Optimization of Material and Fiber Orientation of Laminated Composites

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Abstract – The orientations of fibre directions in layers and number of piles and the thickness of the layers as well as material and fibre orientation are studied using the drive shaft. Drive shaft of a vehicle is made in two segments associated by a help structure, orientation and U-joints and subsequently over all weight of gathering just as vibration issues will be more. Likewise, they have less explicit modulus, explicit quality and low damping limit. On this context, the alternative of steel by using composite material together with most appropriate layout may be an amazing contribution within the weight reduction procedure of force shafts. A formulating and solution technique are implemented through Genetic Algorithm (GA) to optimize composite drive shaft model. The objective function is to reduce the weight of the shaft which is constraint to different constraints like natural frequency, torque and torsional buckling capacity. The optimum thickness of each ply, number of piles needed and stacking sequence were obtained when applying the Genetic Algorithm, which contributes to achieving the minimal weight with suitable Characteristics of the shaft.. The composite shafts weight saving has been achieved by 48.36 % for E-glass and 86% for high strength carbon when compared with steel shaft.

Keywords:Composite material, MATLAB, Genetic Algorithm, Optimization.

1.INTRODUCTION

Composite materials are created by the blend of two constituents vary in their structure into another material which expands its physical and mechanical properties than the first material. Constituent materials are insoluble, and their thickness is perceptible. Most composite consists of two different materials. The one part is known as matrix or binder. Another part is known as reinforcement on which the matrix material is surrounded around it. The reinforcement may take place in the shape of fillers, whiskers, fibers, particles and flakes. Composite materials are commonly used in manufacturing, space vehicles, aircraft, warships, sports equipment, bridges and buildings having large specific rigidity, strength, specific modules, resistance to corrosion, wear resistance and long life of the material.

For the ideal structure thought distinguishing proof of ideal fiber directions and cover thickness in greatest firmness and least weight plan of overlaid composite bars [1].

The model used as cantilever beam for different cross section such as box, rectangle and ellipse. Another way of finding the optimal orientation with objective function as maximizing the stiffness, the algorithm used is a gradient based algorithm [2].Bhajantri et al [3] accomplished modal analysis of shaft having high-strength carbon fibers and epoxy resin. It is found that there is significant less in weight while applying large strength carbon epoxy, as compared to the conventional steel shaft. Total shear stress and total deflections were determined by varying fiber angle orientation. Harshal et al [4] performed analysis for various materials and determined the effect of ply orientations on the weight reduction of the model. Belawagi et al [5] conducted analysis of drive shaft and also determined the effect of ply orientation on the weight, deformation and stress induced in the model. Khoshravan et al [6] have done vibrational analysis composite drive shaft and determined natural frequency of the system. Asmamaw et al. [7] worked on the analysis of composite shaft drive and determined the relationship between various parameters such as deflection, torque, stress and strain. Sagar et al [8] developed model for hollow composite drive shaft and determined the effect of fibre angle orientation and stacking sequence. Panduranga et al [9] have done vibrational analysis on the various composite drive shaft and determined various parameters such as stress, deflection and natural frequency of the system. It is inferred that buckling torque is higher in composite drive shaft than other conventional shafts. Srinivasa Moorthy et al. [10] investigated in the composite drive shaft and determined the influence of ply orientation. Also,they analyzed various materials such as carbon/epoxy, Kevlar/epoxy composite shafts. They found that carbon/epoxy shaft weight reduced by 89.756%. Parshuram et al [11] explored various composite materials such as Carbon, Boron, Kevlar, Carbon-Kevlar, Aluminum-Boron binds with epoxy and compared with Steel for shaft system. They concluded that 72 % - 81 % weight reduction is achieved than other conventional steel shaft. Ghatage et al [12] optimized various process parameters in the drive shaft system using composite material using genetic algorithm through C program.

In the current work, an effort is made toassess the adaptivity of composite materials such as E-Glass / Epoxy and High Strength Carbon for automotive transmission applications. The composite drive shaft for the back-end wheel drive car was optimally designed using GA for E-Glass / Epoxy and High Strength Carbon composites with the aim of limiting the weight of the shaft that is subject to constraints like torque limitation, torsional buckling capacity and natural frequency.

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2. METHODOLOGY

The problem associated with the optimization technique for composite laminates was studied through literature survey. In this work Optimization of material and fiber orientation are obtained and compared to conventional material were done. From the literature survey it indicates that majority of authors selected steel as the Conventional material because it is cheap and readily available and compared with the Composite material drive shaft. In this work two composite material is taken and compared with the steel drive shaft and an equation in terms of thickness, fiber orientation and natural frequency was formulated and that equation is optimized using the MATLAB through Genetic algorithm. Then, the results of the composite shafts and Steel Shafts were compared and validated.

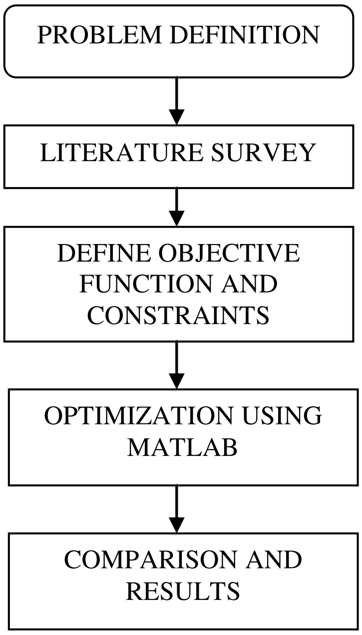

Fig 1: Methodology

3.PROBLEM DEFINITION

The basic natural bending frequency of the shaft for small load vehicles should have minimum6500 rpm or more than that, to exceed vibration, and the drive shaft's torque transmission capability must be higher than 3,500 Nm. The system shaft should not have more than 100 mm outer diameter. The shaft of the transmission system should be optimally designed to satisfy the specification specified.

Table 1: Design constraints details

Sl.no	Name	Notation	unit	Value
1	Ultimate torque	T_{max}	Nm	3500
2	Max speed	N_{max}	Rpm	6500
3	Length of the shaft	L	mm	1250

4. OBJECTIVES

The aim of the study is to determine the adaptivity of composite materials such as E-Glass / Epoxy and High Strength Carbon / Epoxy for automotive transmission applications. The composite drive shaft for the back-end wheel drive car was optimally designed using GA for E-Glass / Epoxy and High Strength Carbon composites with the aim of limiting the weight of the shaft that is subject to constraints like torque limitation, torsional buckling capacity and natural frequency.

5. DESIGN CHARACTERISTICS

A. ASSUMPTIONS

The circular shaft rotating about longitudinal axis at a constant speed. The shaft is completely balanced. This excludes all damping characteristics and non-linear characteristics. For composite material, the stress-strain relationship is linearly elastic; therefore, Hook's law applies to composite materials. The out of plane stress can be applied on the composite because the thickness of ply is too thin.

B. MATERIAL SELECTION AND CROSS-SECTION

The materials Glass reinforced carbon fiber and High Strength Carbon are chosen for this work. Because composites are highly orthotropic, and their fractures have not been fully researched.

Table 2: Material Properties

Property	E-GLASS/EPOXY	HS CARBON
Young's modulus X direction(E11), GPa	50	134
Young's modulus Y direction(E22), GPa	12	7
Shear modulus XY direction(G12), GPa	5.6	5.8
Poisson ratio	0.3	0.3
Density, kg/m^3	2000	1600

C. OBJECTIVE FUNCTION

Objective function should be minimum weight of shaft = min(m)

$m = \rho AL$

$= \rho\pi (d^2_o - d^2_i) L/4$

Where

m = mass

ρ = density

do, di = External and Internal diameter of the shaft

L = Shaft Length

D. DESIGN ATTRIBUTES

The design attributes of the problem are number of plies, stacking Sequence and ply thickness. They are given as follows

- Number of plies [n]
  1<n<17
- Stacking sequence [θ]
  -90 ≤θ ≤ 90
- Thickness of ply [t_k]
  0.0001≤ t_k≤ 0.0005

All these variables have to be included into the objective function equation.
That is mass as a function of n, θ, t_k

E. DESIGN CONSTRAINTS

Torque transmission capacity must be greater than 3500 Nm

$$T \geq T_{max}$$

Natural frequency must be greater than 6500 rpm

$$N \geq N_{max}$$

F. MODIFIED MASS EQUATION

The modified mass equation that is used as the objective function that has to be minimum. This equation used to insert in the MATLAB as function format. So that the genetic optimization can be done.

$$= 13509[0.09 * (n * t_k)^{0.5} * (0.18 - 2 * r)^{0.5} - \frac{4{t_k}^3}{\rho t r^2 \omega^2}\left(\sum_{i=1}^{n} Q_{12} * \epsilon_x + \sum_{i=1}^{n} Q_{22} * \epsilon_x + \sum_{i=1}^{n} Q_{12} * \gamma_{xy}\right) * [\frac{Tn^3}{16\pi r^2}\frac{1}{(\sum_{i=1}^{n} Q_{16} * \epsilon_x + \sum_{i=1}^{n} Q_{26} * \epsilon_x + \sum_{i=1}^{n} Q_{66} * \gamma_{xy})}]^{0.333}$$

where
n- no of piles
t_k-thickness of piles
ϵ_x, ϵ_y – normal strain along x and y direction
γ_{xy} - shear strain
Q_{12},Q_{22},Q_{26},Q_{66} - elements of modified stiffness matrix

6. FORMULATION OF THE OPTIMIZATION USING GENETIC ALGORITHM

Formulation of an optimal design problem involves identification of the design variables, objective function and design constraints. The design constraints are not mandatory for all types of optimization problems. Many design optimization approaches are based on the hypothesis that the design attributes are constant. Almost all design attributes are distinct when it comes into structural optimization. GA used to get the optimal no of layers, ply thickness, and fiber orientation for each layer. All the variables in design are low key in nature and are easily managed by GA. With respect to the middle plane, symmetrical orientations of fibre are adopted.

A. COMPARISON OF GA WITH OTHER APPROACHES

GA varies from conventional optimization technique in many ways. A few merit points are given below.

- GA does not require specific knowledge of a problem in order to perform a search. GA uses only Objective Function values. For example, calculus-based search algorithms use derivative information for performing a search.
- GA uses the traditional methods of optimization to use sample of points at a time as opposed to the single point approach.

B. COMPARISON OF BIOLOGICAL GA TERMS WITH CHROMOSOME

Chromosome - A short rod like a body found in living cells responsible for generic information transmission denotes a coded concept vector in GA. *Gene*-a portion of the chromosome carrying the inherited information denotes each bit in the GA coded template vector. *Population*-denotes a number of variables of coded design within a cell. *Generation* denotes the samples of design attributes obtained after one iteration in alternate ways by setting the maximum iterations as the loop termination process. Those are maximum Number generations after the trail runs are set.

C.COMPUTER PROGRAM

A computer program using MATLAB language was programmed to perform the optimization process, and to obtain the best possible design.

7.RESULTS AND DISCUSSIONS

The flow chart shows working of Genetic algorithm through MATLAB.

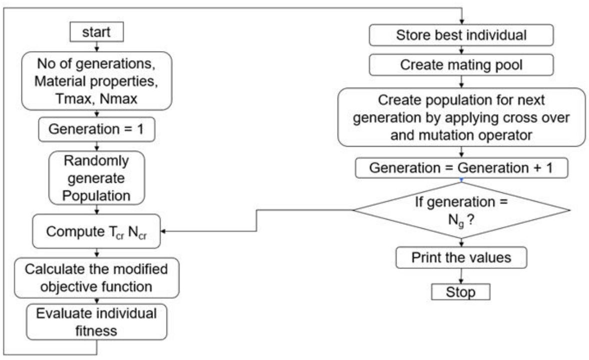

Fig 2: Flow chart of GA

- Variation of HS Carbon / Epoxy and E-Glass / Epoxy shafts based on the objective function value and number of layers with no of generations, first 84 generations of E-Glass / Epoxy shaft and 58 generations of HS-Carbon / Epoxy shaft is found to be changing in weight.

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- The alteration is reduced to a minimal from generation nos. 62-84 in E-Glass / Epoxy shaft and 42-58 in High Strength Carbon shaft but converged later. This is because the population is filled with the best individuals, and no change in the fitness value results from further operations.

Table 3: Comparison composite material and steel shaft

Material	D_o(mm)	L(mm)	n(piles)	T_{cr} (Nm)	N_{cr}(rpm)	Wt(kg)	(%) save
steel	90	1250	1	43857	9323	8.6	
E-glass	90	1250	17	18256	6514	4.2	48.36
HS carbon	90	1250	17	12720	7495	1.029	86

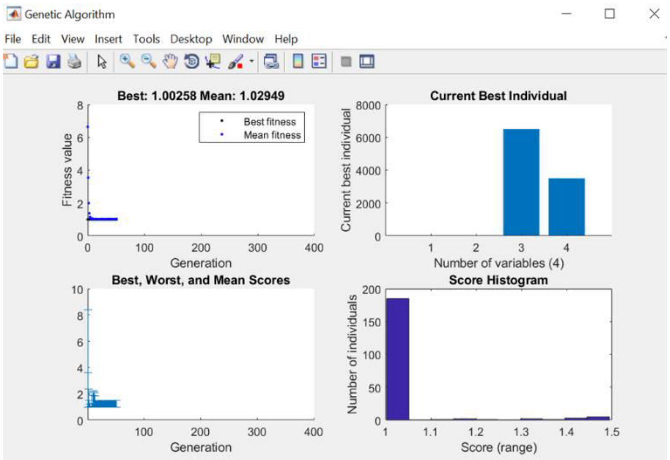

Fig 3 Output from GA using MATLAB

8.CONCLUSIONS

- This study reports the material design and fiber orientation of the drive shaft's laminated composites. The laminate properties achieved using MATLAB code.
- Drive shaft composed of multilayered composites two different such as E-Glass / Epoxy and High Strength Carbon. The optimization using GA through MATLAB for better torque transmission efficiency and speed characteristics the engineered automotive shafts are carried out.
- The replacement of conventional steel shafts with composite and optimization techniques resulted in significant weight savings of between 48.36 for E-glass and 86 percent for High Strength Carbon compared to steel shafts.

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