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Review Article

A Review: Finite Element Simulation of Automotive Drive Shaft Using Composite Materials

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Abstract

Automotive Composite drive shafts offer the potential of lighter and longer life drive train with higher critical speed. This paper presents review on finite element analysis investigation of Composite drive shaft in static, modal and buckling analysis in respect to advantage of using composite materials in terms of weight and stress minimization, effects of fibers winding angle and layers stacking sequence on the critical speed, optimization into single piece drive and critical buckling torque. This review study help to students, academicians and researcher's about current status of FE simulation work and help them to look forward with better and optimized simulation conditions to improve the performance of composite drive shaft.

Keywords: *Composite materials, Drive shaft, Finite Element simulation*

1. Introduction

The term 'Drive shaft' is used to refer to a shaft, which is used for the transfer of motion from one point to another. Whereas the shafts, which propel (push the object ahead) are referred to as the propeller shafts. Propellers are usually associated with ships and planes as they are propelled in water or air using a propeller fan. However the drive shaft of the automobile is also referred to as the propeller shaft because apart from transmitting the rotary motion from the front end to the rear end of the vehicle, these shafts also propel the vehicle forward (Nimesh A. Patel, 2013). In automotive, driveshaft is the connection between the transmission and the rear axle as shown in Fig.1. 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 (M. Arun, 2013). With the replacement of two pieces into one piece composite materials drive shaft has many advantageous. For automotive application, the first composite drive shaft was developed by the spicer U-Joint division of Dana Corporation for Ford econoline van models in 1985.

Composite materials have increased its utilization in automotive applications. The main advantage is its strength to weight ratio, which is important parameter in case of drive shaft. With the replacement of composite materials has resulted in considerable amount of weight reduction. It can be achieved without increase in cost and decrease in quality and reliability. The current paper focus on one-piece composite automotive drive shaft should satisfy the vibration requirements, fuel consumption, damping capacity, torque capacity and fatigue life by finite element simulation results and improved by replacements of advanced composites materials.

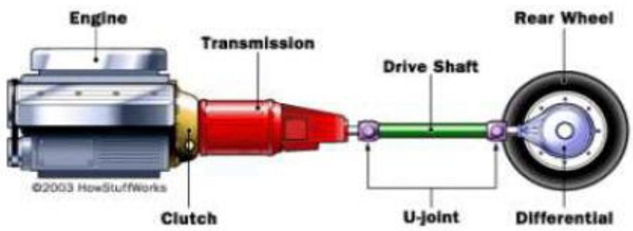

Fig .1 Schematic of Drive Shaft used in passenger car

2. Drive Shaft Design – Review

2.1 FE Simulation 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, Hook's law is applicable for composite materials; (Thimmegowda Rangaswamy, 2005)

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2.2 Selection of cross-section

The drive shaft can be solid circular or hollow circular. Reason for choosing hollow circular cross-section:

- 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. (Sagar R Dharmadhikari, 2013)

2.3 Selection of materials

The Composites materials namely can be used for drive shafts from E-glass/epoxy, S-glass/epoxy, HM Carbon Composite, Kevlar/Epoxy, Carbon / epoxy, Hybrid Aluminum E glass/epoxy composite. The main requirement is, materials should possesses high specific strength, high specific modulus, good buckling strength capability, better shear strength and bending natural frequency.

3. Finite Element Static Analysis Simulation Review

(Nimesh A. Patel, 2013) have proposed the drive shaft of TATA-407 and the modelling of the drive shaft assembly was done using Solid works and ANSYS used for predicting analysis results. The different composite material likes, E glass, Kevlar Epoxy, boron epoxy, etc. are going to analyzed and studied here for drive shaft. E glass composite material is selected for the drive shaft. In this analysis, E- glass epoxy has less stresses (37.162 MPa) generated compared to steel material (215.3MPa) and also the objective of minimization of weight of shaft is done by using Composite materials.

(T.Rangaswamy, 2002) selected the E-Glass/Epoxy and HM Carbon/Epoxy materials for composite drive shaft. Finite element analysis is performed using ANSYS 5.4 software. To model both the composite shaft, the shell 99 element is used and the shaft is subjected to torsion. The shaft is fixed at one end in axial, radial and tangential directions and is subjected to torsion at the other end .The usage of composite materials and optimization techniques has resulted in considerable amount of weight saving in the range of 48 to 86% when compared to steel shaft.

(M. Arun, 2013) here replaced Conventional two piece steel drive shafts with a one piece Hybrid Aluminum E glass/epoxy composite drive shaft for automotive application. The software used to perform FEA analysis is ANSYS. The shaft is fixed at both ends and is subjected to torque at the end for static analysis. Here the design torque taken is 3500 Nm and critical speed of shaft is taken as 6500 rpm (108 Hz) to avoid whirling vibration. The element used for analysis is SHELL 181. Shear stress obtained for hybrid shaft is 37% higher than steel drive shaft and for the same torque applied the total deformation of the hybrid shaft is 60% less than steel drive shaft. So the newly developed Hybrid Aluminum E Glass Epoxy Drive shaft will satisfy the torsional capabilities requirements and safe as steel drive shaft.

(Madhu K.S., 2013) has performed on a finite element model of composite drive shaft made of Steel SMC45, Kevlar49/Epoxy and HM Carbon Composite is developed. Here attempt has been made to check the suitability of one piece composite drive shaft with various composite material combinations to fulfill the functional requirements. For static analysis the shaft is fixed at one end and the other end a torque of 3.5×10^6 N-mm is applied. For Kevlar49/ Epoxy and HM-Carbon/ Epoxy Composite materials has considered 16 and 17 optimum layers respectively. The element considered for FE modeling steel and composite shaft are shell 93 and shell 99 respectively. FEA solver results, shows that torque carrying capacity are more in Kevlar49/Epoxy composite shaft than conventional steel driveshaft. The steel and HM Carbon/Epoxy have lesser shear strength.

(Miss. Priya Dongare, 2013) is considered the composite shaft, which is used for power transmission application as the simply supported beam with torque applied at the centre of the shaft. 3D model of hollow composite shaft is generated using APDL language available in ANSYS Multiphysics. Hollow shaft is meshed using layered element SHELL281 and four numbers of layers are taken into account for analysis. Static analysis is carried out to estimate maximum deformation and stress occurred in shaft. It shows that the maximum stress is developed at fiber3 and deformation at third layer is low.

4. Finite Element Modal Analysis Simulation Review

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. The natural frequency depends on the diameter of the shaft, thickness of the hollow shaft, specific stiffness and the length (Sagar R Dharmadhikari, 2013). The modal analysis is required as the 1st mode frequency of vibration must be less than shaft operating feuency to avoid failure of drive shaft.

(Madhu K.S., 2013) have found the critical speed obtained from FE solvers for steel, Kevlar49/Epoxy and HM Carbon/Epoxy composite material. It is observed that Kevlar49/Epoxy shafts have minimum amount of critical speed compared to the other material shafts. The critical speed depends upon the shaft dimensions, materials and loads. The results are found here is HM Carbon/Epoxy composite have 11617 rpm critical speed value which found lower than compared to Kevlar49/ Epoxy (9245 rpm) value.

(Mohammad Reza Khoshravan, 2011) designed one-piece HM Carbon/Epoxy composite drive shaft using ANSYS software for modal analysis. The shaft rotates with maximum speed so the design should include a critical frequency. If the shaft rotates at its natural frequency, it can be severely vibrated or even collapsed. The modal analysis is performed to find the natural frequencies in lateral directions. A number of fundamental modes, which all are critical frequencies, are obtained. If the shaft's frequencies correspond to these ones, it may be collapsed. The dynamic analysis shows that the first natural frequency is 169.64 Hz, and according to it the critical speed is equal to 10178 rpm, which is much more than the critical rotational speed of 4000 rpm.

(Zorica Đorđević, 2008) presented on a real shaft of TURBO ZETA 85.14B truck made of composite obtained by the combination of aluminum and carbon fibers/epoxy resin, instead of being made of steel, is analyzed in the paper. The basic shaft measures are: length – 1.35 m, mean radius – 0.041 m, thickness of annular cross section wall -0.003 m. The shaft is subjected to the maximum torque of 5000 N-m. The shaft is modelled by the isoparametric tetragonal finite elements in the shape of multiple layer shells. The NeNastran 8.6 software is used for the analysis. The comparison between the critical speeds of steel, aluminum and hybrid aluminum/carbon fibers/epoxy composite shafts leads to the conclusion that the advantage of the composite shaft over the classical metal shaft is in biased limits for the critical value of fundamental natural frequencies and the critical speed. This means that composite shaft may operate at higher speeds and at higher frequencies compared to steel shafts. (M. A. Badie, 2006) has found that fibers orientation angle has a big effect on the natural frequency of the drive shaft. A configuration consists of four layers stacked as [+45°glass/ -45°glass /0°glass /90°glass] analyzed here and it is clear that, fibers must be oriented at zero degree to increase the natural frequency by increasing the modulus of elasticity in the longitudinal direction of the shaft. This explain why the carbon fibers, with their high modulus saved to be oriented at zero angle. The drive shaft loses 44.5% of its natural frequency when the carbon fibers oriented in the hoop direction at 90º instead of 0º. The stacking sequence has no effect on the natural frequency since there is no load applied in defining the natural frequency.

5. Finite Element Buckling Analysis Simulation Review

Since the drive shaft is long, thin and hollow, there is a possibility for it to buckle (M. A. Badie, 2006). Composite drive shaft has capability to transmit more torque, has more buckling torque transmission capability.

(Madhu K.S., 2013) concludes that buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. It is the mathematical instability leading to a failure mode. Buckling loads are critical loads where the structures becomes unstable and each load has an associated with buckled mode shapes. It is observed that the buckling strength of the composite shafts is less compared to steel shaft of the same geometry because these properties depend on the stiffness and cross section of the material. It also depends upon the length to radius ratio (L/R), radius to thickness ratio (R/t) and unsupported length. The FE analysis shows composite shaft Kevlar49/Epoxy has higher critical buckling torque 31153 (Nm) compared to HM- Carbon /Epoxy having load factor around 1 and very low critical buckling torque 4403 (Nm).

Eigen value linear buckling analysis was performed by M. A. Badie to define the critical buckling torque. Buckling analysis analyzed using LUSAS version 13.5-7 commercial software. 3D model was developed and meshing generated by using three-dimensional thick shell element (QTS8). The output from this analysis is a factor multiplied by the applied load to find the critical buckling load. The linear analysis is considered satisfactory in comparison with nonlinear analysis due to the fact that cylindrical shells under torsion load experienced less sensitivity to imperfection mentioning that, in this study, the position of buckling region in the axial length of the shaft is recognized to be shifted towards the end of the shaft when a nonlinear analysis performed. Also, the stacking sequence of the layers has an effect on the buckling strength. The drive shaft buckled when its bending stiffness along the hoop direction can't support the applied torsion load. Effect of stacking sequence on the buckling strength shows that best stacking sequence is [45º/-45º/0º/90º] with a normal bending stiffness and worst stacking is [0º/90º/-45º/45º]
(M. A. Badie, 2006).

Kishor Ghatage worked on comparison of Carbon/Epoxy and Glass-Carbon/Epoxy materials drive shaft. The results show that Carbon/Epoxy has Buckling Torque 2526.43 N-m whereas Glass-Carbon/Epoxy shows 4145.54 N-m Buckling Torque (K.V.N. Parvathi, 2012). Also orientation of fibers has great influence on the dynamic characteristics of the composite material shafts in a positive direction.

Conclusions

The review paper observed that failure of drive shaft by using conventional materials is dangerous. Now days, according to growth of automotive industries perspectives, it's necessary to move to advanced composites materials. Use of different composites materials not only improve the mechanical properties also its affect a lot on manufacturing/maintenance cost, efficiency, and durability. Reviews show FE simulation observation in static, modal and bucking analysis of composite drive shaft. Simulation results shows in brief it's advantageous i.e. ease of design modification, weight minimization and employment of composite materials.

References

Nimesh A. Patel, Pradip M. Patel, Prof. A.B.Patel (2013), FE Analysis of Hollow Propeller Shaft using Steel and Composite Material then Compares It, *IJSRD - International Journal for Scientific Research & Development,* Vol. 1, Issue 3, ISSN (online): 2321-0613, 758-760

Thimmegowda Rangaswamy, Sabapathy Vijayarangan (2005), Optimal Sizing and Stacking Sequence of Composite Drive Shafts, *ISSN 1392–1320 Materials Science (Medžiagotyra)*, Vol. 11, No. 2, 133-139

Ghatage K.D, Hargude N.V (2012), Optimum Design of Automotive Composite Drive Shaft with Genetic Algorithm as Optimization Tool, *International Journal of Mechanical*

Engineering and Technology (IJMET), Volume 3, Issue 3, 438-449

T.Rangaswamy, S. Vijayarangan, R.A. Chandrashekar, T.K. Venkatesh and K.Anantharaman (2002), Optimal Design and Analysis of Automotive Composite Drive Shaft, *International Symposium of Research Students on Materials Science and Engineering*, Chennai, India

M.Arun, K.Somasundara Vinoth, (2013), Design and Development of Laminated Aluminum Glass Fiber Drive Shaft for Light Duty Vehicles, *International Journal of Innovative Technology and Exploring Engineering (IJITEE)* ISSN: 2278-3075, Volume-2, Issue-6, 157-165

Madhu K.S., Darshan B.H., Manjunath K (2013) Buckling Analysis of Composite Drive Shaft for Automotive Applications, *Journal of Innovative Research and Solutions (JIRAS)*, ISSN: 2320 1932 Volume No.1A, Issue No.2, 63 -70

Priya Dongare & Suhas Deshmukh (2013), Effect of Fiber Angle Orientation on Stress, Deformation and Buckling Torque of the Composite Drive Shaft, *Global Journal of Researches in Engineering Mechanical and Mechanics Engineering*, Volume 13, Issue 6, Version 1.0

Sagar R Dharmadhikari, Sachin G Mahakalkar, Jayant P Giri (2013) Design and Analysis of Composite Drive Shaft using ANSYS and Genetic Algorithm A Critical Review, *International Journal of Modern Engineering Research (IJMER)*, Vol.3, Issue.1, 490-496

Mohammad Reza Khoshravan, Amin Paykani, Aidin Akbarzadeh (2011), Design and Modal Analysis of Composite Drive Shaft For Automotive Application, *International Journal of Engineering Science and Technology*, Vol. 3 No. 4, 2543-2549

Zorica Đorđević, Stevan Maksimović, Ivana Ilić (2008), Dynamic Analysis of Hybrid Aluminum/Composite Shafts, *Scientific Technical Review*,Vol.LVIII, No.2

M. A. Badie, A. Mahdi, A. R. Abutalib, E. J. Abdullah and R. Yonus (2006) Automotive Composite Driveshafts: Investigation of the Design Variables Effects, *International Journal of Engineering and Technology*, Vol. 3, No.2, 227-237

K.V.N. Parvathi , CH. Prabhakara Rao (2012) , Structural Design Of Composite Drive Shaft for Rear-Wheel Drive Engine, *International Journal of Advanced Engineering Research and Studies*, Vol. II, Issue,85-89