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OPTIMIZATION OF PLY STACKING SEQUENCE OF COMPOSITE DRIVE SHAFT USING PARTICLE SWARM ALGORITHM

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Abstract

In this paper an attempt has been made to optimize ply stacking sequence of single piece E-Glass/Epoxy and Boron /Epoxy composite drive shafts using Particle swarm algorithm (PSA). PSA is a population based evolutionary stochastic optimization technique which is a resent heuristic search method, where mechanics are inspired by swarming or collaborative behavior of biological population. PSA programme is developed to optimize the ply stacking sequence with an objective of weight minimization by considering design constraints as torque transmission capacity, fundamental natural frequency, lateral vibration and torsional buckling strength having number of laminates, ply thickness and stacking sequence as design variables. The weight savings of the E-Glass/epoxy and Boron /Epoxy shaft from PAS were 51% and 85 % of the steel shaft respectively. The optimum results of PSA obtained are compared with results of genetic algorithm (GA) results and found that PSA yields better results than GA.

Keywords: Composite, Drive shaft, PSA, Stacking Sequence, GA MATLAB.

1. Introduction

Composite materials can be tailored efficiently to meet the design requirements of strength, and stiffness when compared to conventional materials. These materials are known to possess high stiffness to weight ratios. Hence, components made of composite materials would be of significant interest for design improvements in areas where weight reduction is essential without compromising strength and stiffness of the material in aerospace and automotive applications. Composite drive shaft applications have received new impetus during the last decade.

Nomenclatures

C_1	Cognitive parameter
C_2	Social parameter
D	Dimensionality of the search space
d_i	Inside diameter of the shaft, mm
d_o	Outer diameter of the shaft, mm
gbest [ ]	Global best
L	Length of the shaft, mm
n	Number of plies
pbest [ ]	Particle best
present [ ]	Current particle (solution)
rand ()	Random number
t_k	Thickness of ply, mm
v [ ]	Particle velocity
W	Weight of shaft, N
Greek Symbols	
θ_k	Stacking sequence
ρ	Density of the shaft material, N/mm^3

Park et al. [1], Vijayarangan and Rajendran [2], Rangaswamy et al. [3] have used genetic algorithm (GA) for ply stacking sequence optimization which has excellent ability and better chances of finding optimum values, but it has complex operation procedure and low efficiency. Rangaswamy and Vijayarangan [4] have proposed an optimization procedure to design a multilayered single piece composite drive shaft for a given torque, speed and length to achieve minimum weight.

The concept of particle swarm optimization (PSA) was first described by James Kennedy and Russell [5, 6]. From the literature review, it is observed that PSA has been successfully applied in solving engineering structural problems. PSA is used to generate optimal stacking sequence for structural optimization problems [7,8], but not for the ply stacking sequence optimization of composite drive shafts for automobile applications.

In the present work, an attempt is made to propose an optimization procedure to design a multilayered E-Glass/Epoxy and Boron /Epoxy composite drive shafts for given torque, speed and length to achieve minimum weight using PSA. The results obtained from the PSA are compared with the results of GA.

2. Design Optimization of Composite Drive Shaft Using PSA

It is desirable that a transmission system provides the required torque transmission, increased strength, stability, material resource saving, machining required, building of fail-safe design, etc. The common goal in designing a composite drive shaft is to obtain lighter weight shaft under the given functional and geometrical constraints such as static torque transmission capability, torsional buckling and the fundamental natural bending frequency.

The objective function considered for the optimum design of composite drive shaft is the minimization of weight given by,

$$W = \rho AL \text{ or } W = \rho \frac{\pi}{4}\left(d_o^2 - d_i^2\right)L \tag{1}$$

For the optimum design of composite drive shaft the design variables considered with their limiting values is shown in Table 1.

Table 1. Design Variables and their Limiting Values.

Design variables	Limiting values of the design variables	
Number of plies, n	$n > 0$;	n = 1, 2, 3…, 32
Stacking Sequence, θ_k	$-90 \le \theta_k \le 90$;	k =1, 2…, n
Thickness of the ply, t_k	$0.1 \le t_k \le 0.5$	

3. Working of Particle Swarm Algorithm

In particle swarm optimization algorithm, each individual in the particle swarm is composed of three *D*-Dimensional vectors, where *D* is the dimensionality of the search space. The concept of modification of search points is shown in Fig. 1 with the current position x_{i+1}, the previous best position x_i, and the velocity v_i. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. This value is called *pbest* and another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called *gbest*. The current velocity and position of a particle are updated according to Eqs. (2) and (3).

$$v[\,]=v[\,]w+ C_1 rand(\,)(pbest[\,]-present[\,])+C_2\, rand(\,)(gbest[\,]-present[\,]) \tag{2}$$

$$present[\,]=present[\,]+v[\,] \tag{3}$$

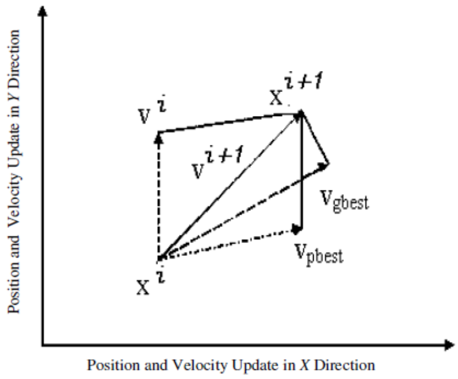

Fig. 1. Concept of Modification of a Searching Point.

PSA operation

Initially, particles are initialized by using random number array and number of swarms of certain specified population is taken and fitness function is evaluated for each particle. From these fitness values, best value or *pbest* of each swarm is found. If there are 150 swarms, 150 best values or *pbests* are found, again from these *pbests* the one global best or *gbest* value is taken. Now best particle or *pbest* in the swarm is propelled or updated by using the PSA's velocity and position Eqs. (2) and (3). If the value is better than the previous, the *pbest* and *gbest* is updated and this will repeat until it reaches the max number of population. The algorithm repeats the same procedure for all swarms. After completion of the entire loop the best value, which is stored in the *gbest* will be displayed. The flow chart describes the working of PSA as shown in Fig. 2 and the input parameters given to the PSA are shown in Table 2.

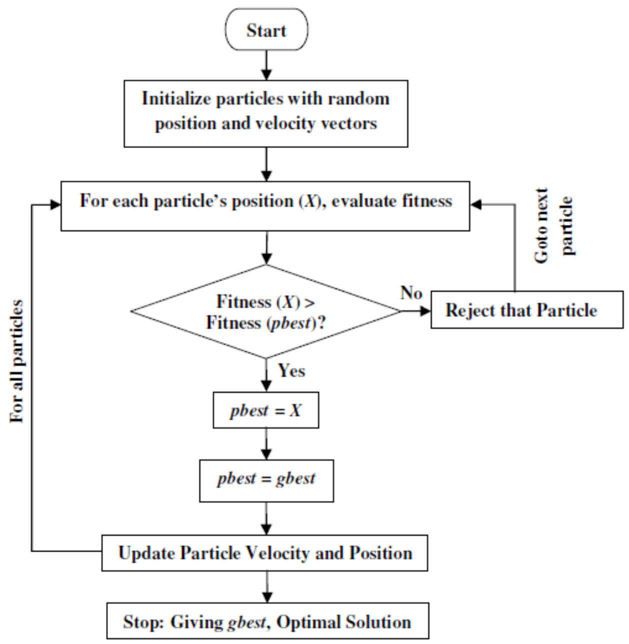

Fig. 2. Flowchart of Particle Swarm Optimization.

Table 2. Input Parameters to PSA.

Inertia weight, W	Varies in between 0 to 1
Random numbers, r_1 and r_2	Varies in between 0 to 1
Leaning Factors, C_1 and C_2	2
Particle Size	50

4. Results and Discussion

A program is developed and run using MATLAB V 7 to perform the optimization process and to obtain the best optimal design values. The design algorithm of composite drive shaft and the flow-chart describing the step by step procedure for optimizing the shaft using PSA are shown in Figs. 3 and 4 respectively.

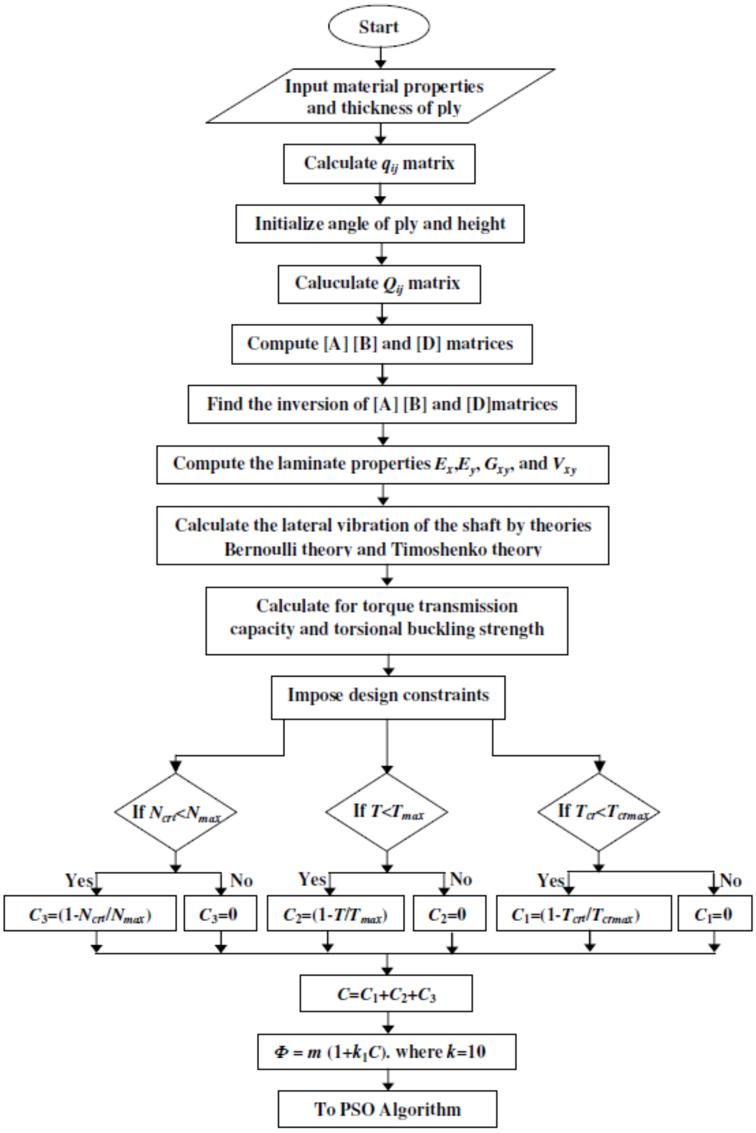

Fig. 3. Design Algorithm of Composite Drive Shaft.

The variation of objective function value of E-glass/epoxy and Boron /epoxy shafts with respect to swarm size are shown in Figs. 5 and 7. The variations of number of layers with respect to swarm size of the PSO are given in Figs. 6 and 8. For the first 130 swarm size of E-glass/epoxy shaft, and 90 swarm size Boron /epoxy shaft, the weight is found to be fluctuating. The fluctuation is reduced to a minimum from generation numbers 130-140 in E-Glass/Epoxy shaft and 90 to 130 in Boron /Epoxy shaft respectively and later they get converged. Weight of the composite shaft is directly related to number of layers. As the number of layer increases, weight also increases, therefore fluctuations in weight and number of layers is seen in Figs. 5 to 8. The optimum ply stacking sequence, torque transmission capability, critical speed, weight savings for E-glass and Boron /Epoxy obtained from PSA is given in Table 3.

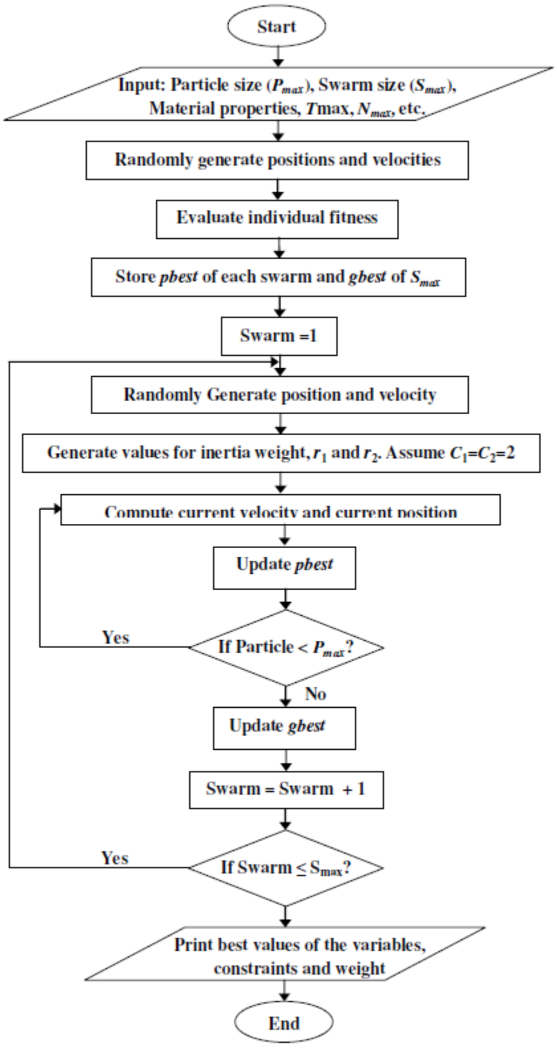

Fig. 4. Flowchart of PSA Based Optimal Design of Composite Drive Shaft.

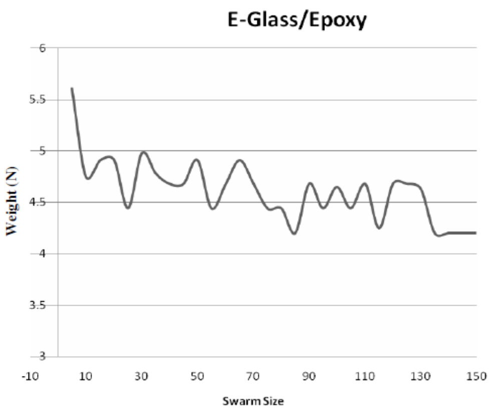

Fig. 5. Variations of Mass of E-Glass/Epoxy Drive Shafts with Swarm Size.

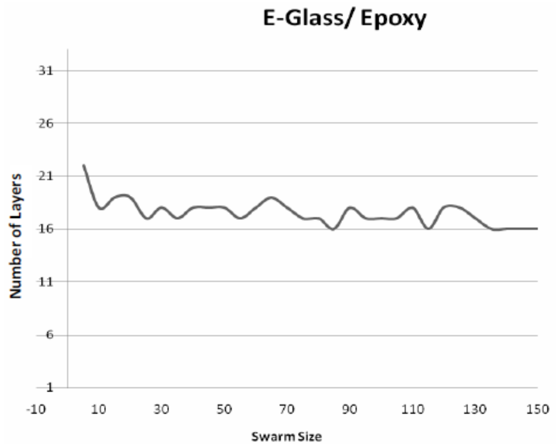

Fig. 6. Variations of Number of Layers of E-glass/Epoxy Drive Shafts with respect to Swarm Size.

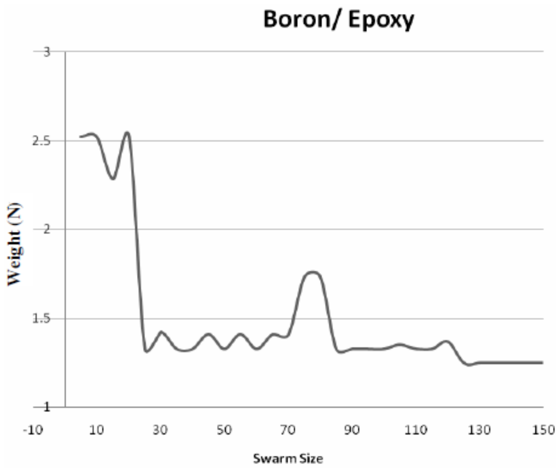

Fig. 7. Variations of Mass of Boron/Epoxy Drive Shafts with Swarm Size.

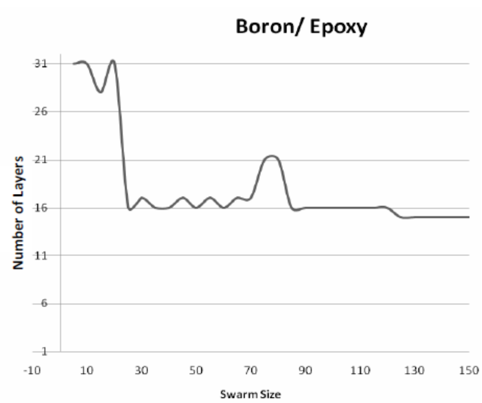

Fig. 8. Variations of Number of Layers of Boron/Epoxy Drive Shafts with respect to Swarm Size.

Table 3. Summary of PSA Results.

Parameter	Steel (SM45C)	E-Glass/ Epoxy	Boron/ Epoxy
Optimum Layers	-	16	15
Thickness, *t* (mm)	3.32	6.4	1.8
Optimum Stacking sequence	-	[4/-13/-13/-2/67/85/-70/18] s	[58/61/-32/-82/-75/ -29/21/63] s
T (Nm)	3501	3508	3519
T_{cr} (Nm)	43858	31967	3850
N_{crt} (rpm)	9320	6520	9838
Weight (N)	86.04	42.10	12.50
Weight saving (%)*	-	51.16	85.47

* taking steel shaft weight as datum

Comparison of PSA and GA results

The weight obtained from the particle swarm optimization algorithm for E-glass/Epoxy and Boron/Epoxy are 42% and 12.50 % respectively are compared with the result of genetic algorithm [3] for E-glass/Epoxy and Boron / Epoxy are 44.4% and 14 % respectively. Figure 9 shows the weight comparison of E-glass/Epoxy and Boron/Epoxy composite drive shafts which shows PSA yields better results than GA.

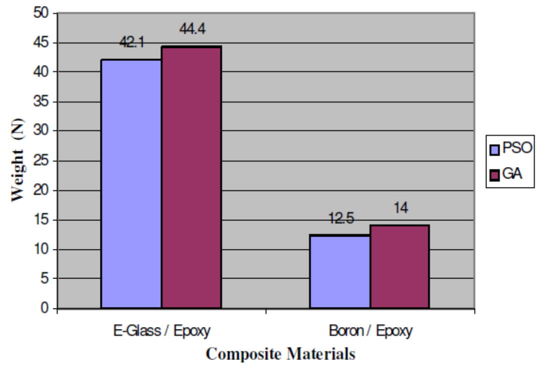

Fig. 9. Comparisons of PSA Results with GA Results [9].

5. Conclusions

Some concluding observations from this research work are given below.

- An optimization procedure is proposed to design a multilayered single piece composite drive shaft for a given torque; speed and length to achieve minimum weight using PSA approach.
- Composite shaft materials of E-glass/Epoxy and Boron/Epoxy are considered for single piece shaft automotive application.
- An optimal stacking sequence is generated using PSA to minimize the weight to meet the functional and performance requirements.
- The weight savings of two material shafts using PSA are compared with Genetic Algorithm results and found that the PSA have better results than GA.

- PSA uses less number of function evaluations, and has better searching capability and more computationally efficient than GA for discrete variables problem.

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