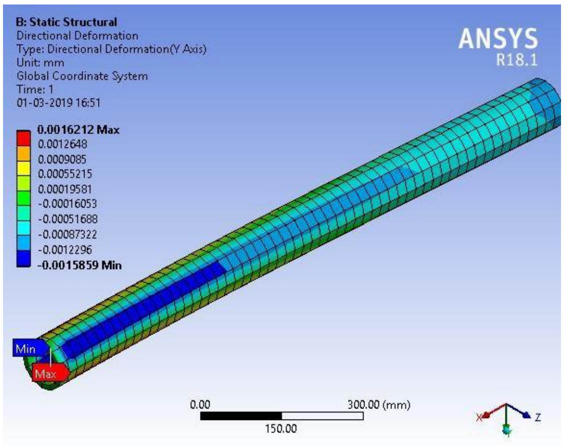

Fig -2.18: Directional Deformation Boron/Epoxy

- Maximum Directional Deformation = 0.0016212 mm
- Minimum Directional Deformation = -0.0015859 mm

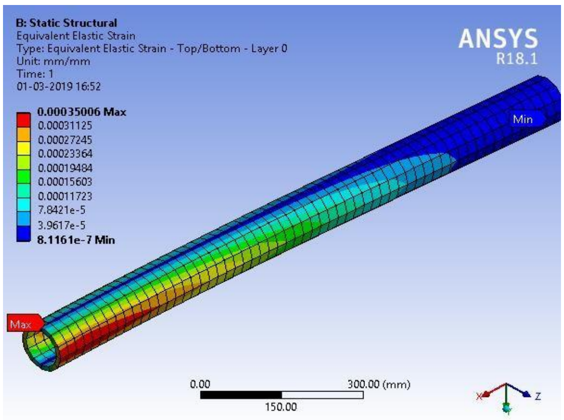

Fig -2.19: Equivalent Elastic Strain Boron/Epoxy

- Maximum Equivalent Elastic Strain = 0.00035006 mm/mm
- Minimum Equivalent Elastic Strain = 8.1161e-7 mm/mm

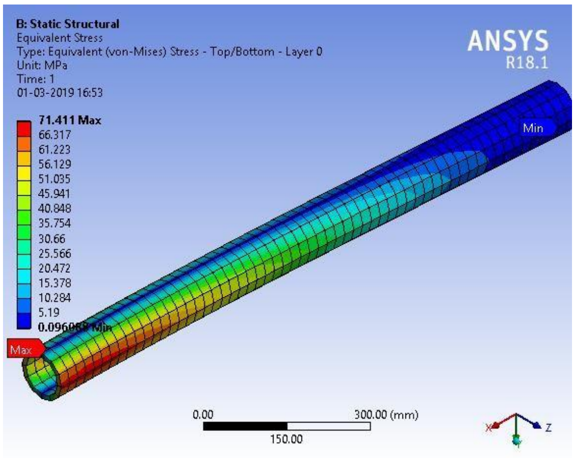

Fig -2.20: Equivalent (von-Mises) Stress Boron/Epoxy

- Maximum Equivalent Elastic Strain = 71.411 MPa
- Minimum Equivalent Elastic Strain = 0.096059 MPa

2.9 Modal Analysis

Modal analysis is used to determine the vibration characteristics such as natural frequencies and mode shapes of a structure or a machine component while it is being designed. As two-piece drive shaft is replaced with single piece the modal analysis is one of the important analysis for drive shaft.

2.9.1 FEA Result

1. **Steel**

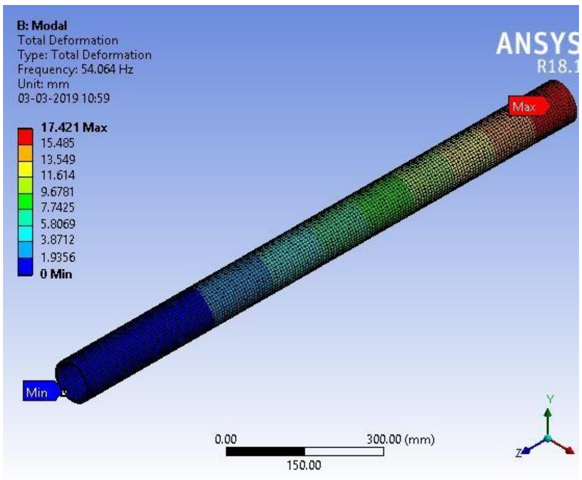

Fig -2.21: Mode 1 f1 = 54.064 Hz

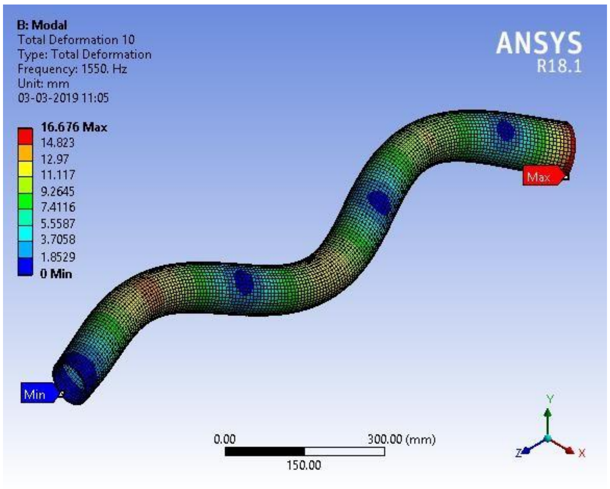

Fig -2.22: Mode 10 f10 = 1150 Hz

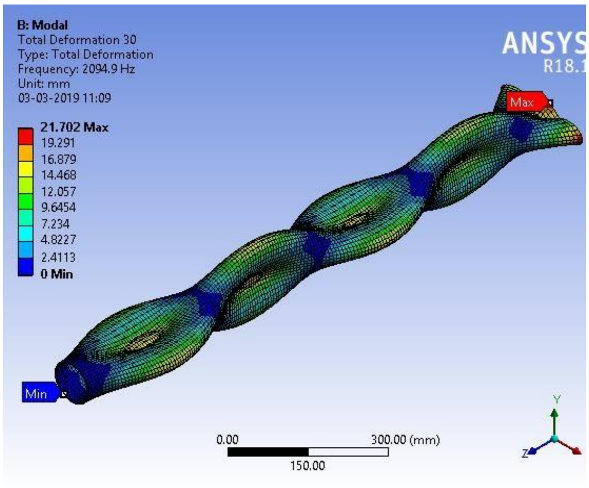

Fig -2.23: Mode 20 f20 = 2094.9 Hz

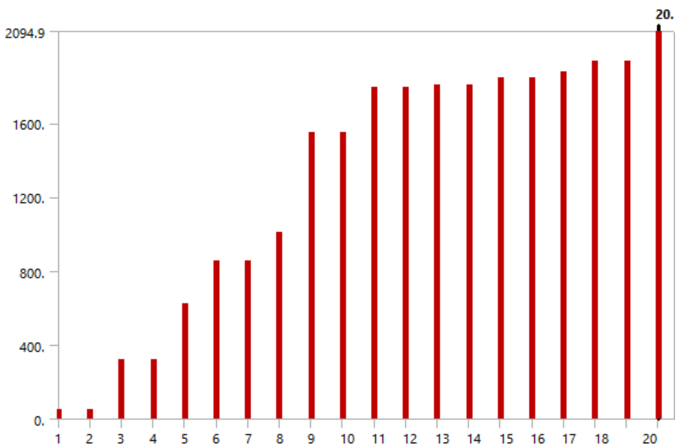

Chart -1: Variation of number of modes vs frequency. X-axis contains number of modes and Y-axis contains frequency

2. **Carbon/Epoxy**

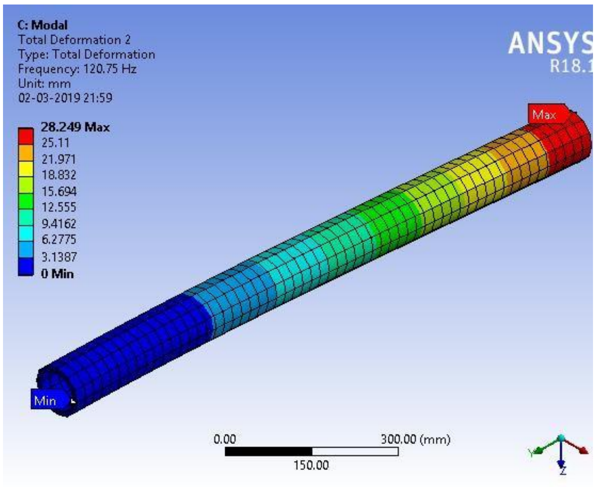

Fig -2.24: Mode 1 f1 = 120.75 Hz

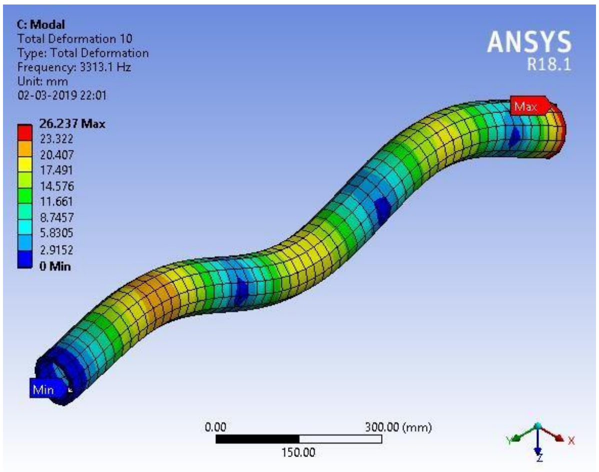

Fig -2.25: Mode 10 f10 = 3313.1 Hz

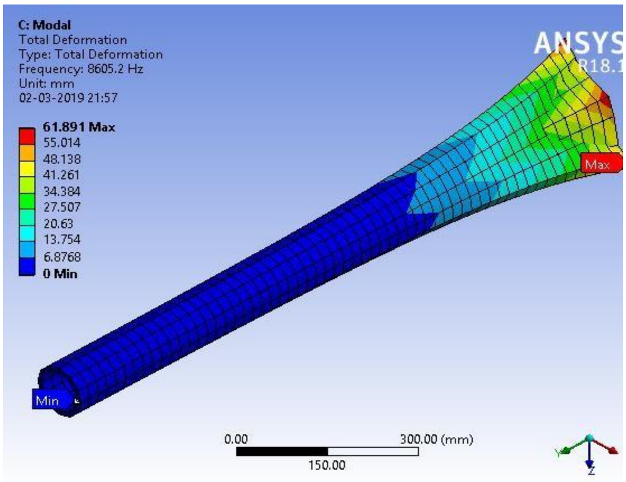

Fig -2.26: Mode 20 f20 = 8605.2 Hz

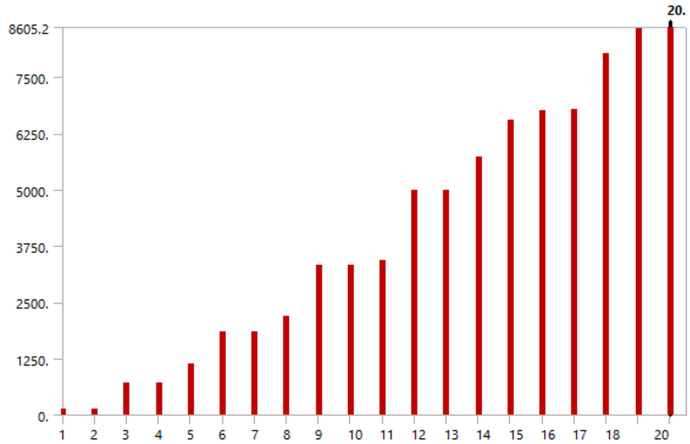

Chart -2: Variation of number of modes vs frequency. X-axis contains number of modes and Y-axis contains frequency

3. **Glass/Epoxy**

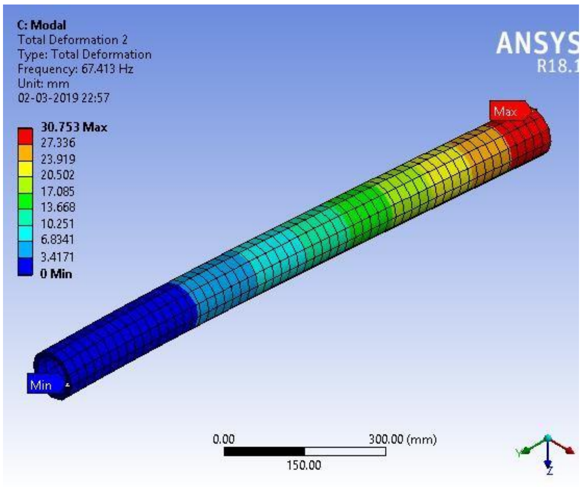

Fig -2.27: Mode 1 f1 = 67.413 Hz

Chart -2: Variation of number of modes vs frequency. X-axis contains number of modes and Y-axis contains frequency

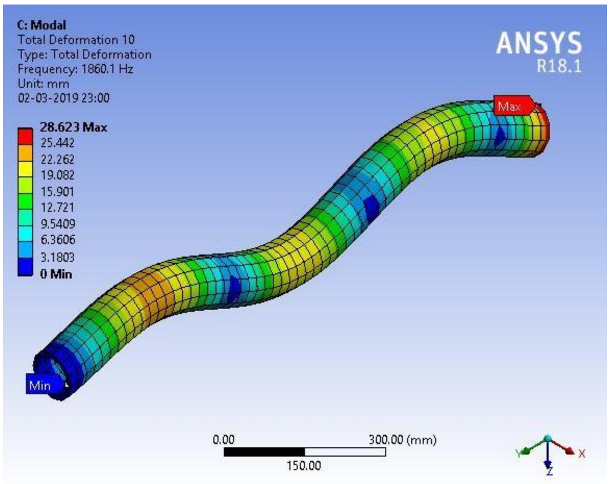

Fig -2.28: Mode 10 f10 = 1860 Hz

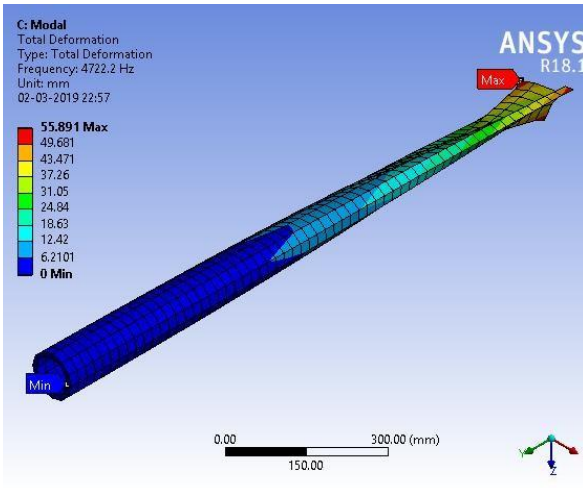

Fig -2.29: Mode 20 f20 = 4722.2 Hz

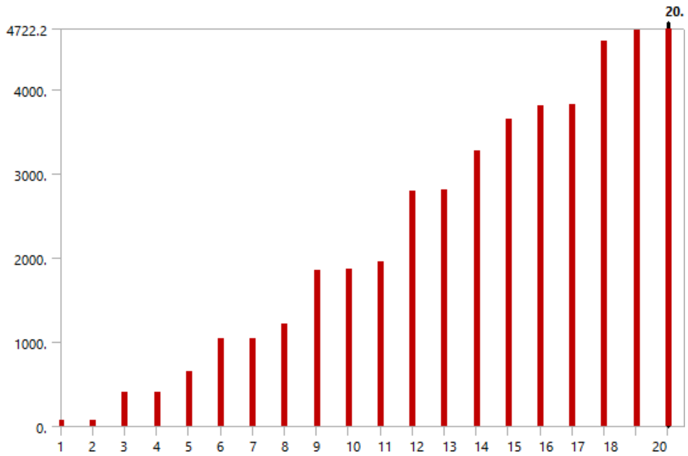

Chart -3: Variation of number of modes vs frequency. X-axis contains number of modes and Y-axis contains frequency

4. **Kevlar/Epoxy**

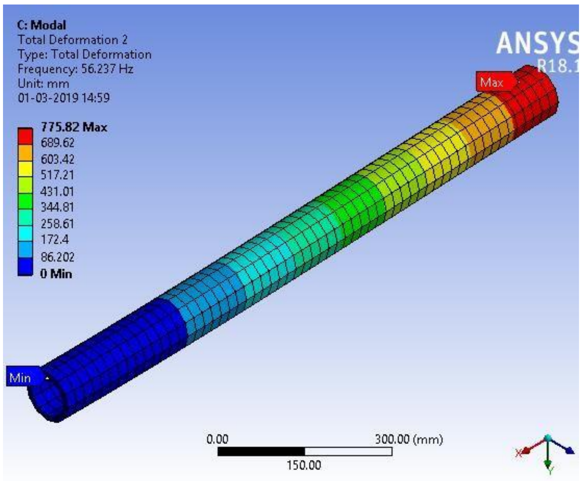

Fig -2.30: Mode 1 f1 = 56.237 Hz

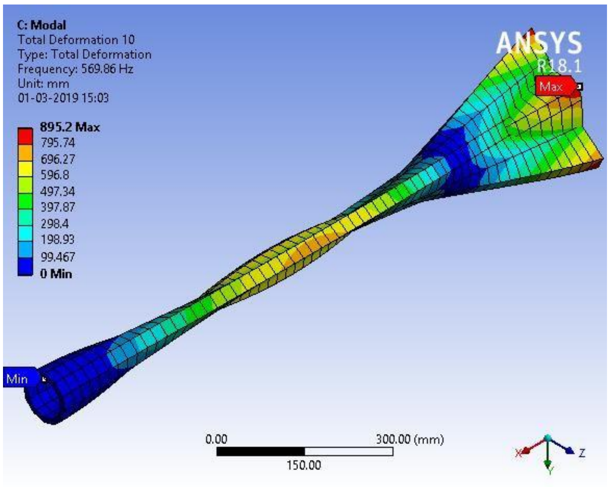

Fig -2.31: Mode 10 f10 = 569.86 Hz

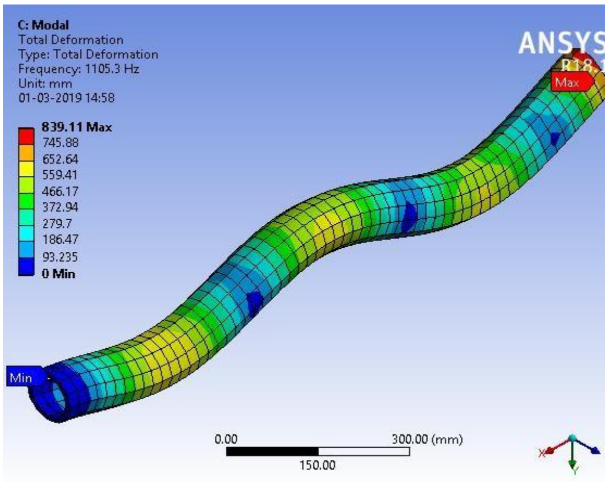

Fig -2.32: Mode 20 f20 = 1105.3 Hz

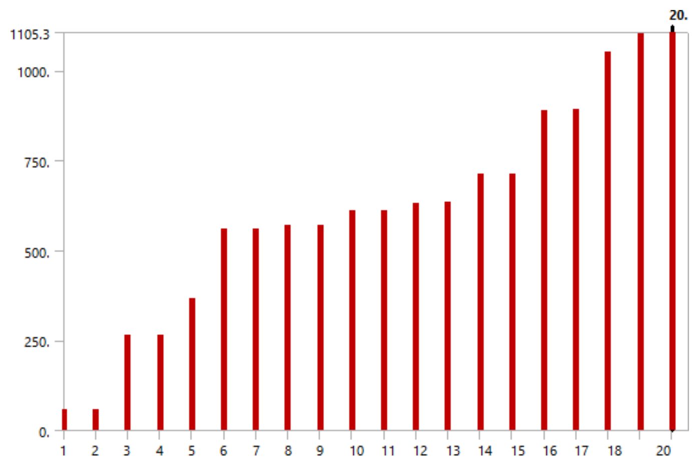

Chart -4: Variation of number of modes vs frequency. X-axis contains number of modes and Y-axis contains frequency

5. **Boron/Epoxy**

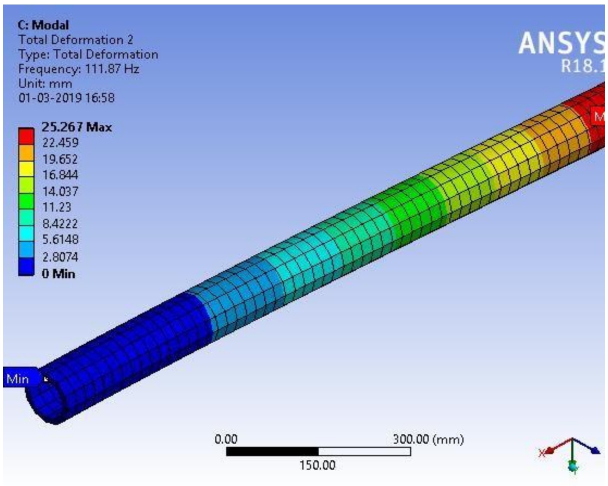

Fig -2.33: Mode 1 f1 = 111.87 Hz

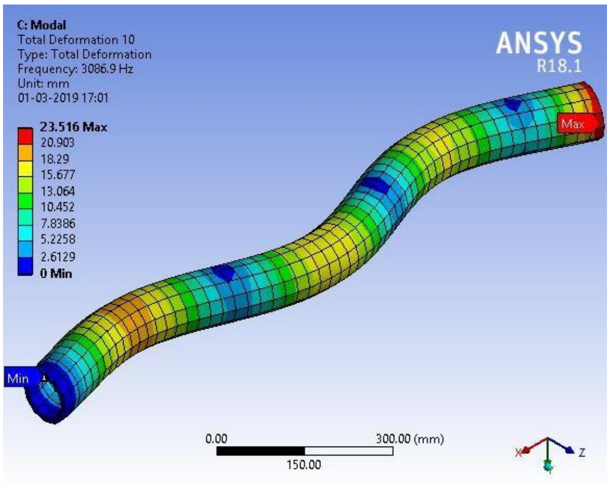

Fig -2.34: Mode 10 f10 = 3086.9 Hz

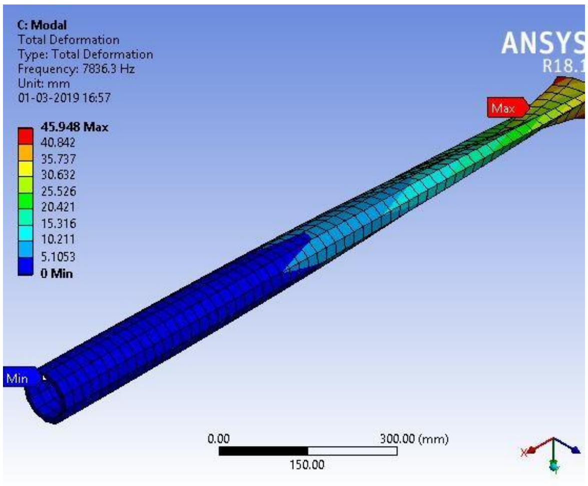

Fig -2.35: Mode 20 f20 = 7836.3 Hz

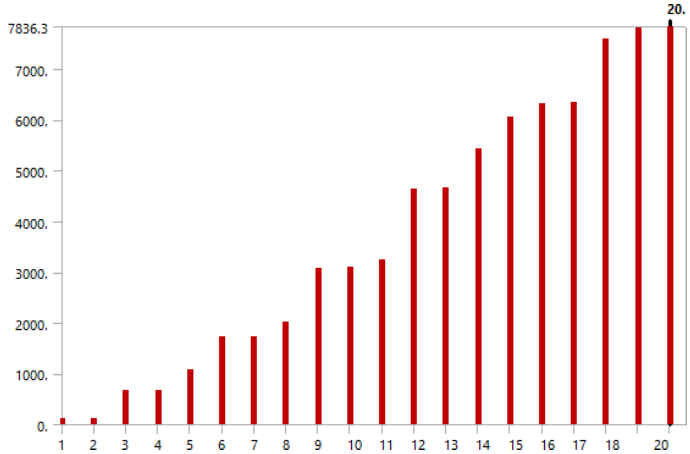

Chart -5: Variation of number of modes vs frequency. X-axis contains number of modes and Y-axis contains frequency

2.10 Harmonic Response

Harmonic response analysis gives you the ability to predict the sustained dynamic behavior of your structures, thus enabling you to verify whether or not your designs will successfully overcome resonance, fatigue, and other harmful effects of forced vibrations. Harmonic response analysis is a technique used to determine the steady-state response of a linear structure to loads that vary sinusoidal (harmonically) with time. The idea is to calculate the structure's response at several frequencies and obtain a graph of some response quantity (usually displacements) versus frequency. "Peak" responses are then identified on the graph and stresses reviewed at those peak frequencies. This analysis technique calculates only the steady-state, forced vibrations of a structure.

2.10.1 FEA Results

1. **Steel**

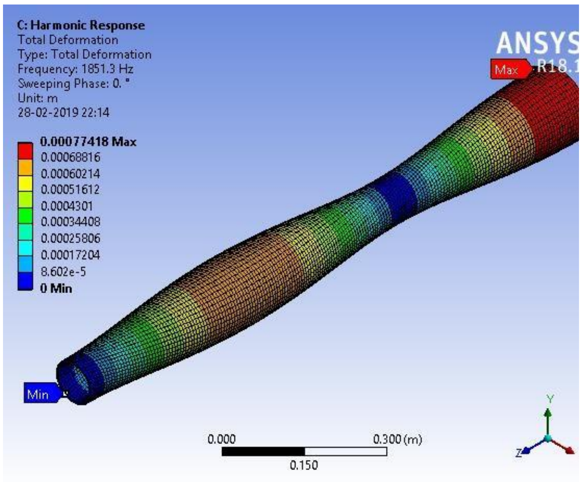

Fig -2.36: Harmonic Response Steel

- Frequency = 1851.3 Hz
- Maximum Total Deformation = 0.77418 mm
- Minimum Total Deformation = 0

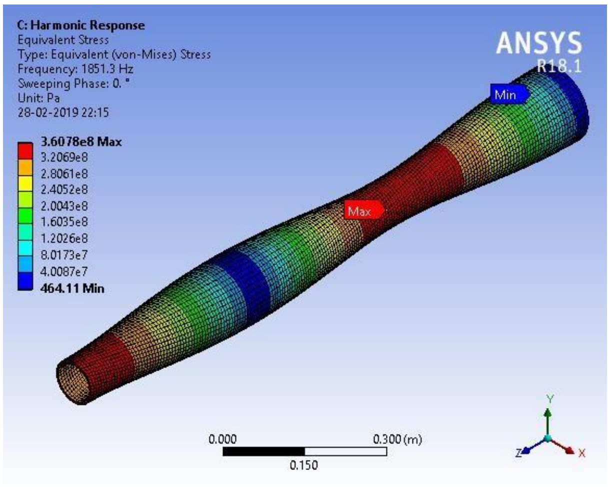

Fig -2.37: Equivalent (von-Mises) Stress

- Frequency = 1851.3 Hz
- Maximum Equivalent Stress = 360.28 MPa
- Minimum Equivalent Stress = 0.456 MPa

2. **Carbon/Epoxy**

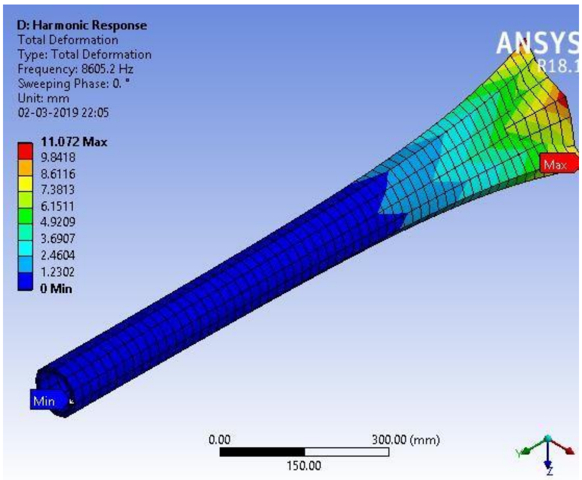

Fig -2.38: Total Deformation Carbon/Epoxy

- Frequency = 8605.2 Hz
- Maximum Total Deformation = 11.072 mm
- Minimum Total Deformation = 0

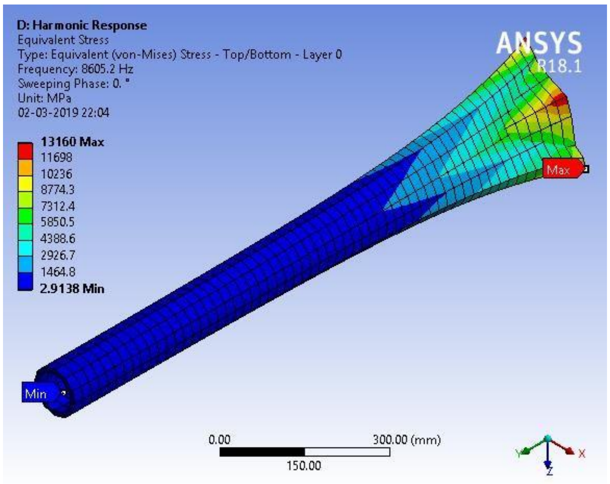

Fig -2.39: Equivalent (von-Mises) Stress Carbon/Epoxy

- Frequency = 8605.2 Hz
- Maximum Equivalent (von-Mises) Stress = 13160 MPa
- Minimum Equivalent (von-Mises) Stress = 2.9138 MPa

3. **Glass/Epoxy**

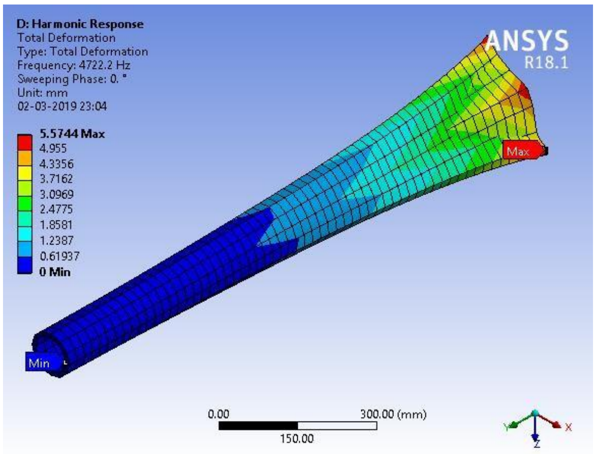

Fig -2.40: Total Deformation Glass/Epoxy

- Frequency = 4722.2 Hz
- Maximum Total Deformation = 5.5744 mm
- Minimum Total Deformation = 0

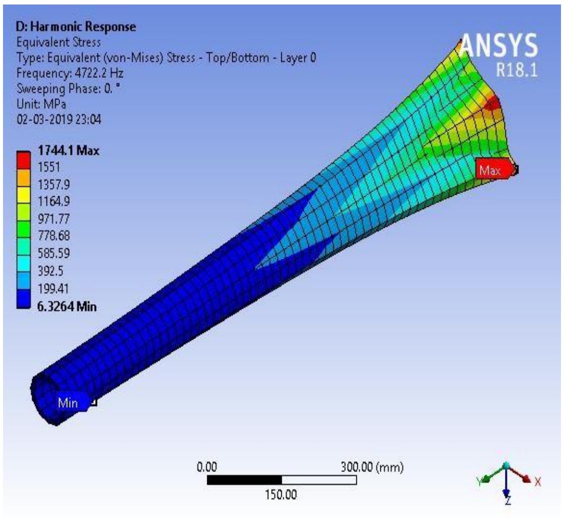

Fig -2.41: Equivalent (von-Mises) Stress Glass/Epoxy

- Frequency = 4722.2 Hz
- Maximum Equivalent (von-Mises) Stress = 1744.1 MPa
- Minimum Equivalent (von-Mises) Stress = 6.3264 MPa

4. **Kevlar/Epoxy**

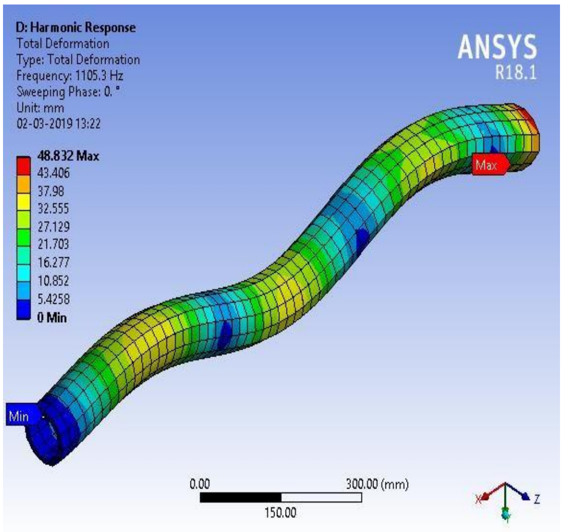

Fig -2.42: Total Deformation Kevlar/Epoxy

- Frequency = 1105.3 Hz
- Maximum Total Deformation = 48.832 mm
- Minimum Total Deformation = 0

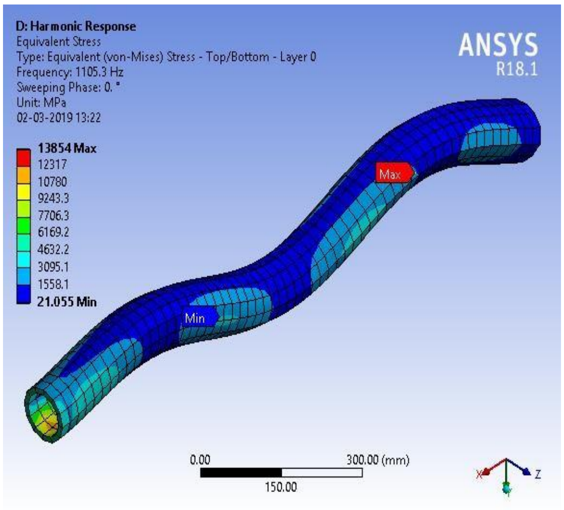

Fig -2.43: Equivalent (von-Mises) Stress

- Frequency = 1105.3 Hz
- Maximum Equivalent (von-Mises) Stress = 13854 MPa
- Minimum Equivalent (von-Mises) Stress = 21.055 MPa

5. **Boron/Epoxy**

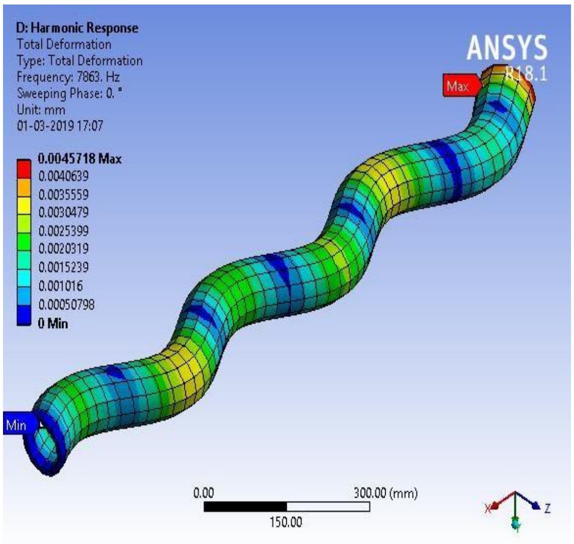

Fig -2.44: Total Deformation Boron/Epoxy

- Frequency = 7863 Hz
- Maximum Total Deformation = 0.0045718 mm
- Minimum Total Deformation = 0

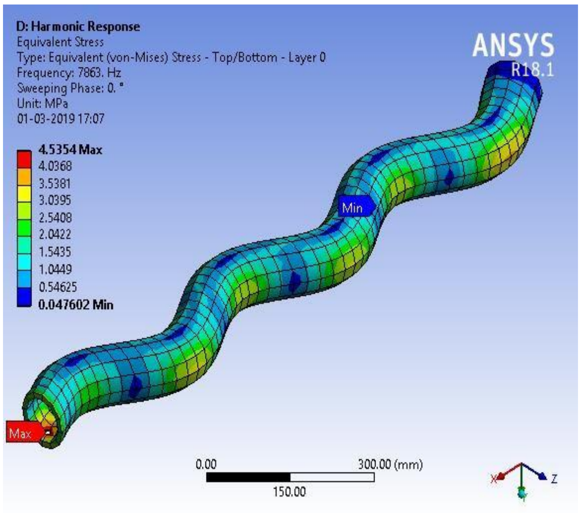

Fig -2.45: Equivalent (von-Mises) Stress Boron/Epoxy

- Frequency = 7863 Hz
- Maximum Equivalent (von-Mises) Stress = 4.5354 MPa
- Minimum Equivalent (von-Mises) Stress = 0.047602 MPa

3. RESULTS AND DISCUSSIONS

Comparison between the results obtained are as follows:

3.1 Mass

Table 3.1: Results of Masses

	Steel	Carbon/ Epoxy	Glass/ Epoxy	Kevlar/ Epoxy	Boron/ Epoxy
Mass (Kg)	12.7	2.7	2.25	3.34	3.34
Mass Saving (%)	-	78.74	82.28	73.7	73.7

From the above table, it can be noticed that by using carbon/epoxy reduces the weight of the propeller shaft by 78.74%. Furthermore, by using glass/epoxy, 82.28% reduction in weight is obtained. For Kevlar/epoxy and boron/epoxy, 73.7% reduction is obtained. Hence, it is observed that glass/epoxy has maximum weight reduction in comparison with the other composite materials.

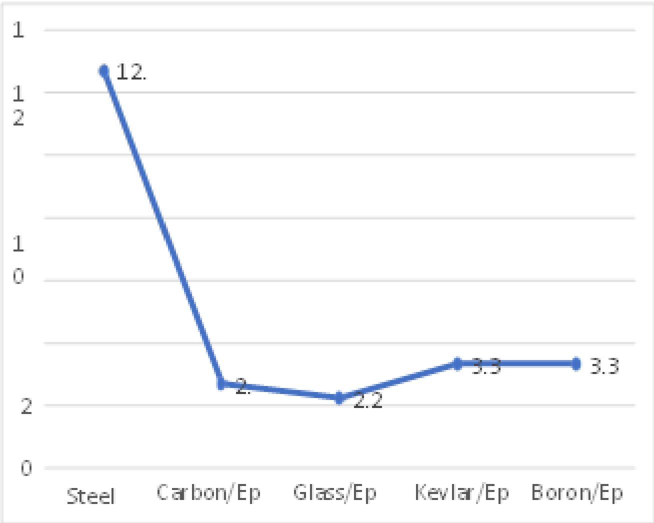

Chart -3.1: Mass Comparison of Materials

3.2. Static Structural

Table 3.2: Results of Directional Deformation

	Minimum (mm)	Maximum (mm)
Steel	-5.29E-01	5.29E-01
Carbon/Epoxy	-1.98E-04	1.43E-04
Glass/Epoxy	-7.22E-04	5.21E-04
Kevlar/Epoxy	-1.67E-02	1.70E-02
Boron/Epoxy	-1.59E-03	1.62E-03

From above table it can be observed that the directional deformation because of the applied boundary conditions is much less in composite material as compared to steel and the stress value obtain in carbon epoxy is least.

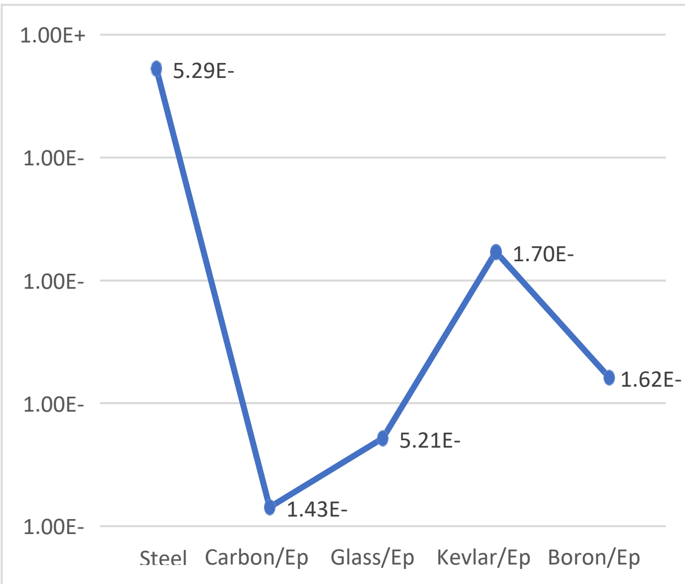

Chart -3.2: Directional Deformation of Materials

Table 3.3: Results of Equivalent Elastic Strain

	Minimum (mm/mm)	Maximum (mm/mm)
Steel	1.54E-05	5.66E-01
Carbon/Epoxy	2.46E-06	3.65E-04
Glass/Epoxy	9.21E-06	1.37E-03
Kevlar/Epoxy	3.65E-06	1.47E-03
Boron/Epoxy	8.12E-07	3.50E-04

From the above table it can be observed that the equivalent elastic strain because of the applied boundary conditions is much less in composite material as compared to steel and the stress value obtained in carbon epoxy is least.

Chart -3.3: Equivalent Elastic Strain of Materials

Table 3.4: Results of Equivalent (von-Mises) Stress

	Minimum (MPa)	Maximum (MPa)
Steel	3.08E-03	
Carbon/Epoxy	0.34815	65.784
Glass/Epoxy	0.35079	66.01
Kevlar/Epoxy	9.52E-02	223.79
Boron/Epoxy	9.61E-02	71.411

Stress in carbon/epoxy is the least compared to other composite material, also the stresses in composite material are much less the steel except for Kevlar/epoxy.

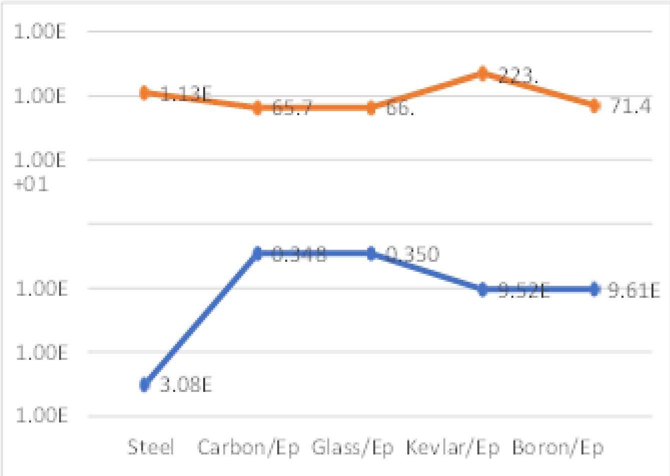

Chart -3.4: Equivalent Shear of Materials

3.3 Modal Analysis

Table 3.5: Results of Modal Analysis

Modes	Steel Frequency (Hz)	Carbon/ Epoxy Freq (Hz)	Glass/ Epoxy Freq (Hz)	Kevlar/ Epoxy Freq (Hz)	Boron/ Epoxy Freq (Hz)
1	54.064	120.75	67.413	56.237	111.87
2	54.065	120.87	67.478	56.299	111.98
3	324.18	714.7	399.71	265.23	663.33
4	324.18	715.63	400.22	265.6	664.18
5	626.07	1144.1	653.51	367.61	1084.5
6	853.63	1853.2	1038.5	559	1723.3
7	853.64	1856.3	1040.2	560.94	1726.2
8	1010.3	2182.4	1218.3	568.29	2021.8
9	1550	3313.1	1860.1	569.86	3086.9
10	1550	3320.2	1864	611.19	3093.3
11	1791	3433.5	1961.1	611.9	3254.6
12	1792.5	4979.4	2800	631.81	4646.6
13	1804.5	4991.7	2806.8	632.85	4657.9
14	1806	5726.1	3270.7	711.33	5427.7
15	1843.5	6540.8	3652.7	712.67	6061.8
16	1845	6768.2	3810.5	887.46	6323.6
17	1878.2	6787	3820.9	891.94	6340.8
18	1932.5	8024.3	4583.3	1051.3	7606.1
19	1933.9	8588	4713	1102.9	7821.4
20	2094.9	8605.2	4722.2	1105.3	7836.3

As the table above shown that natural frequency of composite material is way more than that of steel, highest natural frequency obtained on every mode is of carbon epoxy.

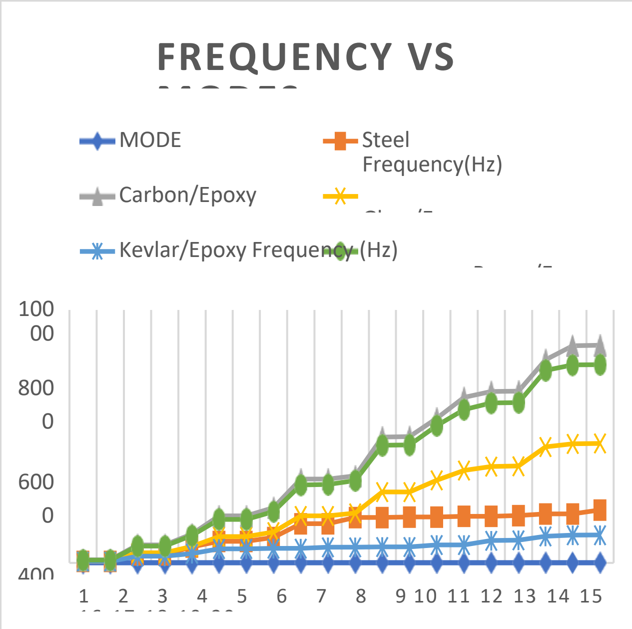

Chart -3.5: Modal Analysis

3.4 Harmonic Response Analysis

Table 3.6: Results of Harmonic Response Analysis

Set	Steel Freq (Hz)	Carbon/ Epoxy Freq (Hz)	Glass/ Epoxy Freq (Hz)	Kevlar/ Epoxy Freq (Hz)	Boron/ Epoxy Freq (Hz)
1	209.49	860.52	472.22	110.53	786.3
2	418.98	1721.	944.44	221.06	1572.6
3	628.47	2581.6	1416.7	331.59	2358.9
4	837.96	3442.1	1888.9	442.12	3145.2
5	1047.5	4302.6	2361.1	552.65	3931.5
6	1256.9	5163.1	2833.3	663.18	4717.8
7	1466.4	6023.6	3305.5	773.71	5504.1
8	1675.9	6884.2	3777.8	884.24	6290.4
9	1885.4	7744.7	4250.	994.77	7076.7
10	2094.9	8605.2	4722.2	1105.3	7863.

As the value of harmonic response analysis are different form the value of model analysis, no response will occur in the propeller shaft for the specified boundary condition.

4. CONCLUSIONS

Thus, it can be concluded that composite material can be the best alternative to use for application of propeller shaft compared to conventional steel shaft as the weight of composite material is 82.3% less than steel shaft. Even the deformation, von-misses stress and stress induce due to the condition are much less in composite material compared to steel, out of all the selected composite material, it can also be concluded that, carbon/epoxy is the best material for the application of propeller shaft.

The present work was aimed at reducing the fuel consumption of the automobile in particular or any machine, which employs drive shaft. This was achieved by reducing the weight of the drive shaft with the use of composite material. This also allow the use of a single drive shaft (instead of a two-piece drive shaft) for transmission of power to the differential part of the assembly. Thus the part complexity is reduced apart from being lightweight, the use of composite also ensures less noise and have excellent vibration damping. Composites require less assembly time, inventory cost and maintenance compered to steel. If cost is considered, glass/epoxy composite is slightly higher than steel but lesser than carbon/epoxy. Also composites have reduced wear on drive train composites and increased tire traction. The composites are recyclable so they can be reuse. So, in comparison of mass, cost, safety and recycling steel shaft can be replaced by composite drive shaft.

4.1 Future scope and limitations

This study leaves wide scope for future investigation. It can be extended to newer composite using other reinforcing phases. The reduction is weight gives further advantage in the increases in the fuel economy of vehicle. The main limitation in this whole process is cost of composite materials.

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