Genetic Algorithm Based Optimal Design of Mono Composite Leaf Spring and Testing

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Abstract:

The role of composites in weight reduction and fuel saving in automobiles is highly significant. The aim of the present work is to replace the steel leaf spring with a Genetic Algorithm based optimally designed composite leaf spring. The Genetic Algorithm based optimization techniques provide robust solutions. The replacement of steel with optimally designed composite leaf spring can provide 93% weight reduction. Moreover the composite leaf spring has lower stresses compared to steel spring. All these will result in fuel saving which will make our country energy independent because fuel saved is fuel produced.

Keywords: Leaf spring; Composite; Improved GA; Weight reduction;

1 Introduction

Weight reduction has been the main focus of automobile manufacturers in the present scenario. The leaf spring suspension accounts for about 10-20% of vehicle unsprung weight. Thus it becomes a potential unit for weight reduction. The weight reduction can be achieved by choosing better materials and optimized design etc [8-9]. In the current work a combination of the above factors is tried. The convention steel leaf spring is replaced by a composite leaf spring. Moreover, an optimal design for the composite spring is achieved using Genetic Algorithm based optimization method. Traditional optimization methods operate on mathematical abstractions of the real design problem thereby giving local optimum only. The GAs promise convergence to the global optimum as they are based on the mechanics of natural selection and natural genetics.

This paper presents an artificial genetic approach for optimally designing composite leaf springs. A GA adapted from the one formulated by Goldberg [1] is used in the current study. In the previous study by S.Vijayarangan [3], a GA formulation was applied for the design optimization of steel leaf springs. Although design optimization of steel springs and composite leaf springs has been the subject for quite few investigators [3,4], no paper appear to have been reported on composite mono leaf spring design using the improved GA approach. However there are some literature regarding GAs [5-7]. GA is fairly new and is described in greater detail in the literature [1, 2]. There were previous studies made by Rajendran [4] on GA based design optimization of steel and composite leaf springs. This paper suggests an improved steady-state GA for optimizing the design parameters of composite leaf springs.

2 Theory

GA is an efficient and effective search procedure that imitates natural genetics and selection. They provide global and robust solutions for various optimization problems. They combine survival of fittest amongst string structures with a structured yet randomized information exchange process [1]. The present study involves a simple GA formulation involving crossover, mutation and replacement operators. The objective of the present study is to minimize the weight of the composite leaf spring. Hence the objective function for the GA is the leaf spring weight.

2.1 Steady state algorithm. The steady state GA's replace only apart of the parent values unlike traditional generational methods which replace the population base with new offspring's. Thus steady state GA's result in obtaining the optimal solution quickly. Moreover the mode of searching is uniform [10]. The steady state GA's are employed for the current work.

2.2 Tournament selection. The population sorting methods like roulette wheel selection, linear ranking method etc uses potentially time consuming methods to sort the entire population of strings. In the current work, the tournament selection sorting method devised by Goldberg and Deb is used. This method aids in faster sorting by employing filtering techniques [10].

3 Design Parameters for composite leaf spring

The constant cross section design is chosen for designing the leaf spring due to its ability for mass production and continuous fiber accommodation [4]. The current design aims in replacing a seven leaf steel spring with a mono leaf composite leaf spring. The design parameters taken for analysis are:

- Design load, W = 3850 N
- Maximum allowable vertical deflection, dmax = 120 mm
- Distance between the eyes in straight condition, L = 1220 mm

4 Optimal problem formulation

A mathematical model for optimal design of composite leaf spring is proposed here. The various steps in the GA procedure is explained below:

4.1 Objective function. The objective is to arrive at the minimum weight of the leaf spring. The objective function, $f(w)$ identified for the study is given below:

$$f(w) = \rho L b t, \quad (1)$$

Where ρ is the density of composite material, L is the leaf spring length, b is the width at centre, t is the thickness at centre.

4.2 Design Variables. The design variables chosen for the present problem are: (1) centre width, b (2) centre thickness, t. The range for the design variables is specified here:

b_{max} = 50 mm and b_{min} = 30 mm

t_{max} = 40 mm and t_{min} = 20 mm

4.3 Design parameters. The design parameters are usually independent of the design variables. The design parameters chosen for the design are, the leaf spring length, L, design load, W, composite material properties – (1) Density, ρ (2) Young's Modulus, E (3) Maximum allowable stress, S_{max}.

4.4 Design constraints. The design constraints limit the functional performance and resource utilization of the leaf spring. In this problem, the constraints are the bending stress, S_b, vertical deflection, d and indirectly the Factor of Safety (FOS).

$$S_b = 1.5\,WL / bt^2, \quad (2)$$

$$d = WL^3 / 4Ebt^3, \quad (3)$$

$$FOS = S_{max} / S_b, \quad (4)$$

The upper and lower limits for the constraints are as follows:

S_{bmax} = 550 MPa and S_{bmin} = 400 MPa

d_{max} = 120 mm and d_{min} = 100 mm

FOS_{max} = 2 and FOS_{min} = 1.5

4.5 Fitness function. GAs are generally formulated for solving maximization problems. Since the current problem involves minimizing the weight, we need to transform the objective function suitably. The fitness function, F(x) used for analysis is

$$F(x) = K - f(w), \quad (5)$$

where K is an arbitrary value.

4.6 Violation Parameter. Constraints on the design parameter require penalties on the parameter values that go out of bound. The penalty function, α(x) used is a discontinuous bi-quadratic:

$$\alpha(x) = \begin{cases} 0, & \min \le x \le \max \\ (x-\max)^4, & x > \max \\ (\min-x)^4, & x < \min \end{cases} \quad (6)$$

The final objective function involving the fitness function (weight) and violation parameters is as follows:

$obj(x) = f(w) + \alpha(FOS) + \alpha(d)$ (7)

To keep the design constraints within limits, Factor of Safety, FOS and deflection, d are chosen as violation parameters. The addition of violation functions α(FOS) and α(d), constrain the objective function values such that there are no penalties for parameter values inside the specified range. The flow chart depicting the GA process involved is shown in the figure 1.

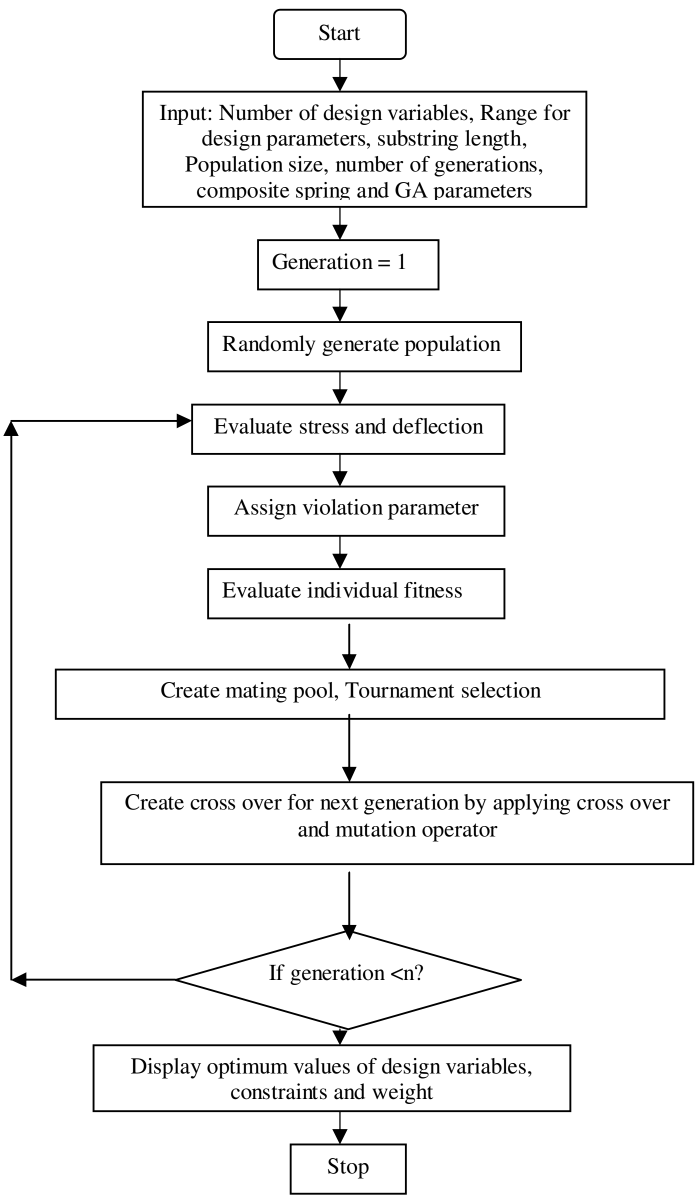

Fig.1 Flow Chart depicting the GA process

5 Parameters for the Genetic Algorithm Formulation

The GA parameters are fixed based on the problem convergence and the solution time. The input parameters chosen for the current study are shown in Table 1.

5.1 Total String Length. The string length (l) is chosen based on the accuracy level required and data available. The chosen length, l, partitions the range from the minimum value of the parameter till the maximum value, into 2^l discrete steps. In the current study a string length of 16 bits for each parameter (total 32) was used.

5.2 Crossover and Mutation Probability. Since we use a steady state GA, the crossover probability is taken to be 1 and the mutation probability is fixed at 0.01.

Table 1 Input parameters for GA formulation

GA Parameters	Values
Number of parameters	2
Total spring length	32
Population size	25
Maximum generations	150
Cross-over probability	1
Mutation probability	0.01
String length for width	16
Range of width (mm)	30-50
String length for Thickness	16
Range of thickness (mm)	20-40

6 Testing of Steel and Composite Mono Leaf Spring

The steel and composite leaf springs are tested in the Leaf spring test rig. The experimental set up is shown in Figs.2 (a) and (c). The leaf springs are tested following standard procedures recommended by SAE. The spring to be tested is examined for any defects like cracks, surface abnormalities, etc. The spring is loaded from zero to the prescribed maximum deflection and back to zero. The load is applied at the centre of spring; the vertical deflection of the spring centre is recorded in the load interval of 50N.

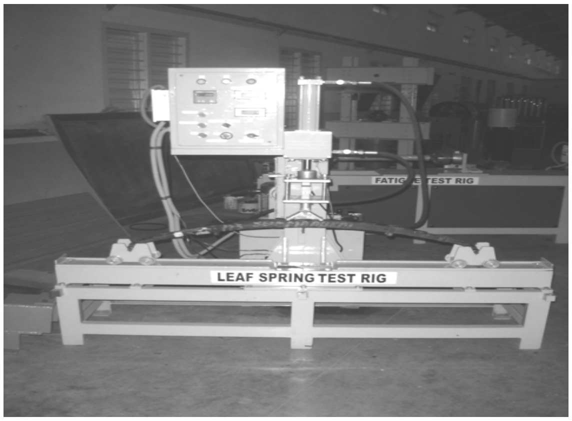

Fig.2 (a) Static test of steel leaf spring

Fig. 2 (b) Static test of composite leaf spring.

7 Results and discussion

The optimum values for the design variables, constraints and leaf spring weight obtained through the GA process. The obtained GA results were compared with experimental data. Results comparison of load, deflection and stresses are shown in Table 2. These optimum values obtained through the GA is shown in Table 3 and illustrated in Fig. 3 to 7.

Table 2 Comparison results of load, deflection and stresses

Material	Static load (N)	Maximum deflection(mm)		Maximum Stress(MPa)		Weight (N)
		Experimental	GA	Experimental	GA	
Steel	3980	107.5	-	503.3	-	260
Glass/Epoxy	4250	105.0	119.84	473.0	386.85	18.04

8 Summary and results

1. The present work provides optimal values for width and thickness of leaf spring.
2. Soft limiting penalty functions were used to include constraints in the objective function.
3. The weight of the composite leaf spring can be reduced by 53.5% from 38.8 N to 18.04 N by applying the GA optimization technique.
4. Composite mono leaf spring reduces the weight by 85% for E-Glass/Epoxy over conventional leaf spring. The reduction of 93%weight is achieved by replacing conventional steel spring with an optimally designed composite mono-leaf spring.
5. From the results, it is observed that the composite leaf spring is lighter and more economical than the conventional steel spring with similar design specifications
6. The study demonstrated that composites can be used for leaf springs for light weight vehicles and meet the requirements, together with substantial weight savings

Table 3 Optimal design values of composite leaf spring

GA output	Values
Width (mm)	30.00
Thickness (mm)	24.64
Stress (MPa)	386.85
Deflection (mm)	119.84
Weight (N)	18.1

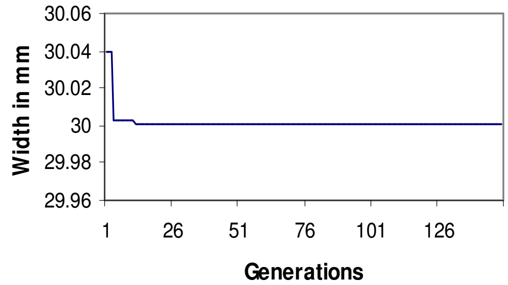

Fig. 3 Comparison of width vs. generations

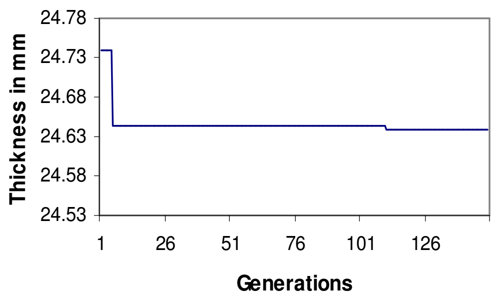

Fig. 4 Comparison of thickness vs. generations

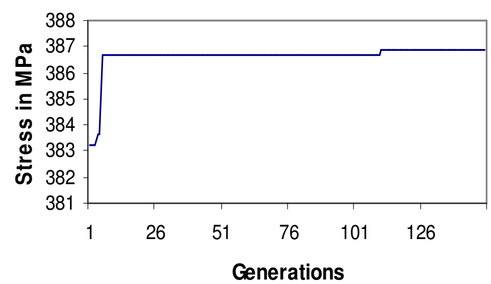

Fig. 5 Comparison of stress vs. generations

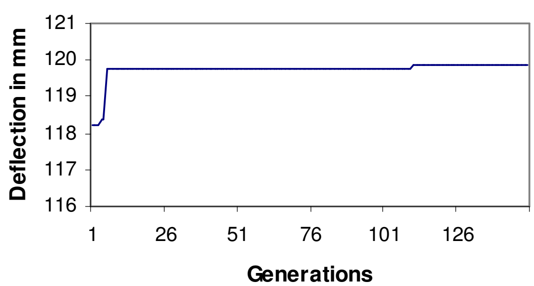

Fig. 6 Comparison of deflection vs. generations

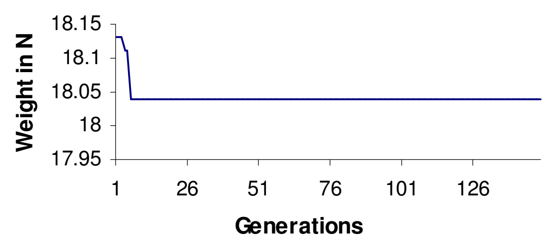

Fig. 7 Comparison of weight vs. generations

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