Optimization and Experimental determination of natural frequency of Hybrid Composite Automobile Drive Shaft”

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ABSTRACT:  
In this paper, a study is focused on optimal design of hybrid composite Automobile over drive shaft for various objectives such as fundamental Natural Frequency and torsional Strength. The Work aims to maximize Maximum Torsional Strength, increases Natural Frequency with minimizing weight. Hence, taugechi optimization method is used to generate a single response for these two performance characteristics. Also, parametric study will be carried to understand the effect of each variable on various design objectives the design variable come from geometrical properties like no. of ply, orientation angle, stacking sequences and materials. The constraint will come from state variables and manufacturing constraint. The optimization will also carry for torsional strength. With minimum weight it is shown that the introduction of new ply orientations compared to the classical 0°, ±45° and 90° plies can lead to significantly improved optimal designs. Furthermore, Taugechi optimization of Automobile over drive shaft is carried out for fundamental natural frequency

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I. INTRODUCTION

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 one in which it is embedded is called the matrix. The reinforcing phase material may be in the form of fibres, particles, or flakes. The Examples of composite systems include concrete reinforced with steel and epoxy reinforced with carbon fibres, etc.

The two piece steel drive shaft consists of three universal joints, a center supporting bearing and a bracket, which increase the total weight of a vehicle. Power transmission can be improved through the reduction of inertial mass and lightweight. Substituting composite structures for conventional metallic structures has many advantages because of higher specific stiffness and higher specific strength of composite materials. Composite materials can be efficiently meet the design requirements of strength, stiffness and composite drive shafts weightless than steel or aluminum of similar strength.

It is possible to manufacture one piece of composite. The Drive shaft to eliminate all of the assembly connecting two piece steel drive shaft. Also composite materials typically have a lower modulus of elasticity. As a result, when torque peaks occur in the driving, the drive shaft act as a shock absorber and decrease stress on part of the drivetrain extending life. Fiber reinforced polymer (FRP) composites can be simply described as multi-constituent materials that consist of reinforcing fibres embedded in a rigid polymer matrix. Many FRPs offer a combination of both strength and modulus that are either comparable to or better than many traditional metallic materials. A diverse range of polymers can be used as the matrix to FRP composites, and these are generally classified as thermoplastic (e.g. polyether-ether-ketone, polyamide) resins or thermoset (e.g. epoxy, polyester).

On the other hand, thermoset resins the most widely used matrices for advanced composites usually consist of a resin and a comparable curing agent. When they two are initially mixed they form a low viscosity liquid that cures as a result of either internally generated or externally applied heat. The curing reaction forms a series of cross links between molecular chains so that one large molecular network is formed, resulting in an intractable solid that cannot be reprocessed on reheating.

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II. OPTIMIZATION OF HYBRID COMPOSITE MATERIAL

In present era of products development composite are being used because of easy in manufacturing and low weight to volume ratio. Moreover apart from this increasing the awareness towards environmental conditioning and required more versatile materials based higher leads to filler composite materials. Taguchi’s parameter design is an important tool for robust design. It offers a simple and systematic approach to optimize the design parameters because this systematic approach can significantly minimize the overall testing time and the experimental costs.

Two major tools used in robust design are signal to noise ratio (S/N), which measures quality with emphasis on variation, and orthogonal array, which accommodates many design factors simultaneously. In design of experiment, the most important stage lies in the selection of the control factors. The cost is most important than quality but quality is the best way to reduced cost.

Through exhaustive literature review on erosion behavior of polymer composites, it has been observed that factors viz., orientation angle, stacking sequences, filler materials, volume fraction and different material etc. mostly influence on the performances of polymer composites. For elaboration of experiments plan the method of Taguchi for five factors at four levels is used, being understood by levels taken by the factors. The selected parameters viz., orientation angle, stacking sequences, filler materials, volume fraction and different material are considered in this study. The control factors and the parameter settings for composite are given in Table 1

<table>
<thead>
<tr>
<th>Control Factors</th>
<th>Symbols</th>
<th>Fixed parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation angle</td>
<td>FACTOR –A</td>
<td>Volume fraction</td>
</tr>
<tr>
<td>Stacking sequences (layer)</td>
<td>FACTOR –B</td>
<td>50:50</td>
</tr>
<tr>
<td>Filler materials</td>
<td>FACTOR –C</td>
<td></td>
</tr>
</tbody>
</table>

The experimental observations are transformed into signal-to-noise (S/N) ratios. There are several S/N ratios available depending on the type of characteristics such as: ‘Smaller-the-better’ characteristic: Nominal-the-better’ characteristics ‘Larger-the-better’ characteristics where n the number of observations, y the observed data, Y the mean and S the variance. The S/N ratio for minimum weight comes under ‘smaller is better’ characteristic,

As you move forward in your design, you can assess the impact that changing certain parameters can have in design. The parameter can include dimensional parameters, The parametric optimization study allows us to, define the parameter range, specific design constraints and analyze the results.

<table>
<thead>
<tr>
<th>Control factor</th>
<th>Levels</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation angle</td>
<td>I II III</td>
<td>Degree</td>
</tr>
<tr>
<td>Stacking sequences (no of layer)</td>
<td>1 2 3</td>
<td>mm</td>
</tr>
<tr>
<td>Filler materials</td>
<td>Carbon Kevlar Metal</td>
<td>Unit less</td>
</tr>
</tbody>
</table>

Table .3 Orthogonal array for L09 Taguchi Design

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Orientation angle</th>
<th>Stacking sequences (no of layer)</th>
<th>Filler materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

III. MANUFACTURING AND TESTING OF FLAMINATES

The design of a laminated composite structure, such as a flat floor panel or a pressure vessel, starts with the building block of laminate, in which fibre and matrix are combined in manufacturing process such as hand lay up or filament winding. The material of the fibre and matrix, processing factors such as packing arrangements and fibre volume fraction determine the stiffness, strength of a single lamina. These properties can be found by using the properties of the individual constituents of the lamina or by experiments.

1. Selection of Matrix Material

Epoxide resin 520, Epoxy hardener-PAM. The epoxy resin and epoxy hardener were mixed in the ratio of 10:1 by the weight as suggested. The epoxy resin has the density of 1.22 g/cc. The Epoxy Resin-520and Epoxy
hardener-PAM were mixed in the ratio of 10:1 by weight as suggested. Epoxy resin and hardener mixture was stirred thoroughly before fiber mats were introduced in the matrix material. Each laminate was cured under constant pressure near about 24 hours in them old and further cured at room temperature at least 12 hours.

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Properties</th>
<th>Epoxy</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific density</td>
<td>1.22</td>
<td>g/cc</td>
</tr>
<tr>
<td>2</td>
<td>Young's Modulus</td>
<td>3.792</td>
<td>Gpa</td>
</tr>
<tr>
<td>3</td>
<td>Ultimate Tensile Strength</td>
<td>82.74</td>
<td>Mpa</td>
</tr>
</tbody>
</table>

2. Material Composition in laminates

The material composition of hybrid composite material with angle orientation with sequence of layer according to manipulation by taguchi method in Mini-Tab software.

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Composition</th>
<th>Size(LxBxH)mm</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hybrid(fiber) % Epoxy%</td>
<td>140x20x3</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Composition</th>
<th>Size(LxBxH)mm</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hybrid(fiber) % Epoxy%</td>
<td>75x20x3</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Composition</th>
<th>Size(LxBxH)mm</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hybrid(fiber) % Epoxy%</td>
<td>100x13x3</td>
<td>6</td>
</tr>
</tbody>
</table>

3. Calculation of Material properties from Stress-Strain Diagram

With the help of stress-strain diagram the material properties such as young's modulus and shear modulus in longitudinal and transverse direction are calculated. Which are tabulated below:

<table>
<thead>
<tr>
<th>Material Property</th>
<th>LaminateNo01</th>
<th>LaminateNo01</th>
<th>LaminateNo01</th>
<th>LaminateNo01</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trail 1</td>
<td>Trail 2</td>
<td>Trail 3</td>
<td>Avg.</td>
</tr>
<tr>
<td>Young's Modulus in Longitudinal Direction(E1)GPa</td>
<td>2.502</td>
<td>3.337</td>
<td>2.201</td>
<td>2.680</td>
</tr>
<tr>
<td>Young's Modulus in Transverse Direction(E2)GPa</td>
<td>2.889</td>
<td>2.998</td>
<td>2.969</td>
<td>2.952</td>
</tr>
<tr>
<td>Shear Modulus in Longitudinal Direction(G12)GPa</td>
<td>0.765</td>
<td>0.979</td>
<td>1.321</td>
<td>1.021</td>
</tr>
<tr>
<td>Shear Modulus in Transverse Direction(G23)GPa</td>
<td>1.351</td>
<td>1.201</td>
<td>1.001</td>
<td>1.184</td>
</tr>
</tbody>
</table>

IV. EXPERIMENTAL ANALYSIS

The block diagram and topology of an FFT analyzer are different to that of the more usual super heterodyne or sweep spectrum analyzer. In particular circuitry is required to enable the digital to analogue conversion to be made, and then for processing the signal as a Fast Fourier Transform. The FFT spectrum analyzer can be considered to comprise of a number of different blocks.

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Optimization and Experimental determination of natural frequency of Hybrid Composite...  

Diagram: 1 Experiental set up  

Diagram - 2 output of FFT Analyzer  

Table 7. Results carried out in FFT Analyzer

<table>
<thead>
<tr>
<th>Natural Frequency</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Natural</td>
<td>1298.9 Hz</td>
</tr>
<tr>
<td>2nd Natural</td>
<td>1493.5 Hz</td>
</tr>
<tr>
<td>3rd Natural</td>
<td>2059.4 Hz</td>
</tr>
</tbody>
</table>

V. RESULTS AND DISCUSSION

The discussion on results obtained by theoretical, experimental analysis is carried out to reach the conclusion. The difference in results is compared for mass and the fundamental natural frequency, also the difference has been found in natural frequency by software analysis (ANSYS15) and experimental analysis is addressed here.

1) Comparison between Analytical Calculations of Steel and Hybrid Composite Propeller Shaft

Table 8 Comparison between steel and Hybrid Composite shaft

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Steel shaft</th>
<th>Hybrid Composite shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Diameter</td>
<td>65 mm</td>
<td>65 mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>3 mm</td>
<td>12 mm</td>
</tr>
<tr>
<td>Applied Torque(T)</td>
<td>914.3N-mm</td>
<td>914.3N-mm</td>
</tr>
<tr>
<td>Natural Frequency((f_n))</td>
<td>513.82 Hz</td>
<td>1252 Hz</td>
</tr>
<tr>
<td>Mass(m)</td>
<td>2.68 kg</td>
<td>1.118 kg</td>
</tr>
<tr>
<td>% Saving In mass</td>
<td>-</td>
<td>58.28 %</td>
</tr>
</tbody>
</table>

Above table it shows that the comparison between steel and composite drive shaft in which applied torque is same for steel and composite drive shaft. The Minimum requirement of natural frequency is 80 Hz which can be achieved by both steel and Composite drive shaft. Composite shafts having very low weight of 1.2 kg whereas steel shaft of weight is 2.68 kg.

Diagram 3: Comparison between mass of Steel and hybrid composite Propeller Shaft

2) Comparison of FEA results and Experimental results for Natural frequency

Here, comparison is made between natural frequencies obtained from FEA and Experimental method for Hybrid composite material drive shaft. It is seen that Hybrid composite material drive shaft is having higher frequency.
VI. CONCLUSION

In this thesis optimization of Hybrid composite material is carried out. The work in this thesis is carried out in four parts. First part is focused on validation of composite overdrive shaft modeling by FEM. Whereas in second part, a parametric study carried out to understand the effect of each design variable on various design objectives. Optimization of composite over drive is carried out by Taguchi Technique with ANSYS. The optimization process reduced the weight, increases the natural frequency and increases torsional strength of composite material.

Finally finite element modal analysis is carried out with help of FEA. After the manufacturing, its experimental modal analysis and torsion testing was performed for finding out the angle of twist. The following conclusions are drawn from the present work.

1) The Single objective optimization for weight is carried using Taguchi Technique.
2) The stacking sequences of 45, 0, and 90 degree are the best results on performances of Automobile over drive shaft like low weight, high natural frequency and torsional strength.
3) The weight of the carbon-Kevlar propeller shaft is reduced by 58.28% as compared to steel propeller shaft.
4) It is found that the fiber orientation and stacking sequence of layer [(0°)c, (+45°k, 0°s, 0°c)] is the optimum angle to have maximum torsion stiffness and natural frequency.
5) The natural frequencies of hybrid composite propeller shaft are increased by 55.58%, 69.70% and 77.66% by FEA as compared to steel shaft.

REFERENCES


*Corresponding Author: AbdAlfith Elbori

Table 9 Comparison of FEA results and experimental results for Natural frequency

<table>
<thead>
<tr>
<th>Frequency</th>
<th>By Experimental</th>
<th>By FEA</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Frequency</td>
<td>1298.9Hz</td>
<td>1259Hz</td>
<td>3.004</td>
</tr>
<tr>
<td>2nd Frequency</td>
<td>1493.5Hz</td>
<td>1512Hz</td>
<td>1.256</td>
</tr>
<tr>
<td>3rd Frequency</td>
<td>2059.4Hz</td>
<td>2152Hz</td>
<td>4.32</td>
</tr>
</tbody>
</table>

48 | Page