Indian J.Sci.Res. 17(2): 77-81, 2017

ISSN: 0976-2876 (Print)
ISSN: 2250-0138(Online)

FREE VIBRATION ANALYSIS AND WEIGHT OPTIMIZATION OF COMPOSITE DRIVE SHAFT

[1]Anamika, [2]Anindya Bhar
[1,2]Department of Applied Mechanics MNNIT, Allahabad, U.P.

Abstract- In the present study, the finite element analysis of design variables of composite materials orientation and stacking sequence provided an insight into their effects on drive shaft's, formulation results in natural frequencies that are reasonably close to test results when compared with previous studies. The formulation can be expanded to transversely isotropic and generally orthotropic materials. The study also done weight optimization of drive shaft. FEA results showed that the natural frequency increases with decreasing fiber orientation angles.

Keywords: Composite materials, ply orientation, drive shaft, optimization.

I. Introduction

Laminated composite materials are extensively used in aerospace, defence, marine, automobile, and many other industries. They are generally lighter and stiffer than other structural materials. A laminated composite material consists of several layers of a composite mixture consisting of matrix and fibers. Each layer may have similar or dissimilar material properties with different fiber orientations under varying stacking sequence. Because, composite materials are produced in many combinations and forms, the design engineer must consider many design alternatives. It is essential to know the dynamic and buckling characteristics of such structures subjected to dyanamic loads in complex environmental conditions. For example, when the frequency of loads matches with one of the resonance frequencies of the structure, large torsion deflections and internal stresses occur, which may lead to failure of structure components. Static and dynamic analysis of laminated composite shaft are investigated by many of the researchers. Wen-Kung et al. [1] presented using finite element model based upon Timoshenko beam theory, laminated composite shaft has been modelled as a Timoshenko shaft by employing the equivalent modulus beam method. Bert et al. [2] presented theoretical analysis for determining the buckling torque of a circular cylindrical hollow shaft with layers of arbitrarily laminated composite materials. Gurban et al. [3] presented analysis the natural frequencies of composite tubular shafts using equivalent modulus beam theory with shear deformation. Sino et al. [4] presented dynamic in stability of an internally damped rotating composite shaft by using equivalent modulus beam theory. Lee et al. [5] provides a one- piece hybrid/composite drive shaft for a rear wheel drive automobile was developed with a new manufacturing method.. Sevkat et al. [6] presented the torsional behavior of hybrid composite shafts was examined by a combined experimental and numerical approach.

In the present work, the finite analysis of design of composite drive shaft and weight optimization by using optistruct software.The effect of different parameters like composite material properties, span to thickness ratio, diameter of shaft and natural frequency is presented.

.II. Mathematical Formulation

Methodology

The following methodology is being adopted to carry out the above mentioned objectives:

1. An interactive interface is created using for analysis and optimization in Optistruct (HYPERWORKS) to compute the overall laminate properties of the composite.
2. Using OPTISTRUCT the overall material properties are computed and tried to validate with Finite element analysis using Abaqus and Euler – Bernoulli beam theory.
3. Using these equivalent properties of the composite the natural frequency computations are done.

Optimization Tool

a. **HyperMesh (Pre-processing)**
- Typically CAD data are imported
- Geometry cleanup and simplification
- Meshing (1D, 2D, 3D)
- Set-up of base design analysis and optimization

b. **Optistruct** all optimization disciplines are available including topology, topography, size, shape, free size, free shape, composite optimization.

c. **Hyperview** (Post-processing) access to contour plots, iso-contour plots, animations etc.

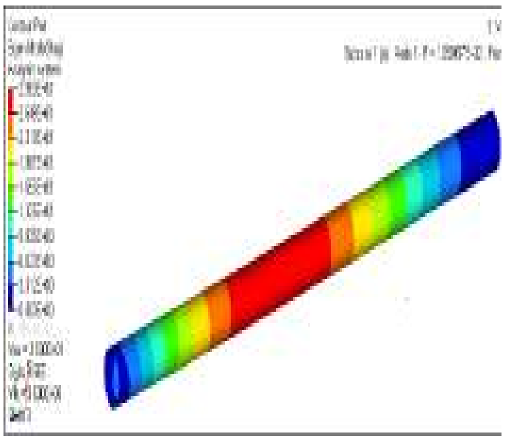
[1]**Corresponding Author**

Composite Optimization

OptiStruct offers a comprehensive optimization solution aimed at guiding and simplifying the design of laminate composite structures. The solution includes the following optimization phases and associated techniques:

Phase I – Free Size

Free-sizing optimization is used to generate design concepts, while considering global responses and optional manufacturing constraints.



Phase II – Size Sizing optimization – with ply-based modeling – is performed to control the thickness of each ply bundle, while considering all design responses and optional manufacturing constraints.

Phase III – Stacking Sequence (Shuffling) Ply-stacking optimization is applied to determine the detailed stacking sequence, again while considering all behavioural responses, manufacturing constraints and various ply book rules. While these techniques can be applied independently, it is recommended to use them together as a three-phase integrated process guiding the design from concept to completion. This is particularly important when manufacturing constraints are involved. In order to satisfy such constraints at the finishing stage, they should be incorporated at the beginning so that the design concept can be carried forward. Automated tools are provided to facilitate the transition between the design optimization phases.

III. Comparison Of Results With Previous Studies

The material properties of boron epoxy layers are E1 = 211,000 MPa, E2 = 24,100 MPa, ν_{12} = 0.36, G_{12} = 6900 MPa, Density = 1.97 E^{-09} mg/mm^3. The properties of the shaft are length = 2470 mm, mean diameter = 126.9 mm, thickness = 1.321 mm, outer diameter 128.221 mm and thickness of each ply 0.1321 mm with lamination sequence (90, 45, -45, 0, 0, 0, 0, 0, 0, 90) laminate from innermost layer to outermost layer.

Table 3.1 : Natural frequency of drive shaft at pinned joint both end

Author	Method Used	Frequency in Hz	Percentage Error
Zinberg and Symonds	Measured experimentally	100	6.2573
Dos Reis et al.	Bernoulli-Euler beam theory. Stiffness determined by shell finite elements	82.37	22.7841
Kim and Bert	Sanders shell theory	97.87	8.25404
Kim and Bert	Donnell shallow shell theory	106.65	0.000
Singh and Gupta	Effective Modulus Beam Theory	95.78	10.2133
Bert	Bernoulli-Euler beam theory	98.65	7.5228
Bert and Kim	Bresse-Timeshenko beam theory	96.47	9.5664
Kim et al.	Timeshenko beam model	91.43	14.291
Change et al.	Continuum based Timeshenko Beam	96.03	9.9789
Qatu and Iqbal	Finite element analysis using Abaqus	95.4	10.569
Qatu and Iqbal	Euler-Bernoulli beam theory	102.47	4.007
Present study	Finite element analysis Optistruct	105.9457	

clearly observed from the above table that the value of frequency calculated very closer to the respective value of frequency taken from the reference paper.

Case 2: Validation of composite hollow drive shaft with single layer

Properties of the shaft similar to those case 1 (Table 3.1) and the materials are graphite/epoxy used are listed below:

E1 = 139,000 MPa

E2 = 11,000 MPa

$\nu_{12} = 0.313$

Theory	Fiber angle (degree)		% Error (0 degree)	% Error (90 degree)
	0	**90**		
Sanders Shell (1995)	92.12	32.28	11.3290	6.7840
Bernoulli-Euler (1995)	107.08	30.22	2.9793	0.4298
Bresse-Timeshenko (1995)	101.20	30.05	2.5889	0.1332
Qatu and Iqbal (2009)	108.68	30.55	4.4077	1.5054
Present Study	103.8897	30.0901	-	-

IV. Result and discussion

Specification of Problem 1: Free vibration analysis of composite shaft

Design specification of the drive shaft

1. Ultimate Torque : 3500 Nm

2. Maximum speed of the shaft: 6500 RPM

3. Length of the Shaft:1250 mm

Table 4.1 **:** Properties of E-Glass/Epoxy, Carbon/Epoxy and Boron Epoxy

SI.No	Property	Unit's	E-glass/ epoxy	Carbon/epoxy	Boron/ epoxy
1	E_{11}	GPa	50	126.9	204
2	E_{22}	GPa	12	11	18.5
3	G_{12}	GPa	5.6	6.6	5.59
4	ν_{12}	…….	0.3	0.3	0.23
5	$\sigma t1 = \sigma c1$	MPa	800	870	1260
6	$\sigma t2 = \sigma c2$	MPa	40	54	61
7	τ_{12}	MPa	72	30	67
8	ρ	Kg/m^3	2000	1600	2000
9	V_f	…….	0.6	0.6	0.6

Find the first mode bending frequency below given cases and optimize the shaft weight

Case 1: $[0^0]$ Single layer of glass epoxy, carbon epoxy, boron epoxy.

Case 2: $[45^0]_4$ All layers of glass epoxy

Case 3: $[45^0]_4$ All layers of carbon epoxy

Case 4: $[45^0]_4$ All layers of carbon epoxy

Case 5: $[90^0]_4$ All layers of glass epoxy

Case 6: $[90^0]_4$ All layers of carbon epoxy

Case 7: $[90^0]_4$ All layers of boron epoxy

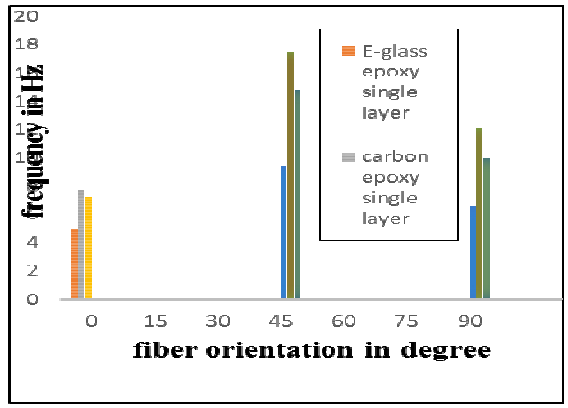


Fig.4.1 First mode of natural frequency for different material with different orientation

Natural frequencies are calculated on different orientation angles:

- It is seen that with natural frequencies decreases the fiber orientation angle for all kind of materials. This is because when orientation angle is increasing the component of longitudinal modulus decrease and this effect in reduction of natural frequency.
- Natural frequency of carbon/epoxy shaft is higher than E-glass/epoxy and boron epoxy shaft at different orientation angle. This is because of weight reduction in composite shaft due to difference in density.
- The layers stacking sequence has no effect on the natural frequency since there is no load applied.

Case 8: Hybrid shaft with stacking sequence $[45^0$glass, -45^0glass, 0^0carbon, 90^0glass$]$

The properties of selected carbon and glass fibers-composite were shown in Table 4.6. The selected thickness for different layers are as follows:

$+45^0$, -45^0 glass/epoxy layers thickness for each = 0.1905mm; 0^0 carbon/epoxy layer thickness = 0.635mm; 90^0 glass/epoxy layer thickness = 1.016mm.

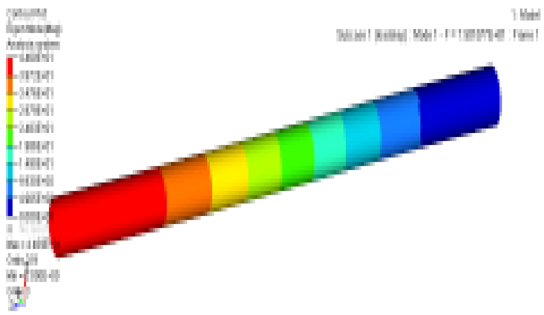


Fig.4.2 First mode natural frequency for hybrid shaft

The fundamental natural frequency of the shaft is found to be 75.015 Hz. This is equivalent to the natural frequency of carbon epoxy single layer shaft.

Specification of Problem 2: Free vibration analysis with respect to shaft thickness

The properties of the shaft taken from problem 1 and stacking sequence is (90, 45, -45, 0) in degree with different shaft thickness t = 2, 2.5, 3, 3.5, 4 in mm. Free vibration analysis for different composite materials are E-glass epoxy, carbon epoxy, boron epoxy.

Table 4.2**:** Natural frequency of shaft for different shaft thickness

Shaft thickness in mm	**E-glass/epoxy**	**Carbon/epoxy**	**Boron/epoxy**
2	58.83658	92.4623	102.077
2.5	58.42387	91.6350	101.109
3	58.05825	90.900	100.2405
3.5	57.7202	90.2217	99.4315
4	57.40368	89.5878	98.67077

Form the table 4.2 we observe that the natural frequency is decrease when shaft thickness is increase. And E-glass/epoxy compared to other composite materials found better results also E-glass/epoxy has lowest cost of all commercially use in FRP industry; therefore four layers are constructed from composite materials.

Specification of Problem 3: Weight optimization of drive shaft

The properties of the drive shaft and the properties of composite materials are taken by problem 1 and the laminated stacking sequence [0^0, 45^0, -45^0 90^0].

Objective Function: Minimization of shaft weight

Design constraints: Shaft bending natural frequency

Design variables: ply thickness

The objective was to minimize the shaft weight under the constraint shaft bending natural frequency. The ply thickness is taken as design variable. A free size optimization is performed on carbon/epoxy composite drive shaft laminated with [0^0, 45^0, -45^0 90^0] . The optimized ply thickness are note down with the variation of shaft length. From that inner diameter of the shaft and optimized mass is calculated, there by percentage saving in mass is also found.

Table 4.3 Optimization result

Composite materials	**Mass in Kg**	**Optimized Mass in Kg**	**% Saving**
Boron epoxy	1.404	0.3571	74.565
Carbon epoxy	1.130	0.2874	74.566
E- glass epoxy	1.341	0.3409	74.572

These results show the mass optimized for different composite materials. And optimized parameter are each ply thickness 0.1270 mm, maximum laminated is 0.508 and inner diameter is 88.984mm. The weight saving 74.565%, 74.566% and 74.572% is obtained by optimizing the design of boron epoxy, carbon epoxy and glass epoxy. Making ply thickness and shaft outer diameter as design variables gives more improved results.

V.Conclusion

In the present work, free vibration analysis and optimization of composite drive shaft have been performed using finite element method. For this purpose, relevant modelling into a FEM software. The drive shaft is simply supported one sided pined and other side roller support. Drive shaft made of Carbon/epoxy, Boron/epoxy, E-glass/epoxy are designed and optimized using OPTISTRUCT software. Optimized results obtained for carbon epoxy and glass epoxy.

From the results, the following main conclusions are made:

- Natural frequencies decreases the fiber orientation angle for all kind of materials. This is because when orientation angle is increasing the component of longitudinal modulus decrease and this effect in reduction of natural frequency.
- The layers stacking sequence has no effect on the natural frequency since there is no load applied.
- The weight saving 74.565%, 74.566% and 74.572% is obtained by optimizing the design of boron epoxy, carbon epoxy and glass epoxy.
- Making ply thickness and shaft outer diameter as design variables gives more improved results.

References

[1]. Charles W. Bert & Chun-Do Kim (1995) ,“ Analysis of buckling of hollow laminated composite drives shafts”, Composites Science and Technology.

[2]. Lien-Wen Chen ,Wen-Kung Peng (1998),“The stability behaviour of rotating composite shafts under axial compressive loads” , Composite Structures.

[3]. R. A. Scott and W. Kim (2001) , “Harmonic wave propagation in an infinite rotating composite Timoshenko shaft”, Journal of Sound and Vibration.

[4]. W. Kim , A. Argento , R. A. Scott (2001) , “Forced vibration and dynamic stability of a rotating tapered composite Timoshenko shaft: bending motions in end-milling operations”, Journal of Sound and Vibration.

[5]. Larry B. Lessard et al. (2004) “Shear buckling of a composite drive shaft under torsion”, Composite Structures.

[6]. Dai Gil Lee et al. (2004) “Design and manufacture of an automotive hybrid aluminium/composite drive shaft”.

[7]. H. B. H. Gubran and K.Gupta, “The effect of stacking sequence and coupling mechanisms on the natural frequencies of composite shafts”, J.Sound and Vibration, vol.282, pp.231-248, 2005.

[8]. R.Sino a, T.N. Baranger, “Dynamic analysis of a rotating composite shaft”, Composites Science and Technology, Vol. 68 337–345, 2008.

[9]. L. Jun, H.Hongxing and S.Rongying, “Dynamic finite element method for generally laminated composite beams”, Int. J. Mechanical Sciences, vol.50, pp.466-480, 2008.

[10]. Mohamad S. Qatu , Javed Iqbal (2010) “Transverse vibration of a two-segment cross-ply composite shafts with a lumped mass”, Composite Structures.

[11]. A.R. Abu Talib et al. (2010) “Developing a hybrid, carbon/glass fiber-reinforced, epoxy composite automotive drive shaft”, Materials and Design.

[12]. M.A. Badie, E. Mahdi , A.M.S. Hamouda (2011) , “ An investigation into hybrid carbon/glass fiber reinforced epoxy composite automotive drive shaft” , Materials and Design.

[13]. Ercan Sevkat , Hikmet Tumer (2013) , “Residual torsional properties of composite shafts subjected to impact loadings” , Materials and Design.

[14]. Ch. Hochard (2013), “Optimization of hybrid high-modulus / high strength carbon fiber reinforced plastic composite drive shafts”.

[15]. Hason Gubran (2014), “Design Optimization of Automotive Propeller Shafts”.

[16]. O. Montagnier , C. Hochard (2014) , “Dynamics of a supercritical composite shaft mounted on viscoelastic supports” , Journal of Sound and Vibration .

[17]. M. H.Rarani, “Effect of ply stacking sequence on buckling behavior of E-glass/epoxy laminated composites”, Computational Material Science, vol.89, pp.89-96, 2014.

[18]. S.S. Rao “Theory of Optimization”, fourth edition.

[19]. A study guide of Altair book Practical Aspects of structural optimization.