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Material Optimization and Weight Reduction of Universal Joint Yoke Using Composite Material

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Abstract: *Universal joint is a joint in a rigid rod that allows the rod to bend in any direction, and is commonly used in shafts that transmit rotary motion. It generally consists of two hinges located close together, oriented at 90° to each other, connected by a cross shaft. It is widely used in industrial applications and vehicle drivelines to connect misaligned shaft. Automobile industries are exploring composite material in order to obtained reduction of weight without significant decrease in vehicle quantity and reliability. This is due to the fact that the reduction of weight of vehicle directly proportional to fuel consumption. Universal joint yoke have certain modification are made in existing geometry and analyzing for the identical boundary condition. Thus in this paper the aim is to replace universal joint by composite material .the following material can be chosen are carbon/epoxy composite, Kevlar/epoxy composite. Analysis is being performed on universal joint yoke.*
Keyword: *Universal joint yoke, composite material, weight reduction.*

I. Introduction

The power transmission system is the system which causes movement of vehicles by transferring the torque produced by the engines to the wheels after some modifications. The transfer and modification system of vehicles is called as power transmission system. The power transmission system of vehicles consists of several components which encounter unfortunate failures. These failures may be attributed to material faults, material processing faults, manufacturing and design faults, etc. A major problem with the use of a Hooke's joint is that it transforms a constant input speed to a periodically fluctuating one. The kinematical consequences of this property of this joint can be remedied, as long as rigid body rotations are concerned, by using two converses Hooke's joint. But if torsional vibrations of the propeller shaft are concerned, there is no way of removing the dynamical consequences of an introduced Hooke's joint in a rear wheel drive vehicle. Figure 1 shows the schematic diagram of universal joint. In a widely used single piece drive shaft, two universal joints are used .Two universal joints are preferred in order to avoid the transformation of constant input speed into a fluctuating speed which is encountered when a single universal joint is used.

In 300BC Greek invented universal joint from historical evidence. The name cordon the Italian mathematician utilizes a similar mechanism to suspend a ship compass horizontal, regardless of ship movement. Mr.Harshal Bankar (2013) studied that the composite material has high specific modulus, strength and less weight. The fundamental natural frequency of composite material can be twice as that of steel and aluminum because composite material have more than 4 times specific stiffness which makes it possible to manufacturing the universal joint. Composite material have good corrosion resistance, greater torque capacity and longer fatigue life than steel. Swati Datey (2014) studies each automobile has different power transmission system constructive feature depends upon vehicle drive line concept.while transmitting a torque different stresses are indues such as tesion stress and bending stress are experience.

Finite element analysis method is used as stress analysis to determine the stress condition at failed section. Siraj mohammad ali sheikh (2012)studied that drive shaft are generally subjected to torsional stress and bendind stress due to weight of component ,thus these rotataing component are susceptiable to fatigue by the nature of their operation common sign of drive shaft.fatigue is vibration or shudder during operation.S G Solankhe (2014) studied that the failure of universal joint is occur due to manufacturing and design fault, raw material faults, maintains faults, material processing faults, drivable joint angle, cyclic load to avoids this problem various such as topology optimization method, weight reduction method, shape optimization method, manufacturing method etc.

II. Problem Statement

The problem for this analysis is taken for the paper of "two cases of failure in the power transmission system on vehicle an universal joint yoke and drive shaft". Universal joint was analyzed in Ansys considering the component to be made up of low alloy steel group(SM45C).typical properties are 1750 Mpa as ultimate tensile strength and 1400 Mpa as yield strength and 200 Nm force applied at spider. The material as well as the loading condition of torsional moment and rotational moment speed kept constant.

Objective

- Study weight reduction that can be obtained without affecting the functionality of the shaft.
- Carry out analysis of universal joint using FEA.
- Comparison is done for two materials to verify best material for universal joint.

III. Modification

Steps To Achieve The Objectives:-

1. Disassemble universal joint from transmission system.
2. To carry out 3D scanning of universal joint.
3. Create a 3D geometry in CAD software from Scanned data.
4. Conduct a stress analysis using FEA software.
5. Conduct a Modal analysis of the same.
6. Conduct a physical test using single axis strain gauge to validate FEA static stress analysis results with physical tests
7. Modify the CAD geometry & material to a universal joint.
8. Conduct a static stress analysis of the modified of universal joint.
9. Conduct a Modal analysis of the modified universal joint.
10. Compare results of both static and modal analysis between existing universal joint and modified universal joint.
11. Conduct iterations if necessary.

A chamfer was provided on the inner hole at the base of the yoke where it is mounted to the power transmitting end of gearbox. In the new develop model radius of 5.5 mm is provided in addition to the chamfer and the rest of geometry kept unaltered. The purpose of this analysis is to study the effect due to change of geometry on behavior of the component under identical loading and boundary condition.

IV. Design Calculation

Design of Conventional Universal Joint Yoke

Convectional universal joint yoke or composite one, the design should be based on the following criteria:

- Torsional strength
- Torsional buckling and
- Bending natural frequency

SM45C steel was selected, since it is widely used for design of convectional steel shaft. The properties of SM45C steel are:

Young Modulus (E) = 207 Gpa
Shear Modulus (G) = 80 Gpa
Poisson's Ratio (μ) = 0.3
Density of Steel (ρ) = 7600 kg/m3
Torsional strength

$$\frac{(\tau_{max})}{F.S} = \frac{(32T\ r_o)}{(\pi[do^4 - di^4])}$$

Where, T =Maximum torque applied in N*M
J = Polar moment of inertia in m^4
d_o and d_i = outer and inner radius of shaft in m
Assuming τ_{max} = 80 Mpa And F.S is 3

T_{max} = 1.8596x10-3

Torsional buckling

A shaft is consider as long shaft, if

$$\left(\frac{1}{\sqrt{1-8^2}}\right)\frac{L^2 t}{(2r)^3} > 5.5$$

$T_b = \tau_{cr}\,(2\pi r2t)$

Where the critical stress (τ_{cr}) is given by,

$$\tau_{cr} = \left[\frac{E}{3\sqrt{2}(1-8^2)^{\frac{3}{4}}}\right]\left(\frac{t}{r}\right)^{\frac{3}{2}}$$

Substituting,

$\tau_{cr} = 81.6875 \times 10^7$ N/m2

$T_b = 63.11735 \times 10^3$ N-m

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Thus, $T_b > T$

Bending natural frequency $F_{nb} = \frac{\pi p^2}{2L^2} \frac{\sqrt{EIx}}{m}$

Where, m = mass per unit length in kg/m

Ix = moment of inertia in x-direction in m^4

$Ix = \frac{\pi}{64}(do^4 - di^4)$

= 3.138 x 10^{-6}m4

$M = \rho\left(\frac{\pi}{4}\right)[do^2 - di^2]$

= 41.949kg/m

Substituting these values,

F_{nb} = 188.806 Hz

Thus,

$F_{nb} > F_{nb\ (min)}$

Thus the designed SMC45 steel driveshaft meets the entire requirement, the total mass of universal joint is:

M = mL

M = 3.23 kg

Design of Composite Universal Joint

Only $0°$,$\pm$ 45° and 90° were considered for the composite ply orientation, owing to their specific advantages.

Design of carbon /Epoxy Universal Joint

60% fiber volume fraction carbon/Epoxy shaft (Vf = 60%) with standard ply thickness of 0.13 mm was selected.

Torsional strength

$$\frac{\tau_{max}}{F.S} = \frac{T}{2\pi r^2 t}$$

Where, r is the mean radius of the shaft.

Since the nature of loading is pure shear, 70% of the plies can be set as $\pm$ 45° and the reaming 30% at 0° and 90° orientation.

$\tau_{max.}$ = 293 Mpa

For a factor of safety (F.S) of 6,

r^2t = 2.6462 x 10^{-6} m^3

Thus, t $\geq$1.8106 x 10^{-3}m

Since the thickness of each ply is 0.13 mm

N = 1.8106 x 10^{-3} m/0.13 x10^{-3}

= 13.93 $\cong$14

Hence the corrected value is

t = 1.82 x10^{-3}m

r_i = 0.009 m

r = 0.027 m

Torsional buckling:-

Considering the hollow composite shaft as an isotropic cylindrical shell, the buckling torque is given by:

$Tb = 2\pi r^2 t\ (0.272)\ (E_x E_y^3)^{1/4}\ (t/r)^{3/2}$

Where,

E_x and E_y are the young modulii in x and y direction respectively.

E_x = 38709.5 Mpa

By permuting (interchanging the percentages of 0° and 90° plies)

E_y = 38709.5 Mpa

Upon substitution,

T_b = 3067.49 N-m (>T)

Bending natural frequency:-

$F_{nb} = \pi/2L^2 \frac{\sqrt{ExIx}}{m}$

The density of carbon/Epoxy laminates (ρ) = 1530 kg/m^3

Hence,

$I_x = 1.179957 \times 10^{-6}$m4

M = 1.03385 kg/m

Upon substitution,

F_{nb} = 101.93 Hz (>80Hz)

The total mass of carbon/Epoxy composite driveshaft is

M = 2.38 kg

Design of Kevlar/Epoxy Universal Joint:-

Setting 70% of the plies in$\pm$ 45° and remaining 30% in 0° and 90° similar to the previous approach from the respective, $\tau_{max.}$ = 95 Mpa

E_x = 23900 Mpa

E_y = 23900 Mpa

Using factor of safety of 6 for V_f = 60% and ply thickness = 0.13 mm

$T > 5.5844 \times 10^{-3}$m

n = 42.96 ≅ 44

The corrected values are

t = 0.00572 m

r_1 = 0.05428 m

r = 0.05714 m

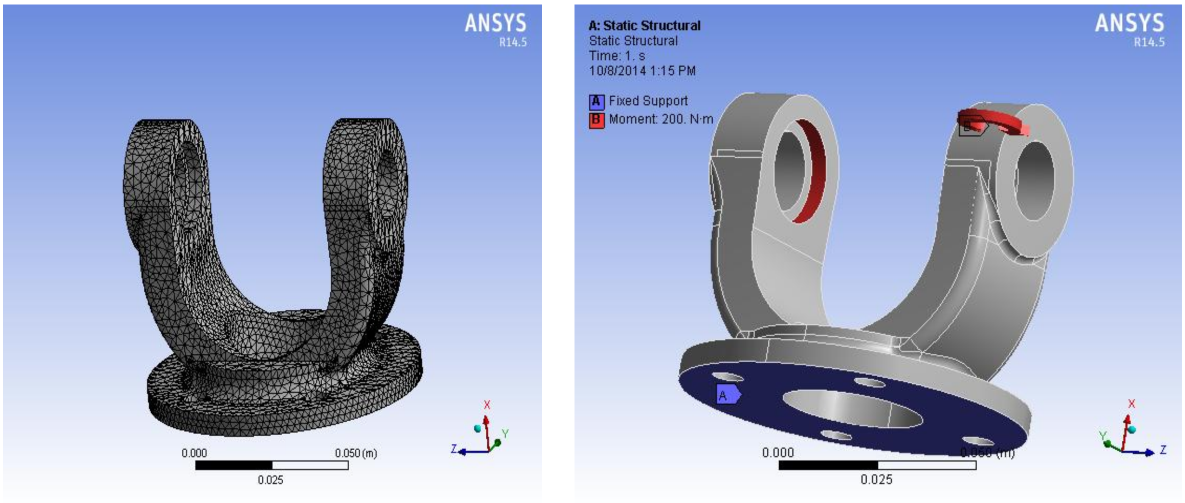
The calculated value of buckling torque, bending natural frequency and the total mass are

T_b = 24161 n-m

F_{nb} = 101.903 Hz

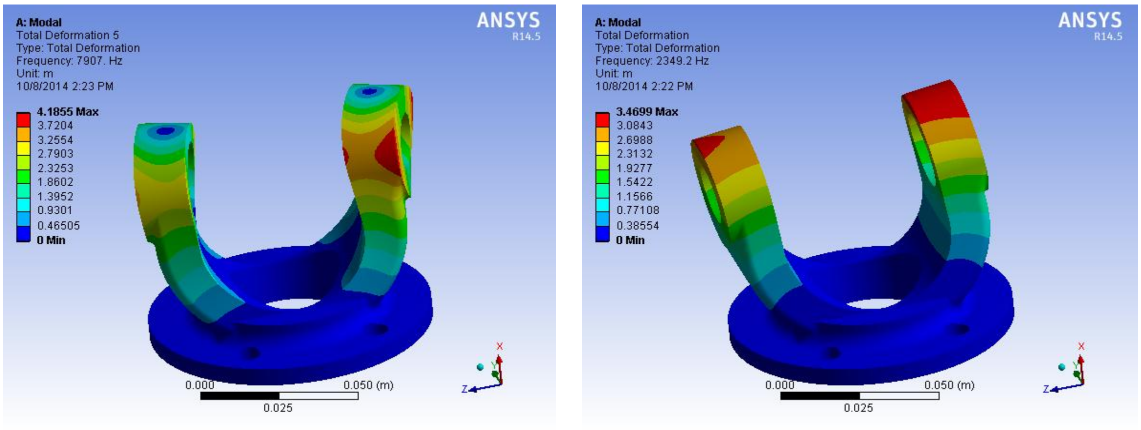
M = 2.83 kg

V. Software Analysis



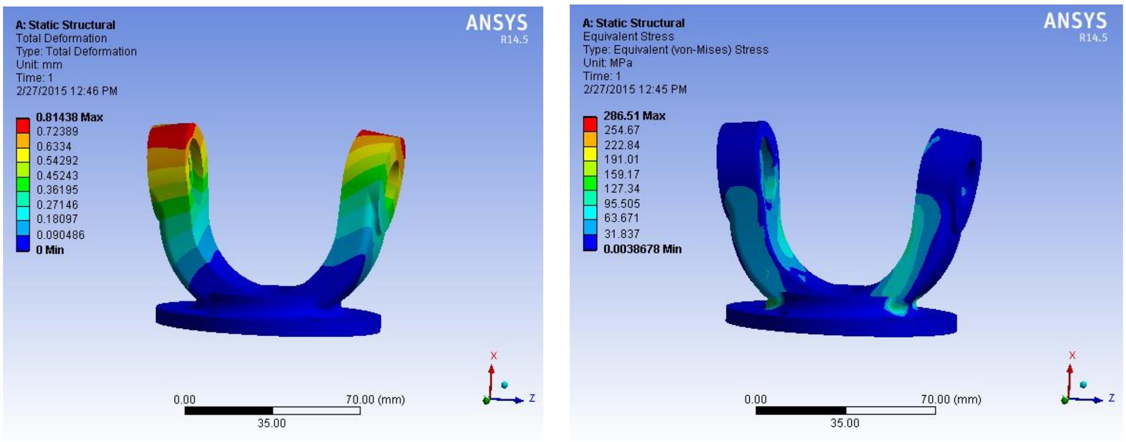
(a) **(b)**

Fig. 1. (a)Modeling of Universal Joint Yoke (b)boundary condition



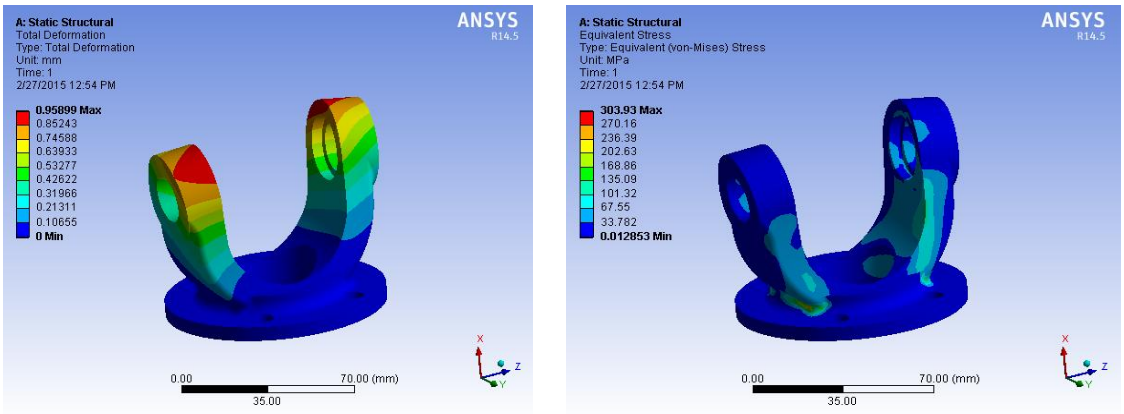
(a) **(b)**

Fig.2. (a) and (b) Total Deformation of universal Joint yoke (structural steel) for Torque 200 N.m



(a) **(b)**

Fig.3. (a) Total Deformation of Carbon Epoxy Material (b) Von-Misses Stresses in Universal joint Yoke



(a) (b)

Fig.4. (a) Total Deformation of Kevlar Epoxy Material (b) Von-Misses Stresses in Universal joint Yoke

VI. Future Scope

Till now the work has focused on study of existing model. All the measurement have been taken and detail like torsional strength, buckling strength and bending natural frequency have been improved by using this approach. Using different material we will find out the weight reduction of existing material. The main purpose of this paper is to improve the existing design and weight reduction of universal joint yoke with improving mechanical properties of the composite material.

VII. Conclusion

The use of composite material reduces the weight of joint significantly as composite having lower density. Initial torque required to give rotation to the transmission system is large as the weight reduces this surplus torque is utilizes. The reduction in weight gives further advantages in increase in fuel economy of vehicle. In this study analysis is being perform on universal joint .in this joint certain modification are made in the existing geometry and analyzes for the identical loading and boundary condition. Universal joint will be analyzing in the ANASYS and result will be compared.

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