Design & Analysis of Composite Shaft of Passenger Vehicle

Mr. A.R. Nadaf [1], Dr.V.A.Raikar[2]

[1]*P.G.Student, Dept. Of Mechanical Engineering, Sanjay Ghodawat Group of Institutions Atigre, Maharashtra, India.*
[2]*Director, Dept. Of Mechanical Engineering, Sanjay Ghodawat Group of Institutions Atigre, Maharashtra, India.*

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Abstract - *A drive shaft is a rotating shaft that transmits power from the engine to the differential gear of rear wheel drive vehicles. The automotive industry is exploring composite materials technology for structure component in order to obtain reduction of weight. 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. This work deals with replacement of conventional steel driveshaft with e-glass/ epoxy, carbon/ epoxy and hybrid composite driveshaft. In this study shaft is designed successfully for both steel and composite driveshaft. Shaft is analyzed using FEA software ANSYS and applied to minimize the weight of shaft which is subjected to constraints such as torque transmission, buckling torque, critical speed and fundamental natural frequency. Results are compared with theoretically obtained results.*

***Key Words*: Driveshaft, Composite Driveshaft, Torsional Strength, Natural Frequency, ANSYS**

1. INTRODUCTION

An automotive drive shaft transmits power from the engine to the differential gear of a rear wheel drive vehicle. The torque capability of the drive shaft for passenger cars should be larger than 3500 N-m and the fundamental bending natural frequency should be higher than 9200 rpm to avoid whirling vibration. Since the fundamental bending natural frequency of a one-piece drive shafts made of steel or aluminum is normally lower than 5700 rpm when the length of the drive shaft is around 1.5m, 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.
The advanced composite materials such as Graphite, Carbon, Kevlar and Glass with suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/density). Advanced composite materials seem ideally suited for long, power driver shaft (propeller shaft) applications. Their elastic properties can be tailored to increase the torque they can carry as well as the rotational speed at which they operate. The drive shafts are used in automotive, aircraft and aerospace applications. The automotive industry is exploiting composite material technology for structural components construction in order to obtain the reduction of the weight without decrease in vehicle quality and reliability. It is known that energy conservation is one of the most important objectives in vehicle design and reduction of weight is one of the most effective measures to obtain this result. Actually, there is almost a direct proportionality between the weight of a vehicle and its fuel consumption, particularly in city driving.

1.1 Purpose of Driveshaft

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. Functions of Driveshaft are as follows:

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.

2. LITERATURE REVIEW

This section includes the literature survey of earlier research work made by various researchers on composite driveshaft.

Various researchers presented the different techniques in the development of composite drive shafts and their optimization. This section presents the summary of these research works.

Dai Gil Lee et.al. (2004) designed and manufactured an automotive hybrid aluminum/composite drive shaft in one piece in which a carbon fiber epoxy composite layer was co-cured on the inner surface of an aluminum tube rather than wrapping on the outer surface to prevent the composite layer from being damaged by external impact and absorption of moisture.

T.Rangaswamy et.al. (2004) in their paper Optimal Design and Analysis of Automotive Composite Drive Shaft a one-piece drive shaft for rear wheel drive automobile was designed optimally using E-Glass/Epoxy and High modulus (HM) Carbon/Epoxy composites.

Mahmood M. Shokrieh et.al (2004) investigated Shear buckling of a composite drive shaft under torsion studied the closed form solution methods to calculate the buckling torque of composite drive shafts, and a finite element analysis is performed to study their behavior the results obtained by the finite element method, a comparison with experimental and analytical results has been done.

S.A.Mutasher (2009) predicated the torsional strength of the hybrid aluminum/composite drive shaft. He investigated the maximum torsion capacity of the hybrid aluminum/composite shaft for different winding angle, number of layers and stacking sequences. The hybrid shaft consists of aluminum tube wound outside by E-glass and carbon fibers/epoxy composite.

A.R.Abu Talib et.al (2010) developed a hybrid, carbon/glass fiber-reinforced, and epoxy composite automotive drive shaft. In this study, a finite element analysis was used to design composite drive shafts incorporating carbon and glass fibers within an epoxy matrix..

M.A. Badie et.al. (2011) investigated the effect of fiber orientation angles and stacking sequence on the torsional stiffness, natural frequency, buckling strength, and fatigue life and failure modes of composite tubes.

Mohammad Reza Khoshravan et.al. (2011) in their paper Design and Modal Analysis of Composite Drive Shaft for Automotive Application studied the design method and vibrational analysis of composite propeller shafts. Its design procedure was studied and along with finite element analysis some important parameter were obtained.

M.Arun, K.Somasundara Vinoth (2013), investigated about Design and Development of Laminated Aluminum Glass Fiber Drive Shaft for Light Duty Vehicles. They founded that increasing the number of composite layers would increase the fatigue strength for a hybrid aluminum/composite drive shaft.

Belawagi Gireesh et.al. (2013) in their paper Finite Element & Experimental Investigation of Composite Torsion Shaft a one-piece composite drive shaft for automobile was designed and analyzed using ANSYS software respectively for E-Glass/ Epoxy and HM-Carbon/Epoxy composites with the objective of minimization of weight of the shaft which is subjected to the constraints such as torque transmission, torsional buckling strength capabilities and natural bending frequency.

G. Kaviprakash et.al. (2014) in their paper Design and Analysis of Composite Drive Shaft for Automotive Application studied the effect of fiber orientation angle and stacking sequence on the torsional stiffness, natural frequency and buckling strength of composite drive shaft using ANSYS.

Naveenkumar Dasanagoudar et.al. (2015) in their paper Numerical Analysis and Optimization of Passenger Car Drive Shaft the analysis was done on drive shaft of Maruti Omini with different materials like aluminum and composite material, it was consisting of three types of analysis such as static, buckling and modal carried out on the component to understand its behavior under defined loading condition using theoretical and various software's.

Pandurang V Chopde et.al. (2015) analyzed Carbon/Epoxy Composite Drive Shaft for Automotive Application. The experimental and theoretical, torsional and vibration analysis is done on conventional SM45C steel drive shaft, carbon epoxy and glass epoxy composite drive shaft.

3. DESIGN OF STEEL DRIVE SHAFT

3.1 Specification of the Problem

The fundamental natural bending frequency for passenger cars, small trucks, and vans of the propeller shaft should be higher than 6,500 rpm to avoid whirling vibration and the torque transmission capability of the drive shaft should be larger than 3,500 Nm. The drive shaft outer diameter should not exceed 100 mm due to space limitations. Here outer diameter of the shaft taken is 51 mm which is of Maruti Omni. The drive shaft of transmission system is to be designed optimally for following specified design requirements as shown in Table 3.1.

Table -3.1: Design requirements and Specifications of Existing Model

Sr.No.	Name	Notation	Unit	Value
1.	Ultimate Torque	T_{max}	Nm	3500
2.	Max. Speed of Shaft	N_{max}	rpm	5700
3.	Length of shaft	L	mm	660
4.	Outer Diameter of Shaft	Do	mm	51
5.	Inner Diameter of Shaft	Di	mm	47

Steel (SM45C) is used for automotive drive shaft applications. The material properties of the steel (SM45C) are taken from literature available. The steel drive shaft should satisfy three design specifications such as

1. Torque Transmission Capability,
2. Buckling Torque Capability
3. Bending Natural Frequency.

3.2 Torque Transmission Capacity of Driveshaft

The maximum torsional strength of the shaft is calculated by using the following equation,

$$\frac{T}{J}=\frac{\tau}{r}=\frac{G\theta}{l}$$

Where,
T is Torque Transmitted in N-m.
J is Polar M.I in m⁴.

$$J=\frac{\pi}{32}\times[do^4-di^4]=\mathbf{0.185\times10^{-6}\ m^4}$$

τ is Shear Stress in N/m².
r is mean radius of shaft in m.

$$r=\frac{ro+ri}{2}=\mathbf{0.0245\ m}$$

G is Shear Modulus in N/m².
θ is angle of twist in radians.
l is length of shaft in m.
Now,

$$\tau=\frac{80\times10^9\times\frac{5\pi}{180}\times0.0245}{0.660}$$

$$\boldsymbol{\tau=259.15\times10^6\ N/m^2}$$

Thus, the torsional strength of the shaft will be calculated by,

$$\frac{T}{J}=\frac{\tau}{r}$$

Therefore, putting this value in shear strength in above equation, we get,

$$T=\frac{259.15\times10^6\times0.185\times10^{-6}}{0.0245}$$

$$\mathbf{T=1956.88\ Nm}$$

The torque transmitted by the steel shaft is 1956.88 Nm.

3.3 Torsional Buckling Capacity of the Drive Shaft

If,

$$\frac{1}{\sqrt{1-\mu^2}}\times\frac{L^2t}{(2r)^3}>5.5$$

7.6 > 5.5

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

$$\tau_{cr}=\frac{E}{3\sqrt{2}\times(1-\mu^2)^{3/4}}\times\left(\frac{t}{r}\right)^{3/2}$$

$$\boldsymbol{\tau_{cr}=1221.37\times10^6\ N/m^2}$$

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

$$T_b=\tau_{cr}\times2\pi r^2t$$

$$\mathbf{T_b=9212.74\ Nm}$$

Here,

$$\mathbf{T_b>T}$$

Therefore, the Design is Safe.

3.4 Bending Natural Frequency

The shaft is considered as simply supported beam undergoing transverse vibration or can be idealized as a pinned-pinned beam. Natural frequency can be found using the following equation,

$$f_{nb}=\frac{\pi}{2}\times\sqrt{\frac{E_x\ I_x}{\bar{m}\ L^4}}$$

Here,
The moment of inertia of hollow shaft is given by,

$$I_x=\frac{\pi}{64}\times(do^4-di^4)=\mathbf{0.2064\times\ 10^{-6}\ m^4}$$

The mass per unit length of the shaft is given by,

$$\bar{m}=\rho\times\frac{\pi}{4}\times(do^2-di^2)=\mathbf{2.4168\frac{kg}{m}}.$$

Therefore upon substitution of above values we get,

$$f_{nb}=\frac{\pi}{2}\times\sqrt{\frac{E_x\ I_x}{\bar{m}\ L^4}}$$

$$\mathbf{f_{nb}=321.05\ Hz>80\ Hz.}$$

Here, the fundamental bending natural frequency of steel shaft is greater than the minimum natural frequency of the shaft assumed. Therefore, the designed Steel Shaft is Safe.

3.5 Critical Speed of Shaft:-

The critical speed of the shaft is given by,

$$N_{cr}=60\times f_{nb}$$

$$\mathbf{N_{cr}=19263.54\ rpm}$$

Therefore, the critical speed of the shaft is 19263.54 rpm which is more than the maximum speed of the transmission system.

3.6 Weight of Steel Driveshaft:-

Weight = Density ×Volume

$$W=\rho\times V$$

$$W=\rho\times\frac{\pi}{4}\times(do^2-di^2)\times L$$

$$W=7850\times\frac{\pi}{4}\times(0.051^2-0.047^2)\times0.660$$

$$\mathbf{W=1.595\ Kg.}$$

The weight of the Steel Driveshaft is 1.595 Kg.

4. DESIGN OF COMPOSITE DRIVE SHAFT

The specifications of the composite drive shaft of an automotive transmission are same as that of the steel drive shaft for optimal design. The driveshaft is to be design for the following design requirements as shown in the Table 3.1.

4.1 Assumptions

1. About longitudinal axis, the shaft rotates at a constant speed.
2. The shaft has a circular and the uniform cross section along the length.
3. The shaft is such that at every cross section, the mass center coincides with the geometric center due to which the shaft is perfectly balanced.
4. All the nonlinear and the damping effects are excluded.
5. The shaft is be made of composite material and Hooke's law is applicable for composite material i.e. the stress strain relationship for composite material is linear and elastic.
6. The shaft is considered as it is under plane stress as the lamina is thin and out-of-plane loads are applied.

4.2 Material selection and Mechanical Properties

The carbon and glass fibers are selected as the best suitable material for the design of composite driveshaft as they are available in market as compared to other materials. Epoxy resin is selected due to its strength, good wetting of fibers and lower curing shrinkage.
Following Cases for fiber volume fraction were considered here,
Case A. 60% fiber volume fraction of Glass/Epoxy shaft (V_{fg} = 60% & V_m=40%).
Case B. 70% fiber volume fraction of Glass/Epoxy shaft (V_{fg} = 70% & V_m=30%).
Case C. 60% fiber volume fraction of Carbon/Epoxy shaft (V_{fc} = 60% & V_m=40%).
Case D. 70% fiber volume fraction of Carbon/Epoxy shaft (V_{fc} = 70% & V_m=30%).
Case E. 60% fiber volume fraction of Carbon and Glass/Epoxy shaft (V_{fg} = 40% & V_{fc} = 20% & V_m=40%).
Case F. 70% fiber volume fraction of Carbon and Glass/Epoxy shaft. (V_{fg} = 40% & V_{fc} = 30% & V_m=30%).

The material properties of the above considered shaft were calculated using fiber volume fraction theory. Considering the first case for unidirectional ply properties can be calculated by using properties presented in Table 4.2 above as follows,

1. **Elastic modulus along the fiber direction, *E_l***

$$E_l = E_f V_f + E_m V_m$$
$$E_l = (74000 \times 0.6) + (4500 \times 0.4)$$
$$\boldsymbol{E_l = 46200\ MPa}$$

2. **Elastic modulus in the transverse direction to the fiber axis, *E_t***

In the following equation, E_{ft} represents the elastic modulus of the fiber in the direction that is perpendicular to the fiber.

$$E_t = E_m \times \left[\frac{1}{(1-V_f) + \frac{E_m}{E_{ft}} \times V_f}\right]$$
$$\boldsymbol{E_t = 10310\ MPa}$$

3. **Shear modulus, *G_{lt}***

An order of magnitude of this modulus is given by the following expression in which G_{flt} represents the shear modulus of the fiber.

$$G_{lt} = G_m \times \left[\frac{1}{(1-V_f) + \frac{G_m}{G_{ft}} \times V_f}\right]$$
$$\boldsymbol{G_{lt} = 3704\ MPa}$$

4. **Poisson Coefficient, μ_{lt}**

The Poisson coefficient represents the contraction in the transverse direction when a ply is subjected to tensile loading in the longitudinal direction.

$$\mu_{lt} = \mu_f V_f + \mu_m V_m$$
$$\boldsymbol{\mu_{lt} = 0.31}$$

5. **Modulus along any direction, *E_x***

It is possible to evaluate elastic and shear modulus along any direction within the plane. The longitudinal modulus along direction *x*, called E_x, is presented in the following equation where c=cosθ and s=sinθ . It should be noted that this module decreases rapidly when *x* departs from the fiber direction i.e. as θ increases.
To increase the torsional strength of the shaft as per the literature the fiber orientation is taken as θ=45°.

$$E_x = \frac{1}{\frac{c^4}{E_l} + \frac{s^4}{E_t} + 2c^2s^2 \times \left(\frac{1}{2G_{lt}} - \frac{\mu_{lt}}{E_l}\right)}$$
$$\boldsymbol{E_x = 10700\ MPa}$$

6. **Density, ρ**

The mass density of a ply can be calculated as,

$$\rho = \rho_f V_f + \rho_m V_m$$
$$\boldsymbol{\rho = 2040\ kg/m^3}.$$

Using the above formulas the mechanical properties for the remaining cases are calculated in presented in the table 4.3 below.

Table -4.3: Material properties of Composite Material.

Properties	Glass Fiber		Carbon Fiber		Glass and Carbon Fiber	
	60-40 Case A	70-30 Case B	60-40 Case C	70-30 Case D	60-40 Case E	70-30 Case F
Longitudinal modulus in ℓ direction, E_l (MPa)	46,200	53,150	1,39,800	1,62,350	77,400	99,950
Transverse modulus in t direction, E_t (MPa)	10,310	13,140	7,760	8,830	9,300	10,900
Shear modulus, G_{lt} (MPa)	3,704	4,750	3,820	4,970	3,750	4,850
Poisson ratio, μ_{lt}	0.31	0.295	0.34	0.33	0.32	0.31
Elastic Modulus in x direction, E_x (MPa)	10,700	13,600	10,200	12,650	10,600	13,300
Density, ρ (kg/m³)	2040	2180	1530	1585	1870	1925

The material properties of the composite material and its cases are given in Table 4.3. The composite drive shaft should satisfy three design specifications such as,

1. Torque Transmission Capability
2. Buckling Torque Capability
3. Bending Natural Frequency.

4.3 Torque Transmission Capacity of Driveshaft

Considering Case A the composite driveshaft is designed to meet the design requirements and specifications as mentioned above. The maximum torsional strength of the shaft is calculated by using the following equation,

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l}$$

Now,

$$\tau = \frac{G \times \theta \times r}{l}$$

$$\boldsymbol{\tau = 11.99 \times 10^6\ N/m^2}$$

Therefore, putting this value in shear strength in above equation, we get,

$$T = \frac{\tau \times J}{r}$$

$$\boldsymbol{T = 285.29\ N\ m}$$

The torque transmitted by the steel shaft is 285.29 Nm.

4.4 Torsional Buckling Capacity of the Drive Shaft

Since long thin hollow shafts are vulnerable to torsional buckling, the possibility of the torsional buckling of the composite shaft was checked by considering the hollow composite shaft as anisotropic cylindrical shell the buckling torque is given by:

$$T_b = 2\pi r^2 t \times 0.272 \times \left(E_x \times E_y^3\right)^{\frac{1}{4}} \times \left(\frac{t}{r}\right)^{\frac{3}{2}}$$

Where,
E_x = Young's modulus in x direction.
E_y = Young's modulus in y direction.
Here, we considered the composite driveshaft as orthotropic lamina. Therefore,

$$T_b = 2\pi \times 0.0235^2 \times 0.007 \times 0.272 \times [(10700 \times 10700^3)]^{\frac{1}{4}} \times \left(\frac{0.007}{0.0235}\right)^{\frac{3}{2}}$$

$$\boldsymbol{T_b = 11{,}492\ Nm}$$

Here, $\boldsymbol{T_b > T}$
Therefore, the design is safe.

From the above equation, we can see that the torsional buckling capability of composite shaft is strongly dependent on the thickness of composite shaft and the average modulus in the hoop direction.

4.5 Bending Natural Frequency

The shaft is considered as simply supported beam undergoing transverse vibration or can be idealized as a pinned-pinned beam. Natural frequency can be found using the following equation,

$$f_{nb} = \frac{\pi}{2} \times \sqrt{\frac{E_x\ I_x}{\overline{m}\ L^4}}$$

Here,
The moment of inertia of hollow shaft is given by,

$$I_x = \frac{\pi}{64} \times (do^4 - di^4) = \mathbf{0.2064} \times\ \mathbf{10^{-6}}\ \boldsymbol{m^4}$$

The mass per unit length of the shaft is given by,

$$\overline{m} = \rho \times \frac{\pi}{4} \times (do^2 - di^2) = \mathbf{2.10}\,\frac{\boldsymbol{kg}}{\boldsymbol{m}}.$$

Therefore upon substitution of above values we get,

$$\boldsymbol{f_{nb} = 138.85\ Hz} > 80\ Hz.$$

Here, the fundamental bending natural frequency of composite shaft is greater than the minimum natural frequency of the shaft assumed.
Therefore, the designed Composite Shaft is Safe.

4.6 Critical Speed of Shaft:-

The critical speed of the shaft is given by,

$$N_{cr} = 60 \times f_{nb}$$

$$\boldsymbol{N_{cr} = 8331\ rpm}$$

Therefore, the critical speed of the shaft is 8331 rpm which is more than the maximum speed of the transmission system.

4.7 Weight of Composite Driveshaft:-

$$W = \rho \times V$$

$$W = 2040 \times \frac{\pi}{4} \times (0.054^2 - 0.040^2) \times 0.660$$

W=0.8290 Kg

The weight of the Composite Driveshaft is 0.8290 Kg.
By using the above formulas we have calculated the values for the remaining cases and presented in the table 4.4 given below,

Table -4.4: Design Requirements of Cases of Shaft.

Design Requirements	Steel (SM45C)	Glass Fiber		Carbon Fiber		Glass and Carbon Fiber	
		60-40 Case A	70-30 Case B	60-40 Case C	70-30 Case D	60-40 Case E	70-30 Case F
Shear Stress τ, (MPa)	259.16	11.99	15.38	12.37	16.09	12.14	15.70
Torsional Strength *T*, (Nm)	1956.88	285.29	365.92	294.22	388.04	289	373.21
Buckling Torque T_b, (Nm)	9,212.78	11,492	14,606	10,955	13,586	11,385	14,284
Natural Frequency f_{nb}, (Hz)	321.05	138.85	151.49	156.56	171.66	144.41	159.38
Critical Speed N_{cr}, (rpm)	19,263.54	8,331	9,089	9,394	10,300	8,665	9,563
Weight W, (Kg)	1.595	0.8290	0.8859	0.6217	0.6440	0.7599	0.7823

5. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It also can be used to analyze either small or large scale deflection under loading or applied displacement. In this project finite element analysis was carried out using the FEA software ANSYS. Static, Modal and Buckling analysis was carried out using the mentioned dimensions and material properties in the table given above for both steel and composite driveshaft.

Static Modal and Buckling analysis was carried out as follows

1. Model was created in ANSYS by taking 51mm as O.D. and 47mm as I.D. and 660mm length. The loading and boundary condition applied to shaft is shown in Fig-5.1

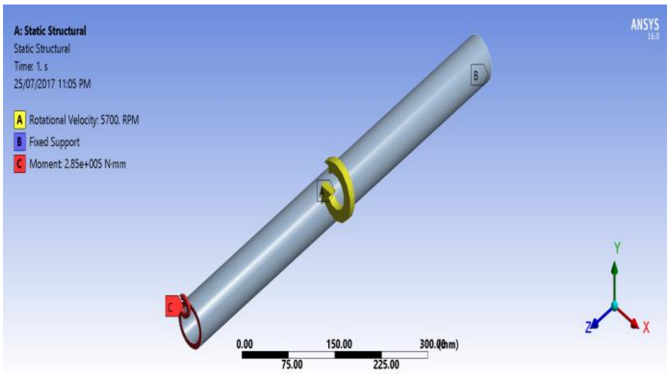

Fig -5.1: Loading and Boundary Conditions applied to shaft

2. The Model was solved for Static, Modal and Buckling analysis to obtain results as shown in Fig-5.2, Fig-5.3 and Fig-5.4.

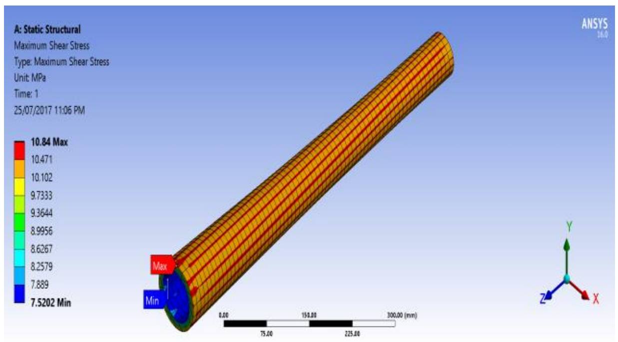

Fig-5.2: Maximum Shear Stress

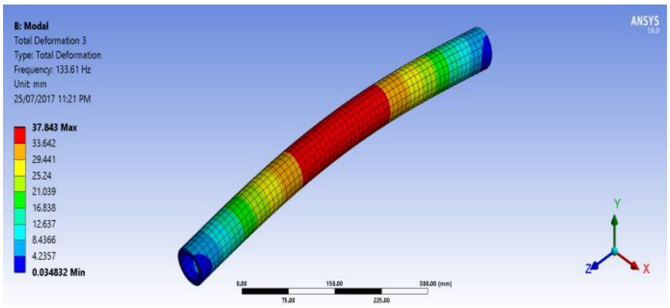

Fig-5.3: 1st Mode Natural Frequency

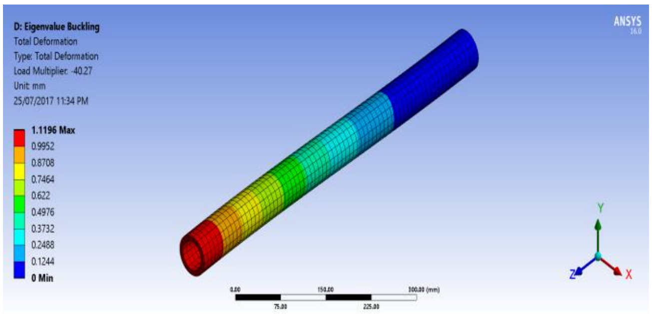

Fig-5.4: Eigenvalue Buckling Analysis

Analysis is carried out on various cases of shaft and presented in the table 5.1 below.

Table 5.1 Results of ANSYS

Cases	Material	Torque Applied (Nm)	Shear Stress (MPa)	Natural frequency (Hz)	Load Multiplier	Buckling torque (Nm)
1.	Steel (SM45C)	1900	251.12	309.77	4.7233	8,974.27
A.	Glass Fiber with 60% Fiber Volume	285	10.84	133.61	40.27	11,476.9
B.	Glass Fiber with 70% Fiber Volume	365	14.45	145.93	38.48	14,045.2
C.	Carbon Fiber with 60% Fiber Volume	294	11.27	134.42	32.056	9,424.46
D.	Carbon Fiber with 70% Fiber Volume	383	15.43	141.09	28.07	10,750.8
E.	Glass and Carbon Fiber with 60% Fiber Volume	289	11.081	132.76	36.35	10,505.2
F.	Glass and Carbon Fiber with 70% Fiber Volume	373	14.45	141.85	33.98	12,674.5

6. CONCLUSION

Following conclusion are obtained from thesis paper:

1. The designed shafts meet the design requirements for the designing of shaft. Composite Shafts and Steel Shaft are designed to meet the design requirements.
2. The theoretical values of shaft design are nearly same to the analytical values of shaft obtain using analysis tool ANSYS.
3. Hybrid driveshaft i.e. Glass and Carbon Fiber driveshaft with 70% fiber volume fraction; the torsional buckling strength of the hybrid composite driveshaft was 14,284 Nm which is more than the maximum torque applied to the shaft which is 3500 Nm. The fundamental bending natural frequency of the composite shaft is 159.38 Hz and the minimum required bending natural frequency is 80 Hz. The critical speed of the composite shaft is 9,563 rpm and is more than the maximum speed. Hence, the designed hybrid composite shaft is safe for torsional buckling, fundamental bending natural frequency and critical speed theoretically.
4. Torsional strength of the shaft with higher fiber volume fraction is higher. Thus it can be concluded that fiber volume fraction is the deciding factor in designing.
5. Hybrid composite driveshaft's have better mechanical properties than conventional composite driveshaft as it contains two fiber materials. Fiber materials having high cost can be used with less cost fiber materials in proportion so that it can obtain the mechanical properties of both the material and can be relief in cost reduction. Carbon fibers have the major contribution over glass fibers in increasing the torsional stiffness.
6. Compare to steel driveshaft more than 60% of weight can be reduced by using the composite driveshaft instead of steel driveshaft. The advantage is less weight and less power required for transmission from engine to driveshaft to rear wheel of the vehicle and it gives less noise and vibration while rotating shaft.

FUTURE SCOPE

Composite Shaft can be Manufactured using various combinations of materials and can be tested experimentally for torsional test of shaft, buckling capability of shaft, critical speed test and natural frequency.

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