# Use of Genetic Algorithm for designing a Composite Drive Shaft

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**Abstract**: This paper highlights the wide use of advanced composite materials such as Graphite, Carbon, Kevlar and Glass with suitable resins because of their high specific strength (strength/ density) and high specific modulus (modulus/ density). Advanced composite materials seem ideally suited for long, power driver shaft (propeller shaft) applications. Their elastic properties can be tailored to increase the torque they can carry as well as the rotational speed at which they operate. The drive shafts are used in automotive, aircraft and aerospace applications. The automotive industry is exploiting composite material technology for structural components construction in order to obtain the reduction of the weight without decrease in vehicle quality and reliability. It is known that energy conservation is one of the most important objective in vehicle design and reduction of weight is one of the most effective measures to obtain this result. Actually, there is almost a direct proportionality between the weight of a vehicle and its fuel consumption, particularly in city driving.

Almost all automobiles (at least those which correspond to design with rear wheel drive and front engine installation) have transmission shafts. The weight reduction of the drive shaft can have a certain role in the general weight reduction of the vehicle and is a highly desirably goal, if it can be achieved without increase in cost and decrease in quality and reliability. It is possible to achieve design of composite drive shaft with less weight to increase the first natural frequency of the shaft and to decrease the bending stresses using various stacking sequences. By doing the same, maximize the torque transmission and torsional buckling capabilities are also maximized.

This work deals with replacement of a conventional steel drive shaft with E-Glass/Epoxy, High Strength Carbon/ Epoxy and High Modulus Carbon/Epoxy composite drive shafts for an automobile application. The overall objective is to design composite drive shaft for power transmission applications. Genetic Algorithm (GA) is successfully applied to minimization of the weight of shaft which is subjected to the constraints such as torque transmission, and fundamental natural frequency. The design variable are Number of plies and Thickness of the ply.

***Keywords****: Composite Materials, elastic properties, Genetic Algorithm (GA).*

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## I. INTRODUCTION:

Composites consists of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. The constituents are combined at a macroscopic level and or not soluble in each other. The main difference between composite and an alloy are constituent materials which are insoluble in each other and the individual constituents retain those properties in the case of composites, where as in alloys, constituent materials are soluble in each other and forms a new material which has different properties from their constituents.

Classification of Composites

Composite materials can be classified as

- Polymer matrix composites
- Metal matrix composites
- Ceramic Matrix

Technologically, the most important composites are those in which the dispersed phase is in the form of a fiber. The design of fiber-reinforced composites is based on the high strength and stiffness on a weight basis. Specific strength is the ratio between strength and density. Specific modulus is the ratio between modulus and density. Fiber length has a great influence on the mechanical characteristics of a material. The fibers can be either long or short. Long continuous fibers are easy to orient and process, while short fibers cannot be controlled fully for proper orientation. Long fibers provide many benefits over short fibers. These include impact resistance, low shrinkage, improved surface finish, and dimensional stability. However, short fibers provide low cost, are easy to work with, and have fast cycle time fabrication procedures. The characteristics of the fiber-reinforced composites depend not only on the properties of the fiber, but also on the degree to which an applied load is transmitted to the fibers by the matrix phase.

The principal fibers in commercial use are various types of glass, carbon, graphite and Kevlar. All these fibers can be incorporated into a matrix either in continuous lengths or in discontinuous lengths as shown in the. The matrix material may be a plastic or rubber polymer, metal or ceramic. Laminate is obtained by stacking a number of thin layers of

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fibers and matrix consolidating them to the desired thickness. Fiber orientation in each layer can be controlled to generate a wide range of physical and mechanical properties for the composite laminate.

Advantages of Fiber Reinforced Composites

The advantages of composites over the conventional materials are

- High strength to weight ratio
- High stiffness to weight ratio
- High impact resistance
- Better fatigue resistance
- Improved corrosion resistance
- Good thermal conductivity
- Low Coefficient of thermal expansion. As a result, composite structures may exhibit a better dimensional stability over a wide temperature range.
- High damping capacity.

Limitations of Composites

The limitations of composites are

- Mechanical characterization of a composite structure is more complex than that of a metallic structure.
- The design of fiber reinforced structure is difficult compared to a metallic structure, mainly due to the difference in properties in directions.
- The fabrication cost of composites is high
- Rework and repairing are difficult.
- They do not have a high combination of strength and fracture toughness as compared to metals
- They do not necessarily give higher performance in all properties used for material selection

Applications of Composites

The common applications of composites are extending day by day. Nowadays they are used in medical applications too. The other fields of applications are,

- Automotive
- Aircraft
- Space
- Marine
- Chemical Industries
- Electrical & Electronics
- Sports Goods

Purpose of the Drive Shaft (or Propeller shaft)

The torque that is produced from the engine and transmission must be transferred to the rear wheels to push the vehicle forward and reverse. The drive shaft must provide a smooth, uninterrupted flow of power to the axles. The drive shaft and differential are used to transfer this torque.

- First, it must transmit torque from the transmission to the differential gear box.
- During the operation, it is necessary to transmit maximum low-gear torque developed by the engine.
- The drive shafts must also be capable of rotating at the very fast speeds required by the vehicle.
- The drive shaft must also operate through constantly changing angles between the transmission, the differential and the axles.
- The length of the drive shaft must also be capable of changing while transmitting torque.

Drive Shaft Arrangement in a Car Model

Conventional two-piece drive shaft arrangement for rear wheel vehicle driving system is shown in figure below.

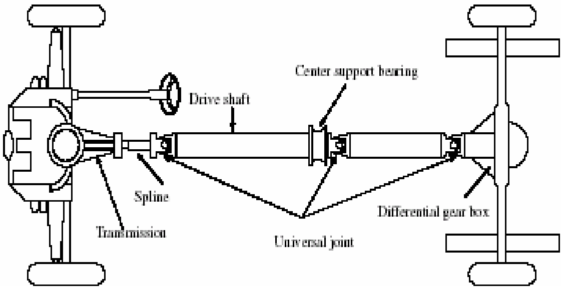


Fig. No. 1 - Two piece drive shaft arrangement for rear wheel vehicle driving system

Demerits of a Conventional Drive Shaft

- They have less specific modulus and strength.
- Increased weight.
- Conventional steel drive shafts are usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft is inversely proportional to the square of beam length and proportional to the square root of specific modulus.
- Its corrosion resistance is less as compared with composite materials.
- Steel drive shafts have less damping capacity.

Merits of Composite Drive Shaft

- They have high specific modulus and strength.
- Reduced weight.
- Due to the weight reduction, fuel consumption will be reduced.
- They have high damping capacity hence they produce less vibration and noise.
- They have good corrosion resistance.
- Greater torque capacity than steel or aluminium shaft.
- Longer fatigue life than steel or aluminium shaft.
- Lower rotating weight transmits more of available power.

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Drive Shaft Propeller and Zincs

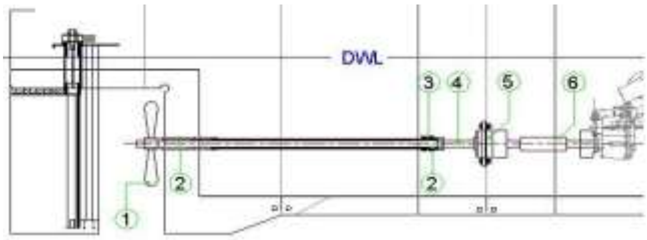


Fig No. 2 Drive Shaft Propeller and Zincs

| | | | |
|---|---|---|---|
| 1 | Propeller | 4 | V 174 steel shaft |
| 2 | Cutless bearing | 5 | Aqua drive thrust bearing |
| 3 | PSS shaft seal | 6 | CV shaft |

Selection of Reinforcement Fiber

Fibers are available with widely differing properties. Review of the design and performance requirement usually dictate the fiber/fibers to be used.

- **Carbon/Graphite fibers :** Its advantages include high specific strength and modulus, low coefficient of thermal expansion, and high fatigue strength. Graphite, when used alone has low impact resistance. Its drawbacks include high cost, low impact resistance, and high electrical conductivity.
- **Glass fibers :** Its advantages include its low cost, high strength, high chemical resistance, and good insulating properties. The disadvantages are low elastic modulus, poor adhesion to polymers, low fatigue strength, and high density, which increase shaft size and weight. Also crack detection becomes difficult.

Here, both glass and carbon fibers are selected as potential materials for the design of shaft.

Selection of Resin System

The important considerations in selecting resin are cost, temperature capability, elongation to failure and resistance to impact (a function of modulus of elongation). The resins selected for most of the drive shafts are either epoxies or vinyl esters. Here, epoxy resin was selected due to its high strength, good wetting of fibers, lower curing shrinkage, and better dimensional stability.

Selection of Materials

Based on the advantages discussed earlier, the E-Glass/ Epoxy, High Strength Carbon/Epoxy and High Modulus Carbon/ Epoxy materials are selected for composite drive shaft. The Table 6.1 shows the properties of the E-Glass/ Epoxy, High Strength Carbon/ Epoxy and High Modulus Carbon/ Epoxy materials used for composite drive shafts.

| **Sl. No** | **Property** | **Units** | **E-Glass/ Epoxy** | **HS Carbon/Epoxy** | **HM Carbon/Epoxy** |
|---|---|---|---|---|---|
| 1. | $E_{11}$ | GPa | 50.00 | 134.00 | 190.0 |
| 2. | $E_{12}$ | GPa | 12.0 | 7.0 | 7.7 |
| 3. | $G_{12}$ | GPa | 5.6 | 5.8 | 4.2 |
| 4. | V12 | - | 0.3 | 0.3 | 0.3 |
| 5. | $S^{1}_{1}= S^{c}_{1}$ | MPa | 800.0 | 880.0 | 870.0 |
| 6. | $S^{1}_{2}= S^{c}_{2}$ | MPa | 40.0 | 60.0 | 54.0 |
| 7. | $S_{12}$ | MPa | 72.0 | 97.0 | 30.0 |
| 9 | □ | Kg/ $m^3$ | 2000.0 | 1600.0 | 1600.0 |

Design of steel drive shaft

Steel (SM45C) is used for automobile drive shaft application. The steel drive shaft should satisfy three design specification such as torque transmission capability and fundamental natural frequency.

Specification of the Problem

- The torque transmission capability of the drive shaft for passenger cars, small trucks, and vans should be larger than 3,500Nm ($T_{max}$).
- Fundamental natural bending frequency of the shaft should be higher than 6,500 rpm ($N_{crt}$) to avoid whirling vibration.
- The outer diameter ($d_o$) should not exceed 100 mm due to space limitations and here $d_o$ is taken as 90 mm. and length of shaft is 1250 mm
- The drive shaft of transmission system was designed optimally to the specified design requirements

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Design of composite drive shaft

For designing a composite drive shaft, Genetic Algorithm (GA) is successfully applied to minimization of the weight of shaft which is subjected to the constraints such as torque transmission, torsional buckling capacities and fundamental natural frequency. The design variables are Number of plies and Thickness of the ply.

- Mass of the steel shaft
- Torque transmission capacity of steel drive shaft
- Fundamental natural frequency

Steel (SM45C) is used for automobile drive shaft application. The material properties of Steel (SM45C) are given in Table No.3.1.1. The steel drive shaft should satisfy three design specification such as torque transmission capability and fundamental natural frequency.

Mechanical properties of steel

| Mechanical properties | Symbol | Unit | Steel |
|---|---|---|---|
| Young modulus | E | Gpa | 207 |
| Poisson's ratio | v | -- | 0.3 |
| Density | ρ | $Kg/m^3$ | 7600 |
| Shear strength | $S_S$ | Mpa | 370 |
| Shear modulus | G | Gpa | 80 |

Parameter of shaft

| Parameter of shaft | Symbol | Value | Unit |
|---|---|---|---|
| Outer diameter | $d_o$ | 90 | mm |
| Inner diameter | $d_i$ | 83.36 | mm |
| Length of the shaft | L | 1250 | mm |
| Thickness of shaft | t | 3.32 | mm |

1. **Mass of the steel shaft**

$$m = \rho AL= \rho\times\pi/4\times ( d_0^2 - d_i^2 ) \times L$$

$$= 7600 \times 10\text{^-}9 \times \pi/4\times ( 90^2 - 83.36^2) \times 1250$$

$$=8.58 \text{ kg}$$

2. **Torque transmission capacity of steel drive shaft**

$$T = s_s \times \pi/16\times[ (d_0^4 - d_i^4 ) / d_o ]$$

$$= 370\times\pi/16\times [( 90^4 - 83.36^4 ) / 90 ]$$

$$= 55.93 \times 10\text{^}3 \text{ Nm}$$

3 **Fundamental natural frequency**

- **Lateral or Bending vibration**

The shaft is consider as simply supported beam undergoing transverse vibration . Natural frequency can be found using the Timoshenko beam theory- Ncrt

- **Timoshenko beam theory- $N_{crt}$**

It consider both transverse shear deformation as well as rotary inertia effect. Natural frequency base on the Timoshenko beam theory is given by

$$f_{nt} = k_s ( 30 \pi p^2)/ L^2 \times ( E r^2 /2\rho)\text{^}(1/2)$$

$$N_{crt}= 60 f_{nt}$$

$f_{nt}$ = natural frequecy base on Timoshenko beam theory, HZ

$k_s$ = shear coefficient of lateral natural frequency

p = 1 , first natural frequency

r = mean radius of shaft

$$1 / K_s^2 = 1+ (n^2\pi^2r^2)/2L^2 \times [1+ f_sE/ G ]$$

$f_s$ = shape factor,2 for hollow circuler cross section

$$1/ K_s^2 = 1+ ( 1^2 \pi^2 \; 43.34^2)/ 2 \times 1205^2 [1+2\times207\times1063/80\times10\text{^}3]$$

$$K_s = 0.982$$

$$f_{nt} = K_s ( 30 \pi p^2 ) / L^2 (E r^2/2\rho) \text{^}(1/2)$$

$$= 299.54$$

$$N_{crt} = 60 \times 299.54$$

$$= 17972.4 \text{ rpm}$$

Genetic Algorithm

Genetic algorithm is non traditional method of optimization in which solving the problem of minimize or maximize the objective function. Non traditional algorithm are very difficult to solve. Solution for nontraditional algorithm can be obtained by computerizing algorithm using C- language.

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Benefits of Genetic Algorithms

- Many ways to speed up and improve a GA-based application as knowledge about problem domain is gained
- Easy to exploit previous or alternate solutions
- Flexible building blocks for hybrid applications
- Substantial history and range of use

Formulation of work using genetic algorithm

- **Objective Function:** To minimize the weight of the shaft.

(mass) $m = \rho AL = \rho \times \pi/4 \times (d_0^2 - d_i^2) \times L$

$= \rho \times \pi/4 \times [d_0^2 - \{d_o - 2(t_k \times n)\}^2] \times L$

$f(x) = f(x1,x2) = \rho \times \pi/4 \times [d_0^2 - \{d_o - 2(x_2 \times x_1)\}^2] \times L$

- **Design Variable**:

1. no. of ply

$0<n<32$

2. thickness of ply.

$0.1 < t_k < 0.5$

The objective is to minimize the function

$f(x) = f(x1,x2) = \rho \times \pi/4 \times [d_0^2 - \{d_o - 2(x_2 \times x_1)\}^2] \times L$

in the interval $0 < x_1 < 32$, $0.1 < x_2 < 0.5$.

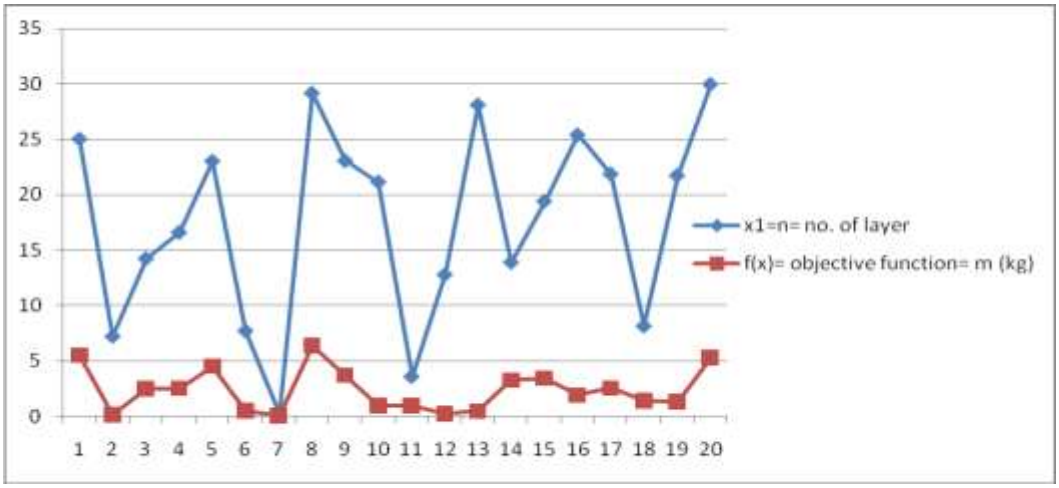
After performing number of iterations for the above stated range, following results were obtained.

**Optimum Design value of Composite shaft with steel**

| Material | $d_o$ (mm) | L (mm) | $t_k$ (mm) | n (mm) | t (mm) | Wt (kg) | (%) saving |
|---|---|---|---|---|---|---|---|
| Steel | 90 | 1250 | 3.32 | 1 | 3.32 | 8.6 | |
| HS carbon/ epoxy | 90 | 1250 | 0.10 | 17 | 1.7 | 0.918 | 89.32 |

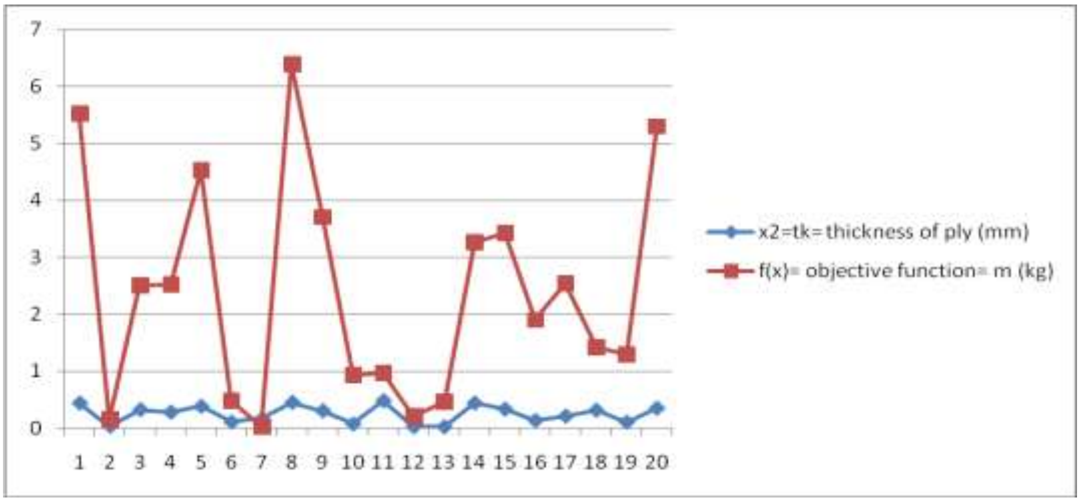
When the value of tk is 0.10 & value of n is 17 then minimize the weight of composite drive shaft of 89.32 % of steel shaft.

**Graph showing the relationship between Objective Function f(x) and No. of Ply (n) after Evaluation & Reproduction in first generation**



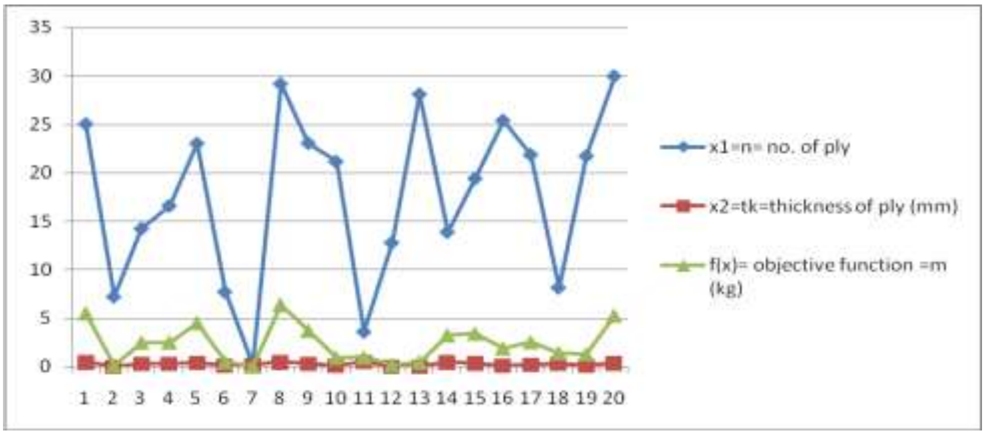

1. The Relationship between f(x) and $x_1$ is not linear.
2. But , however the minimum value of f(x) is found when $x_1$ is 7

**Graph showing the relationship between Objective Function f(x) and Thickness of Ply ($t_k$) after Evaluation & Reproduction in first generation**



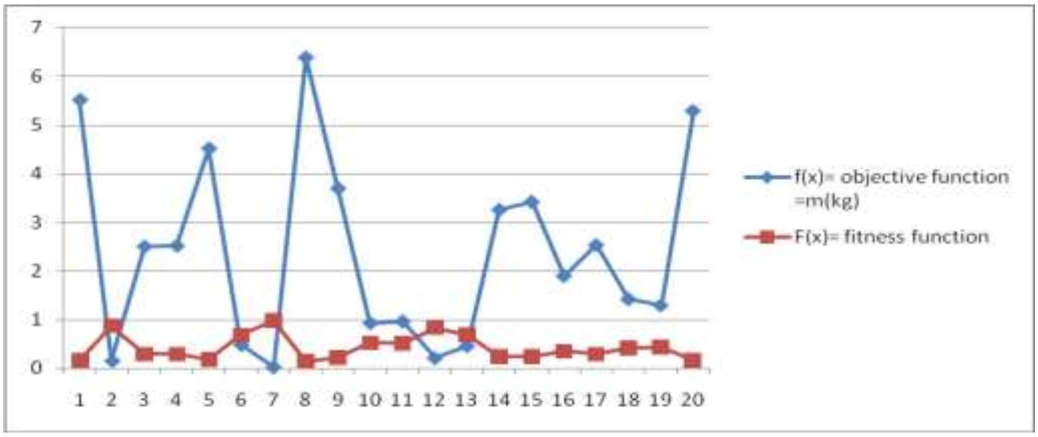

1. The Relationship between f(x) and $x_2$ is not linear.
2. But , however the minimum value of f(x) is found when $x_2$ is 0.10

**Graph showing the relationship between Objective Function f(x) and Thickness of Ply ($t_k$) and No. of Ply (n) after Evaluation & Reproduction in first generation**




1. The Relationship between f(x) and $x_2$ and is not linear.
2. But , however the minimum value of f(x) is found when $x_2$ is 0.10 and $x_1$is1

**Graph showing the relationship between Objective Function f(x) and Fitness function F(x) after Evaluation & Reproduction in first generation**




1. The Relationship between f(x) and F(x) and is not linear.
2. But , however the minimum value of f(x) is found when F(x) is 1

## II. CONCLUSIONS:

- The High Strength Carbon/ epoxy composite drive shaft have been design to replace the steel drive shaft of an automobile.
- A one piece composite drive shaft for rear wheel drive automobile has been design optimally by using genatic algorithm for High Strength Carbon/ epoxy composites with the objective of minimisation of weight of shaft.
- The weight saving of the High Strength Carbon/ epoxy composite drive shaft were equal to 86.90% of the weight of steel shaft respectively.
- The torque transmission capacity of composite drive shaft have been calculated.
- Natural frequency calculated by using Timoshenco beam theory.

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