Design, Analysis and Optimization in Automobile Drive Shaft

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Abstract

Present study covers design, analysis and development of driveshaft for automobile applications. This covers dimension calculations of drive shaft based on engine power required. Accordingly shaft couplings e.g. universal joints, transmission gears for axle and axle design will be performed considering all static and dynamic loads acting upon it. All design process will be performed with aid of FE analysis using ANSYS software. Optimization will be followed after performing design which includes weight reduction of drive shaft and material selection. It has been observed from results of study that by using composite material in place of steel material, weight reduction of up to about 80% is obtained. When study is carried out for different epoxy materials of composites, it has been observed that Kevlar/Epoxy composite has proved maximum strength compared to the others. When study has been carried out for different fiber angles for composite layers, it has been observed that 90^{o} angle of fibers is providing better fundamental frequency compared to other angles.

Keywords: ANSYS software, Geometry of shaft, MESHING

I. INTRODUCTION

Drive shafts are used generally in power transmission applications e.g. automobiles, aerospace, pumping industries etc. Current study is deals with the study of automobile drive shafts. In automobiles drive shaft is connected with two ends by using universal joints to transmit power at angle. These shafts are experienced to twisting movement and dynamic loading due to transport acceleration of vehicle. Simple arrangement of drive shaft is shown in following figure.

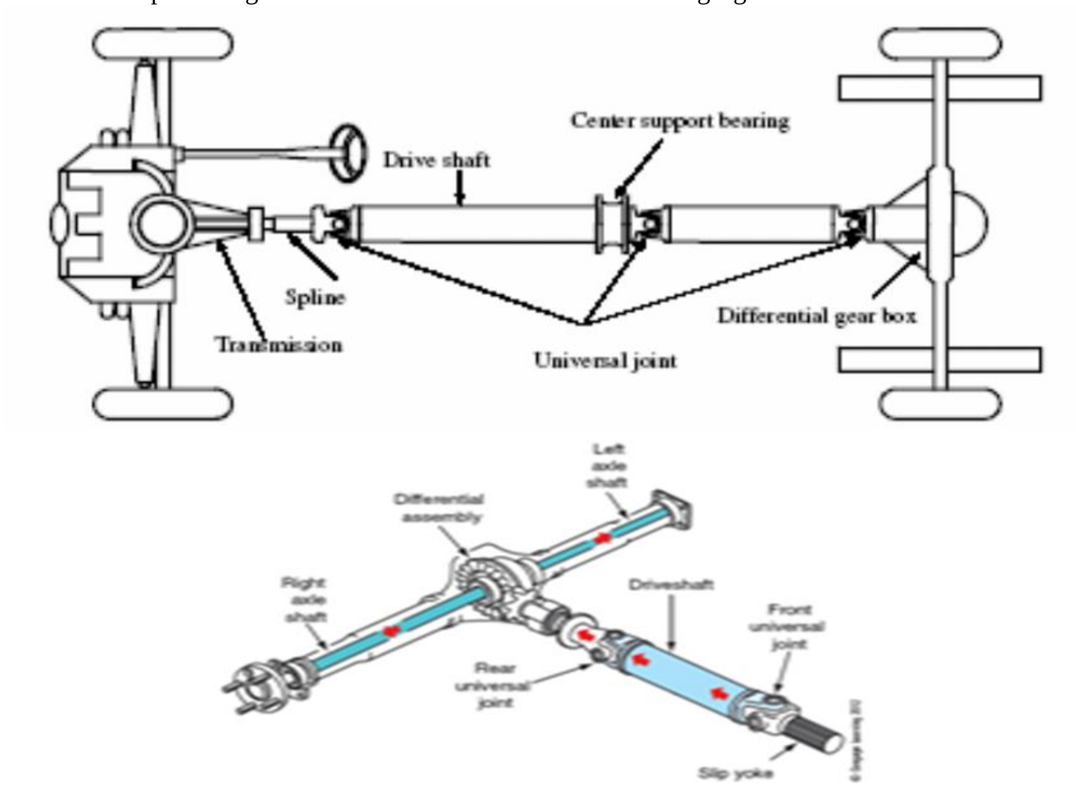


Fig. 1.1: Arrangement of drive shaft in automobiles

One of the major roles of drive shaft is to transmit torque as follows,

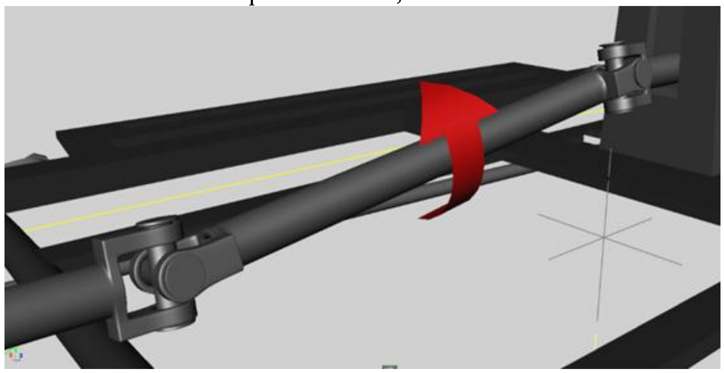


Fig. 1.4: Transmission of torque by drive shaft

As dynamic load is acting on drive shaft, natural frequency will be one of the essential factor for design; hence dividing drive shaft in two pieces using an additional universal joint at its Centre will raise fundamental natural frequency of the driveshaft.

Also weight reduction is very important factor in automobile applications. By the use of composite materials e.g. carbon epoxy for manufacturing of drive shafts will provide larger strength to weight ratio compared to metallic shafts. Also composites have bettered corrosion resistance, large damping capacity and low coefficient of thermal expansion which provides better dimensional stability.

A. Advantages of Composites over Conventional Materials:

- High strength / weight ratio
- High stiffness / weight ratio
- Greater fatigue resistance
- Bettered corrosion resistance
- Better thermal conductivity
- Low Coefficient of thermal expansion; so, composite structures provide better dimensional stability over a wide temperature range.
- High damping capacity

B. Manufacturing of Composite Shaft:

- Shaft are manufactured by filament winding process, Fiber strands are unwound from the creels and passed continuously to the resin (matrix) Tank.

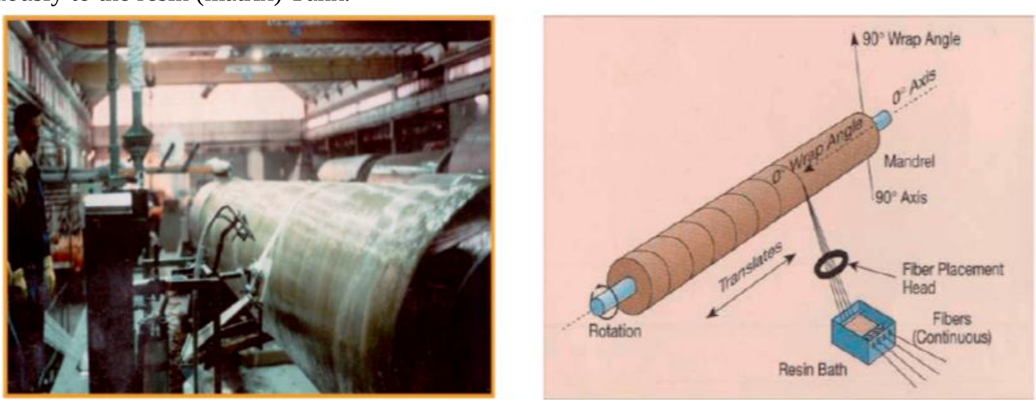


Fig. 1.5: Filament winding process arrangements

- In the resin tank, the fiber strands are impregnated completely with resin.
- Resin impregnated strand are passed on to a rotating mandrel.
- Stands are wound around the mandrel in a controlled manner and in a specific fiber orientation.
- Curing of the composite is done with heat and final composite product is taken out from mandrel.
- To remove the metallic mandrel from the composite part hydraulic rams may be used.

1) *Main Components of Filament Winding Process:*

- Fiber creel
- Resin impregnation system
- Carriage

- Rotating Mandrel

2) *Controlling Parameters:*
- Fiber tension
- Winding speed
- Design of resin bath
- Viscosity of Resin
- Fiber Orientation
- Carriage Movement

II. DESIGN AND MODELLING OF THE SHAFT

A. *Initial Diameter of Shaft:*
- Considering material of shaft as steel, shear stress = 180 MPa
- Factor of safety for shaft design = 1.5
- Design shear stress = 180/1.5 = 120 MPa
- - Torque T = P x 60 / (2πN) (P in W)

Standard values of Power for conventional steel shaft of Maruti Alto VX is taken

As 46200 W according to SAE J901 standard

T = 88.28N.m = 88280 N.mm

The fundamental natural bending frequency of drive shaft of passenger cars, small trucks, and vans should be higher than 6500 rpm to avoid whirling vibrations and the torque transmission capacity of the drive shaft should be larger than 3500 Nm. The drive shaft outer diameter should not exceed 100 mm due to space limitations.

$$\frac{D_0^4 - D_i^4}{D_0} = \frac{16T}{\tau\pi}$$

Considering $D_i = 0.70D_o$

$(0.657D_o^4)/D_o = 0.657D_o^3 = 16T/\pi\tau$

Assuming initial diameters of drive shaft and by performing iterations, following , Diameter vales reflects shaft shear stress value = 110 MPa, which is less than

Allowable shear stress value as mentioned above.

$D_o = 60$ mm

$D_i = 40$ mm

B. *Geometry:*
By using above design calculations the modeling of the drive shaft is done as below and its simple geometry is shown below:

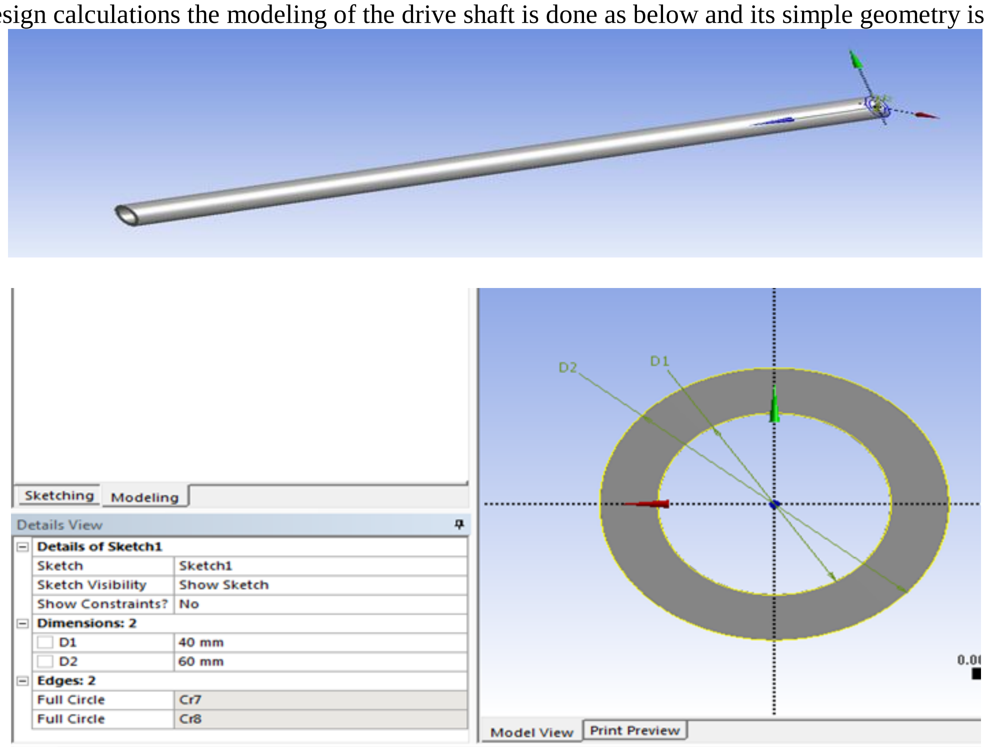


Fig.- Geometry of shaft

C. Boundary Condition:
Boundary condition is specified as shown that one end is fixed and moment is applied at other end.

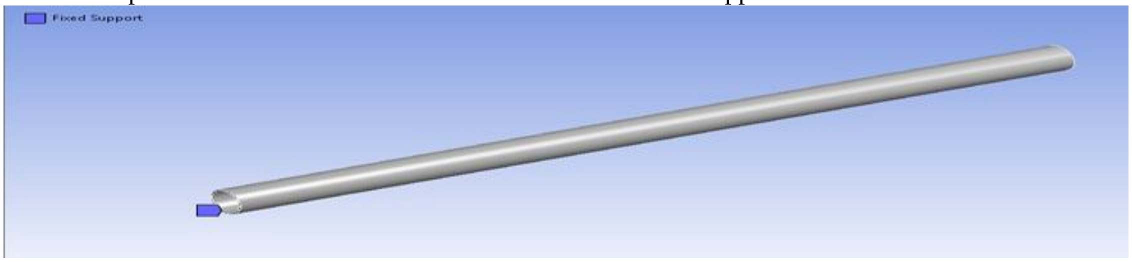


Fig. - Fix shaft at one end

D. Load Condition:

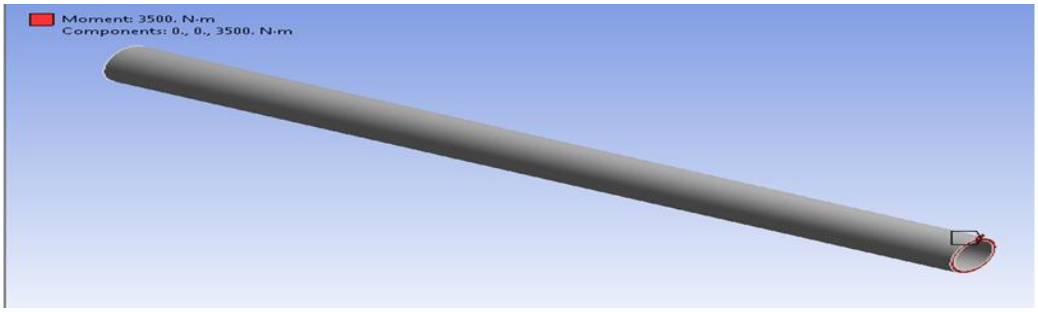


Fig. - Torsional moment 3500 Nm at other end

E. Meshing:
Meshing is the process in which geometry is spatially discredited into elements and nodes.
Type of meshing-Hex dominant
Type of elements-structural
Structural element-Solid 95/186
Total no. of nodes-15638
Total no. of elements-23542

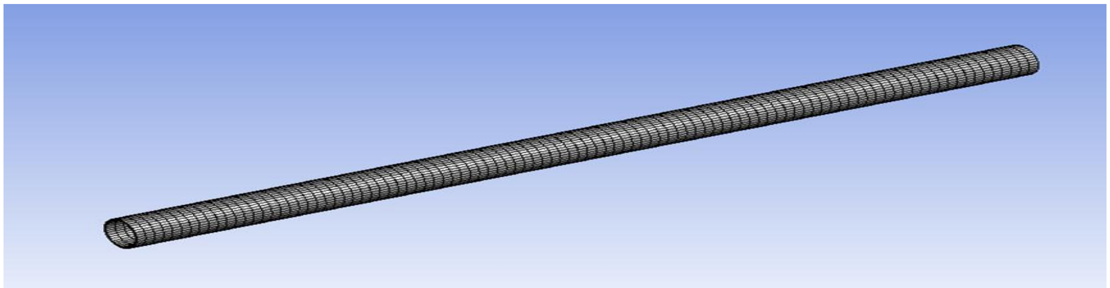


Fig. – Meshing

III. MATERIAL PROPERTIES

A. Steel:

Properties of Outline Row 3: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	7850	kg m^-3		
3	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
12	Alternating Stress Mean Stress	Tabular			
16	Strain-Life Parameters				
24	Tensile Yield Strength	2.5E+08	Pa		
25	Compressive Yield Strength	2.5E+08	Pa		
26	Tensile Ultimate Strength	4.6E+08	Pa		
27	Compressive Ultimate Strength	0	Pa		

Fig. - Properties of steel and glass fiber

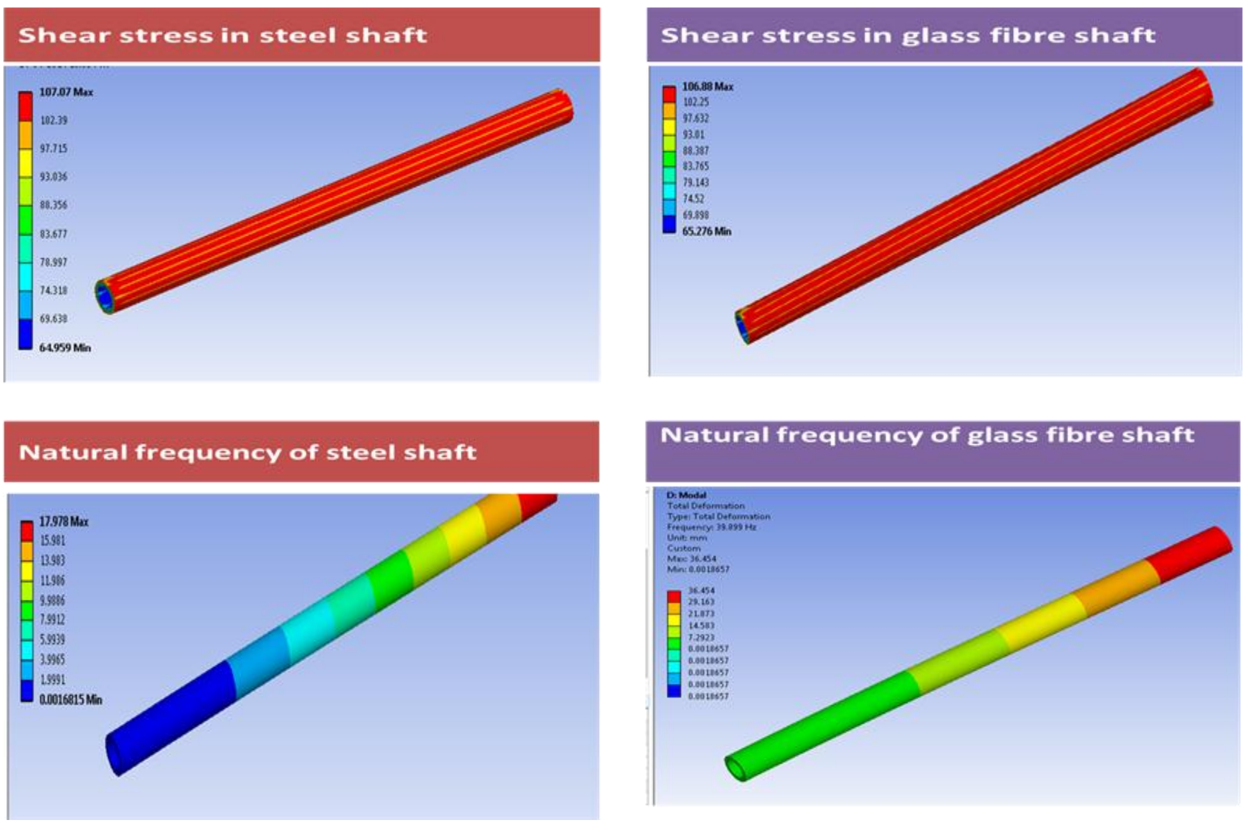
B. Glass Fiber (Class G10):

Properties of Outline Row 3: G10

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1900	kg m^-3		
3	Orthotropic Instantaneous Coefficient of Thermal Expansion	Tabular			
10	Orthotropic Elasticity				
11	Young's Modulus X direction	3.05E+10	Pa		
12	Young's Modulus Y direction	2.67E+10	Pa		
13	Young's Modulus Z direction	1.59E+10	Pa		
14	Poisson's Ratio XY	0.29			
15	Poisson's Ratio YZ	0.32			
16	Poisson's Ratio XZ	0.06			
17	Shear Modulus XY	6.8E+09	Pa		
18	Shear Modulus YZ	5.7E+09	Pa		
19	Shear Modulus XZ	4.8E+09	Pa		
20	Tensile Ultimate Strength	4.14E+08	Pa		
21	Compressive Ultimate Strength	7.49E+08	Pa		

Fig. - Properties of steel and glass fiber

IV. ANALYSIS OF THE SHAFT



V. WHIRLING OF SHAFT

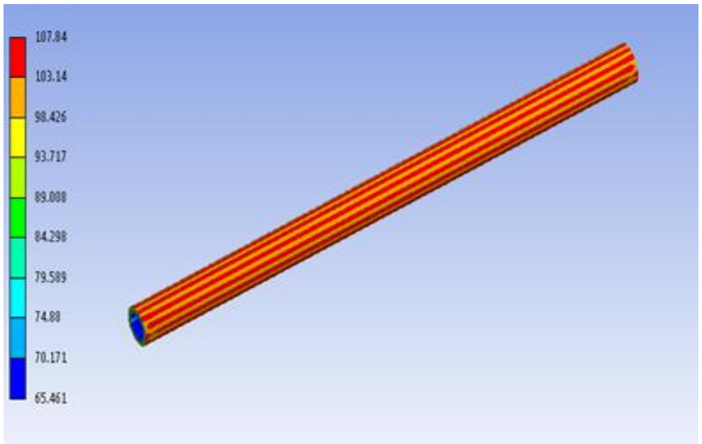
Critical speed of shaft:
$N_c = (30/\Pi) * \sqrt{(g/\delta st)}$
Where,
$\delta st = (5wL^3) / (384EI)$
$g = 9.81\ m/s^2$, w = 2.98 kg / m , L =1000 mm, E =1.59 E+10 Pa
Substituting values in above parameters,
Nc = 6159 RPM
Since critical speed of shaft is less than maximum speed (N = 6500 rpm), design of composite shaft is safe for critical speed.

VI. COMPARISON BETWEEN DIFFERENT COMPOSITE SHAFTS

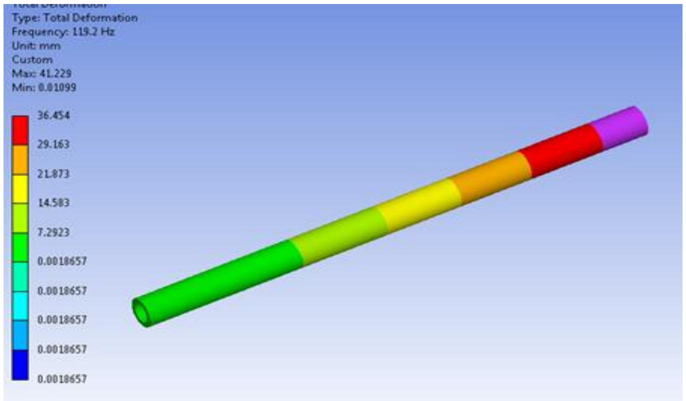
Composite	Shear Stress (MPa)	Fundamental Natural Frequency (Hz)
Boron-Epoxy	107.23	73.83
Kevlar-Epoxy	107.83	119.2
Carbon Kevlar/Epoxy	107.54	90.74
Aluminum Boron/Epoxy	107.75	105.06

A. Kevlar/Epoxy:

3) Shear Stress:



4) Natural Frequency:



B. Material Properties of the Kevlar Epoxy:

Sr No.	Property	Symbol	Unit	Value
1	Longitudinal Modulus	E11	GPa	232.2
2	Transverse Modulus	E22	GPa	7.413
3	Shear Modulus	G12	GPa	4.05
4	Poisson's ratio	ν		0.262
5	Density	δ	Kg/m3	2080

VII. COMPARISON OF COMPOSITE SHAFT AT DIFFERENT STACKING ANGLE

Sr No.	Property	Symbol	Unit	Value
1	Longitudinal Modulus	E11	GPa	232.2
2	Transverse Modulus	E22	GPa	7.413
3	Shear Modulus	G12	GPa	4.05
4	Poisson's ratio	ν		0.262
5	Density	δ	Kg/m3	2080

A. Maximum Shear Stress:

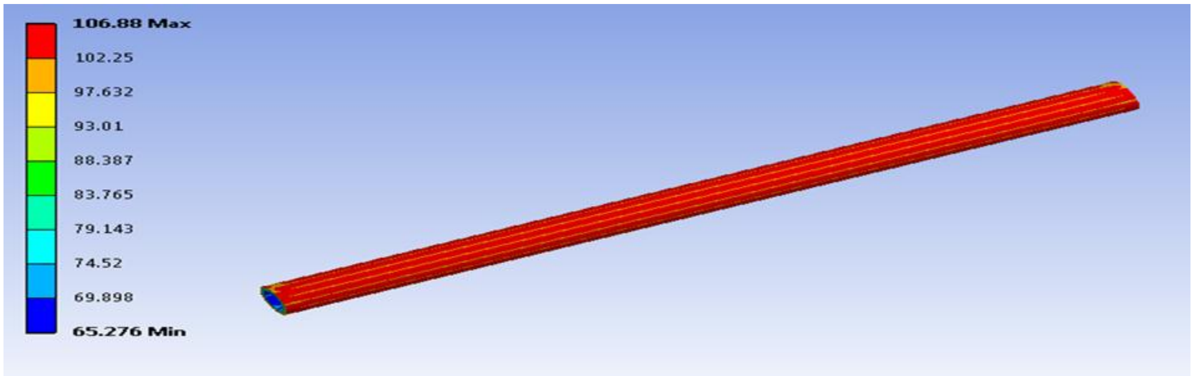


Fig.- Maximum shear stress (Fibers oriented at 90^{o})

B. Maximum Principal Stress:

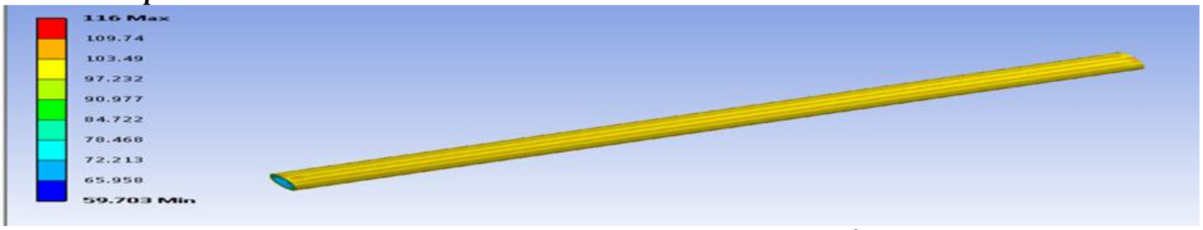


Fig. - Maximum principal stress (Fibers oriented at 90^{o})

C. Minimum Principal Stress:

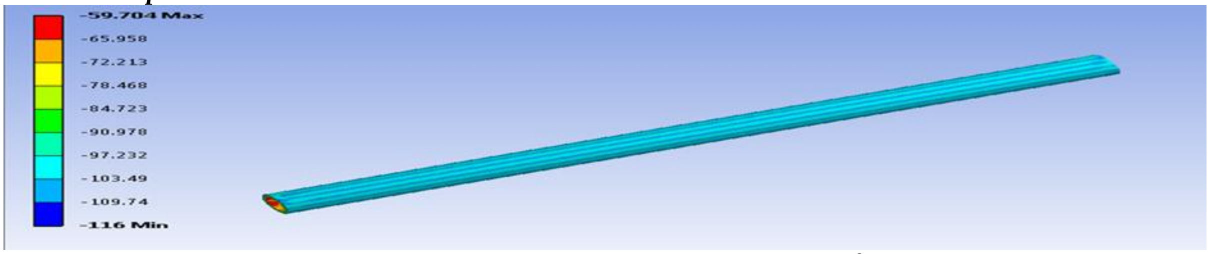


Fig. - Minimum principal stress (Fibers oriented at 90^{o})

D. Natural Frequency:

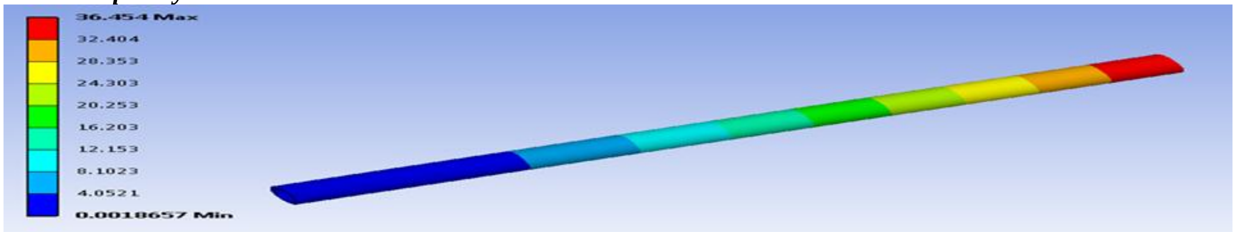


Figure- Natural Frequency (Fibers oriented at 90^{o})

VIII. CONCLUSION

It has been observed from results of study that by using composite material in place of steel material, weight reduction of up to about 80% is obtained.

When study is carried out for different epoxy materials of composites, it has been observed that Kevlar/Epoxy composite has proved maximum strength compared to the others.

When study has been carried out for different fiber angles for composite layers, it has been observed that 90o angle of fibers is providing better fundamental frequency compared to other angles.

In present work, main aim in concentrated towards reducing overall weight of shaft with same strength, which ultimately results in less fuel consumption. Moreover by using composite drive shaft we can avoid using two piece drive shaft, since composite materials are providing much better natural frequency compared to the steel material.

Moreover use of composite as replacement of the steel drives shaft, results in less noise and vibration.

REFERENCES

[1] Dai Gil Lee, Hak Sung Kim, Jong Woon Kim, Jin Kook Kim; Design and manufacture of an automotive hybrid aluminium /composite drive shaft, www.elsevier.com/locate/compstruct, Composite Structures 63 (2004) 87–99
[2] H. Bayrakceken *, S. Tasgetiren, _I. Yavuz; Two cases of failure in the power transmission system on vehicles: A universal joint yoke and a drive shaft, Engineering Failure Analysis, 14 (2007) 716–724
[3] S.A. Mutasher; Prediction of the torsional strength of the hybrid aluminium /composite drive shaft, Materials and Design 30 (2009) 215–220
[4] 1Anup A. Bijagare*, 2P.G. Mehar and 3V.N. Mujbaile; Design Optimization & Analysis of Drive Shaft, VSRD-MAP, Vol. 2 (6), 2012, 210-215
[5] Arun Ravi: Design, comparison and analysis of a composite drive shaft for an automobile, International Review of Applied Engineering Research. ISSN 2248-9967 Volume 4, Number 1 (2014), pp. 21-28
[6] A.R. Abu Talib, Aidy Ali, Mohamed A. Badie, NurAzidaCheLah , A.F. Golestane; P. Balasubramanian and T. Senthilvelan,Developing a hybrid, carbon/glass fibre-reinforced, epoxy composite automotive drive shaft, Materials and Design 31 (2010) 514–521
[7] M.A. Badie, E. Mahdi ⇑, A.M.S. Hamouda; An investigation into hybrid carbon/glass fibre reinforced epoxy composite automotive drive shaft Materials and Design 32 (2011) 1485–1500
[8] K.V.N. Parvathi, CH. PrabhakaraRao; STRUCTURAL DESIGN OF COMPOSITE DRIVE SHAFT FOR REAR-WHEEL DRIVE ENGINE , International Journal of Advanced Engineering Research and Studies E-ISSN2249–8974
[9] M.R. Khoshravan, A. Paykani; Design of a Composite Drive Shaft and its Coupling for Automotive Application
[10] HarshalBankar, VirajShinde, P. Baskar;Material Optimization and Weight Reduction of Drive Shaft Using Composite Material, Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 10, PP 39-46
[11] S V Gopals Krishna, B V Subramanian, and R Srinivasulu; Finite Element Analysis and optimization of Automotive Composite Drive Shaft, International Journal of Engineering Trends and Technology (IJETT) – Volume 5 Number 7- Nov 2013
[12] BelawagiGireesh, SollapurShrishail B, V. N. Satwik;Finite Element & Experimental Investigation of Composite Torsion Shaft, International Journal of Engineering Research and Applications, Vol. 3, Issue 2, March -April 2013, pp.1510-1517
[13] Madhu K.S., Darshan B.H., Manjunath K.;BUCKLING ANALYSIS OF COMPOSITE DRIVE SHAFT FOR AUTOMOTIVE APPLICATIONS, Journal of Innovative Research and Solutions, Volume No.1A, Issue No.2, Page No: 63 -70,2013
[14] T.Rangaswamy, S. Vijayarangan, R.A. Chandrashekar, T.K. Venkatesh and K.Anantharaman; OPTIMAL DESIGN AND ANALYSIS OF AUTOMOTIVE COMPOSITE DRIVE SHAFT, International Symposium of Research Students on Materials Science and Engineering December 2002-04