Design and Analysis of Composite Drive Shaft

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Abstract - *A Drive shaft is used to transmit the power in automobile [1]. In conventional practice the drive shaft made up of metal. Due to use of metal i.e. Steel the weight of the shaft increase considerably and it has to manufacture in two pieces due to its length and low natural frequency [2]. The current paper focuses on replacing the steel shaft with composite shaft of material carbon fiber/glass epoxy material [3]. As it having high weight to strength ratio and the natural frequency is very much high than steel. In this work we aim to find out natural frequency of steel and composite drive shaft and find best suitable composite material for the purpose of weight reduction of shaft and manufacturing of shaft in one piece.*

***Key Words*: Natural frequency, torsional buckling capacity, critical speed, laminate stacking sequence, orientation angle**

1. INTRODUCTION

Composite materials can be defined as a macroscopic combination of two or more materials having a recognizable interface between them[5]. composite materials typically have a fiber or particle phase that is stiffer and stronger than the continuous phase [4]. composite materials consist high stiffness, high weight to strength ratio and high natural frequency, less weight. hence it attracts the attention to use it for manufacturing of composite drive shaft of an automobile. The general weight reduction of the vehicle is a highly desirable goal, if it can be achieved without increase in cost and decrease in quality and reliability for the reason of efficiency improvement of the vehicle. Compare the performance of the composite drive shaft over steel drive shaft and suggested the suitability of composite materials in the automobile industries.

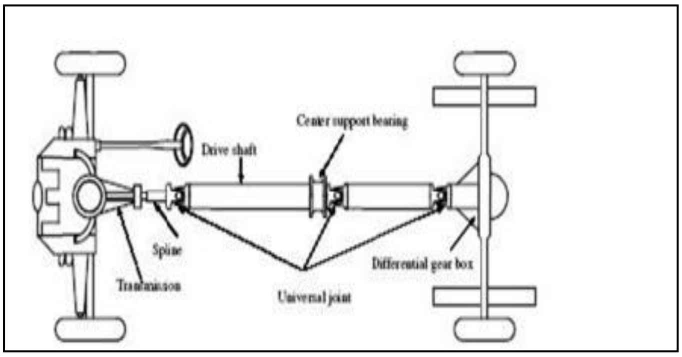

FIGURE NO :1

2. LITERATURE SURVEY

1. Design and analysis of Automotive composite propeller shaft using FEA B. James Prasad Rao et al.[1].propeller shaft was analyzed using FEM techniques (ANSYS). Modelling of the propeller shaft is done in the ANSYS software by giving the boundary conditions as one end is fixed and one end having twisting mome (al.)nt about x axis. Various analysis like free vibration analysis, buckling analysis, is done. The torsional buckling load is higher than the ultimate torque transmission by the shaft 5 times.

2. Design and comparison of the strength and efficiency of drive shaft made up of Steel and composite material. C.Elanchezhian et al.[2]. In this paper drive shaft made up of SM45c Steel is compared with the Kevlar composite shaft. Restraint and efficiency of the complete drive shaft is also tested, for this Catia v5 is used software for the 3D modelling and ANSYS is used for the analysis. And concluded Steel drive shaft has less damping capacity. The fundamental natural frequency of the Carbon fibre composite drive shaft can be twice as high as that of steel or aluminum as well as the greater torque capability Longer fatigue life. Lower rotating weight transmits more available power.

3. Design and manufacture of an automotive hybrid aluminium/composite drive shaft. Dai Gil Lee et al. [3].One-piece hybrid aluminium composite drive shaft for a rear wheel drive automobile was developed. The composite materials where stack on the inner surface of the aluminum tube and co-cured to prevent the hybrid shaft from being damage by external impact and moisture. And concluded the hybrid aluminum composite shaft is suitable and better than the conventional steel shaft. The static torque and natural frequency is satisfied design requirement.

4. Weight Optimization and finite element analysis of composite Automotive drive shaft for maximum stiffness P. Satheesh Kumar Reddy et al.[4]. The modelling of the complete drive shaft is made in the analysis software ANSYS. Comparison made based on static analysis and free vibration analysis and tensional buckling analysis and days on weight saving.

5. Review on the design and analysis of the composite drive shaft. Shoaib Nadeem Sk et al.[5] **.** The objective of the paper is to review the work carried out on the composite drive shaft which are used in the automotive application and fabrication techniques and material used in the fabrication of composite shaft. Finite element analysis on the composite shaft and steel shaft. And hence recommended the thickness of drive shaft for Boron/Epoxy, carbon/Epoxy and E-Glass/Epoxy.

6. An investigation into hybrid carbon/glass fiber reinforced epoxy composite automatic drive shaft. M.A. Badie et al.[6]Four types of the finite element analysis where perform to study the different effect of layer stacking on the critical performance characteristics and fatigue resistance. Natural frequency increases with decreasing fiber orientation angle. The composite drive shaft has reduction equal to 54.3% of its frequency when orientation angle is 0 to 90 degrees. Critical buckling talk has pick value at 90 degree and lowest at the range of 20 to 40 degree. Composite tubes of fiber orientation angle of±45-degree experiences higher load carrying capacity and higher torsional stiffness.

3. STEEL DRIVE SHAFT CALCULATIONS

In this project based on the existing model of TATA 407 pickup, the outer diameter of the drive shaft is taken as 76.3 mm and length of the shaft is 1457 mm

3.1 Design of conventional steel drive shaft

The material properties of the steel (SM45C) are given in table

TABLE:1 Properties of Steel

Mechanical properties	Symbol	Units	Steel
Young's Modulus	E	GPa	210
Shear modulus	G	GPa	80
Poisson's ratio	μ	-	0.3
Density	ρ	Kg/m3	7800
Yield Strength	S_y	MPa	370

So, the torque is maximum at 1st gear, when the speed of vehicle is low. Therefore, the maximum torque will be,

$$T_{Max} = 250 * 6.01 \qquad \therefore T_{max} = 1502.5\ N-m$$

3.2 Design of steel shaft based on Torsional Strength basis

Torsional Strength: The primary load in the drive shaft is torsion. The maximum shear stress, $\tau_{\max}$ in the drive shaft is at the outer radius, and is given as

$$\tau = \frac{16M_t}{\pi d_0^3(1-C^4)} \qquad \therefore C = 0.9497$$

We know,

$$C = \frac{d_i}{d_o} \qquad 0.9494 = \frac{d_i}{0.0763} d_i = 0.07246m \qquad \therefore d_i = 72.46mm$$

3.3 Design of steel shaft based on Rigidity basis

$$\theta = \frac{584M_tL}{Gd_0^4(1-C^4)} \qquad \therefore \theta = 2.5280°$$

The permissible angle of twist for machine tool application is 0.25^0 per meter length. For line shaft in between 3^0 to 4^0 is the limiting value.

3.4 Thickness of Steel Drive Shaft

$$t = \frac{d_o - d_i}{2} \qquad t = 1.95 * 10^{-3}m \qquad \therefore t = 1.95mm$$

3.5 Mass of steel drive shaft

$$m = \rho AL \quad m = \rho * \frac{\pi}{4}(d_o^2 - d_i^2) * L \quad m = 5.k1763\ g$$

3.6 Torsional buckling capacity of the drive shaft

$$T_b = (2\pi r_m^2 t)(0.272)(E)\left(\frac{t}{r_m}\right)^{\frac{3}{2}}$$
$$\therefore T_b = 11623.2094 \quad N-m$$

Thus, the shaft need to withstand Torsional buckling (T_b) capacity such that T_b>T. Hence the condition is satisfied.

3.7 Natural frequency

Bernoulli Euler theory

Naturals frequency based on the Bernoulli Euler theory is given by

$$f_{nt} = \frac{\pi P^2}{2L^2}\sqrt{\frac{EI_x}{m_1}}$$

Where,

$$f_{nt1} = 101.0632\ Hz$$

This value is greater than the minimum desired natural frequency of 60Hz. F_{nt} = natural frequency based on Bernoulli Euler theory, Hz

P =1, first natural frequency
r = mean radius of shaft
I_x =Area moment of inertia in x direction in m4
m_1 = mass per unit length in kg/m

Now the second moment of inertia, I is

$$I_x = \frac{\pi}{4}(r_o^4 - r_i^4) \qquad \therefore\ I_x = 3.2368 * 10^{-7} m^4$$

The mass per unit length of the shaft is

$$m = \pi(r_o^2 - r_i^2)\rho \qquad m = 3.643\, {}^{Kg}/_{m}$$

To get the natural frequency following Bernoulli Euler formula is used

$f_{nt1} = \frac{\pi P^2}{2L^2}\sqrt{\frac{EI_x}{m_1}}$Thus, the steel design of a hollow shaft of outer diameter 76.3 mm and thickness 1.95 mm is an acceptable design.

The critical speed of shaft is given by,

$$N_{crt1} = 60 f_{nt1} f_{nt1} = 6063.7920 rpm$$

Similarly, for P = 2, Second natural frequency

$$f_{nt_2} = 404.2788 Hz \quad N_{cr_2} = 60 f_{nt_2} N_{cr_2} = 24256.7280\ rpm$$

Similarly, for P = 3, Third natural frequency

$$f_{nt_3} = 909.6272\ Hz N_{cr_3} = 60 f_{nt_3}$$

$$N_{cr_3} = 54577.6320\ rpm$$

3.8 Analytical results

Table2: Analytical results of steel drive shaft

Sr. No	Parameter	Steel shaft
1	Outer Diameter	76.3mm
2	Thickness	1.95 mm
3	Applied Torque (T)	1502.5 N-m
4	Torsional Buckling (T_b)	11623.2094 N-m
5	Natural Frequency (f_{nb})	101.0632 Hz
6	Critical speed (N_{cr})	6063.7920 rpm
7	Mass (m)	5.1763 kg

4.ANALYSIS OF STEEL DRIVE SHAFT

1. MODEL OF STEEL DRIVE SHAFT:

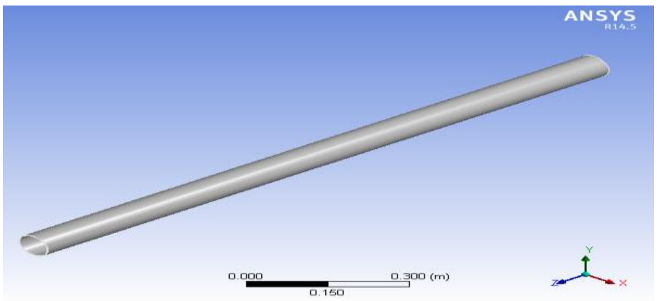

FIGURE NO:2

2. NATURAL FREQUENCY WHEN ONE END IS FIXED AND OTHER END IS FREE:

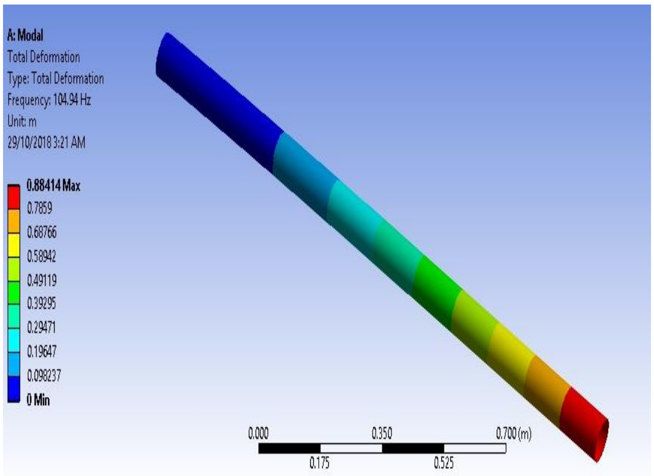

FIGURE NO:3

5. COMPOSITE DRIVE SHAFT

A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix. The reinforcing phase material may be in the form of fiber, particles, or flakes [7]. Composite material is widely used in the automobile industry due to its properties like high strength, corrosion resistance, low weight, high impact energy absorption etc. Drive shaft is the element in the vehicle which is continuously rotates and transmit power. Because of this the drive shaft faces vibration, and impact on it. The weight of the steel drive shaft is more and it also having less damping capacity. Use of composite material can help us to solve of these problems and improve the performance of the vehicle and improve efficiency by reduction in weight

5.1 Micromechanical Analysis of Lamina

Volume fraction of fiber – 0.6 (60%)
Volume fraction of matrix – 0.4 (40%)
Volume of composites– 1 (100%)

1. **Density of composite**

$$\rho_c = \rho_f V_f + \rho_m V_m$$

2. **Weight of fiber**

$$W_f = \frac{\rho_f}{\rho_c} V_f$$

3. **Weight of matrix**

$$W_m = \frac{\rho_m}{\rho_c} V_m$$

4. **Sum of mass fractions**

$$Sum\ of\ mass\ fraction = W_f + W_m$$

5. **Young's modulus of lamina(Longitudinal direction)**

$$E_1 = E_f V_f + E_m V_m$$

6. **Young'smodulus of lamina(Transversedirection)**

$$\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{E_m}$$

7. **Major Poisson's ratio**

$$\mu_{12}. = \mu_f V_f + \mu_m V_m$$

8. **Minor Poisson's ratio**

$$\mu_{21} = \mu_{12} * \frac{E_2}{E_1}$$

9. **Shear modulus**

$$\frac{1}{G_{12}} = \frac{V_f}{G_f} + \frac{V_m}{G_m}$$

$$* G_f = \frac{E_f}{2(1+\mu_f)}$$

$$* G_m = \frac{E_m}{2(1+\mu_m)}$$

10. Ultimate longitudinal strength

a. **Ultimate failure strain of fiber**

$$(\varepsilon_f)_{ult} = \frac{(\sigma_f)_{ult}}{E_f}$$

$$(\varepsilon_f)_{ult} = \frac{(\sigma_f)_{ult}}{E_f}$$

b. **Ultimate failure strain of Matrix**

$$(\varepsilon_m)_{ult} = \frac{(\sigma_m)_{ult}}{E_m}$$

c. **Ultimate longitudinal strength**

$$(\sigma_1^T)_{ult} = (\sigma_f)_{ult} V_f + (\varepsilon_f)_{ult} E_m (1 - V_f)$$

d. **Ultimate transverse tensile strength**

$$(\sigma_2^T)_{ult} = E_2 (\varepsilon_2^T)_{ult}$$

$$* (\varepsilon_2^T)_{ult} = (\varepsilon_m^T)_{ult} (1 - V_f^{\frac{1}{3}})$$

10. Minimum fiber volume fraction

$$(V_f)_{\min} < \frac{(\sigma_m)_{ult} - E_m(\varepsilon_f)_{ult}}{(\sigma_f)_{ult} - E_m(\varepsilon_f)_{ult} + (\sigma_m)_{ult}}$$

11. Critical fiber volume fraction

$$(V_f)_{critical} < \frac{(\sigma_m)_{ult} - E_m(\varepsilon_f)_{ult}}{(\sigma_f)_{ult} - E_m(\varepsilon_f)_{ult}}$$

12. Shear strength

$$(\tau_{12})_{ult} = G_{12}(\gamma_{12})_{ult} \quad Where,^{*} (\gamma_{12})_{ult} = \frac{(\tau_{12})_{m\ ult}}{G_m}$$

The fiber diameter to fiber spacing ratio is

$$\frac{d}{s} = \left[\frac{4V_f}{\pi}\right]^{\frac{1}{2}}$$

Therefore, the shear strength is given by,

$$(\tau_{12})_{ult} = G_{12}\left[\frac{d}{s}\frac{G_m}{G_f} + \left(1 - \frac{d}{s}\right)\right](\gamma_{12})_{m\ ult}$$

Using the formula of micromechanical analysis of lamina following properties are calculated which is shown in Table 3

Table 3: Properties of composite lamina (carbon fiber and epoxy resin)

SR. NO	COMPOSITE PROPERTIES	SYMBOL	VALUE	UNIT
1	Young's Modulus (Longitudinal	E_1	146.4	GPa
2	Young's Modulus (Transverse	E_2	7.36	GPa
3	Major Poison's	μ_{12}	0.3	-
4	Minor Poison's ratio	μ_{21}	0.0151	-
5	Shear Modulus	G_{12}	2.82	GPa
6	Ultimate longitudinal	$(\sigma_1^T)_{ult}$	2.50	GPa
7	Ultimate transverse	$(\sigma_2^T)_{ult}$	27.66	MPa
8	Minimum fiber volume fraction	$(V_t)_{min}$	0.498	%
9	Critical fiber volume fraction	$(V_t)_{cr}$	0.507	%
10	Shear strength	τ	18.6	MPa

6. RESULT AND COMPARISON

Material: steel	Analytical result	Ansys result
Natural frequency	101.0632 Hz	104.94 Hz

7. CONCLUSIONS

1. Strength of the composite material i.e. carbon fiber is more than steel.
2. Weight to strength ratio of composite material is more than the steel.
3. Composite material is having internal damping capability.
4. Composite material can reduce weight of drive shaft up to by 90% as compare to steel drive shaft

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