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Optimization of Helical Extension Spring for Static Load Using Genetic Algorithm

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Abstract

The cost of object is an important factor and it can be reducedby savingof material of the component and material saving depends on design. The objective of this paper is to design a helical extension spring by optimizing its weight using genetic algorithm (GA). Results obtained here shows that a great reduction in weight can be obtained without any influence on the performance of the spring.

***Keywords*—** Genetic Algorithm, Helical Extension Spring, Weight, *Engineering Design, MATLAB*

1. Introduction

Helical springs find their application every aspect of mechanical engineering. So a lot of attention has been paid to its design optimization.

G.Agrawal (1978) studied the design of helical spring for minimum weight by geometric programming. He obtained an explicit solution of the optimization problem and applied to a numerical example. Quimin et al (2007) used particle swarm algorithm and matlab to optimize the design of the helical spring.Vijayarangan et al used GA technique for the design optimization of leaf spring. He obtained the optimum value of the design parameters for minimum weight of the spring. Different methods of optimization algorithm, i.e. traditional and non-traditional, were proposed by Kalyanmoy Deb(1995). He presented the non-traditional algorithms with the help of numerical examples.Azarm et al optimized the helical spring with the help of consol-optcad and extended his work to the optimization of flywheel. Kolahan (2006) adopted the ant colony and simulated annealing optimization technique for the optimization of the design of a helical compression spring. Martikka(1985) used fuzzy design and FEM to obtain the optimal re-design of the helical spring. Parametrical optimization of compression helical springs against instability was done by Kruzelecki (1996). The volume of the spring, theinitial compression rigidity and also the slenderness ratio of thespring is considered as the equality constraints.

In Optimization, we find a solution with most effective performance under the given constraints and maximize the desire objective and minimize the undesired ones. In optimization we can obtain better results under certain circumstances. Optimization in design can be done with the help of different optimization techniques. In springs, design problem has large number of variables, equality and non-equality equations so traditional optimization techniques cannot solve these equations.

We can use nontraditional optimization techniques such as, genetic algorithm, particle swarm optimization, simulated annealing etc. In helical spring, we can optimize weight because it is a factor that directly affects the cost of the material, Material can be saved with the help of design optimization. Optimization techniques are able to obtain optimal or near optimal solution. An objective in optimization problem depends on our requirements and variables as well. For different problems we prepare a mathematical model and then use suitable technique. Constraints represent relationships among the design variables and certain resource limitations. Some bounds are also provided by designer for different variables according to available space.

The main objective of the work is to investigation use of genetic algorithm for optimization of helical spring for weight.

2. Genetic Algorithm

A genetic algorithm is a method for solving both constraints and unconstraint optimization problem based on natural selection. Algorithm is started with a set of solutions represented by chromosomes called populations.

0 1 0 1 0 0 0| 0 1 1 1 0 0 0 |1 0 1 1 0 1 0| 1 0 0 1 1 1 0

Figure 1Binary coding of a chromosome

In figure1,chromosome defined in binary form, 7 bits represents one variable and one chromosome represents four variables.

0 1 0 1 0 0 0

Figure 2 first seven bits presents one variable.

Size of population and number of populations depend on complexity ofthe problem. In starting all populations are randomly selected and if we decode those chromosomes of population directly than our variable values will not be in bounds, so another decoding formula is used for decoding, as[11] follows

$$d = \frac{(binary\ to\ decimal\ of\ \text{chromosome})}{(2^{\text{chromosome}length} - 1)}(H - L) + L$$

Where d is the decoded value, chromosome length is the number of bits in chromosome, H and L are higher and lover bound of that variable.

Selection is a process to select parents for crossing and that parents should have higher fitness value of populations. There are different methods for selection and there are more chances that high fitness value gets selected more than one time and worst valueis eliminated.

Crossover is the process of producing child from two pre-selected parents. Points required for crossing are selected randomly. Crossover may be done by a single point or multiple points.

0 0 1 1 1 0 1 (P1)	**0 0 1** 1 0 1 0 (C1)
1 1 0 1 0 1 0 (P2)	1 1 0 **1 1 0 1**(C2)

Fig. 3 Single point crossover

Where P1 and P2 are parents and C1 and C2 are children and here single point crossover is presented in fig. 3.Crossing produces new populations and that provides new solutions of objective.

Mutation applies after crossover and it prevents algorithm to be trapped in local minima, after some iterations populations become homogenous in algorithm. So in order to obtain optimal results, a requirement arises to find new populations. After mutation we decode populations and find optimum solution among all populations and then we can make changes in old populations. In all iterations theobjective will improve until optimal solution is obtained.

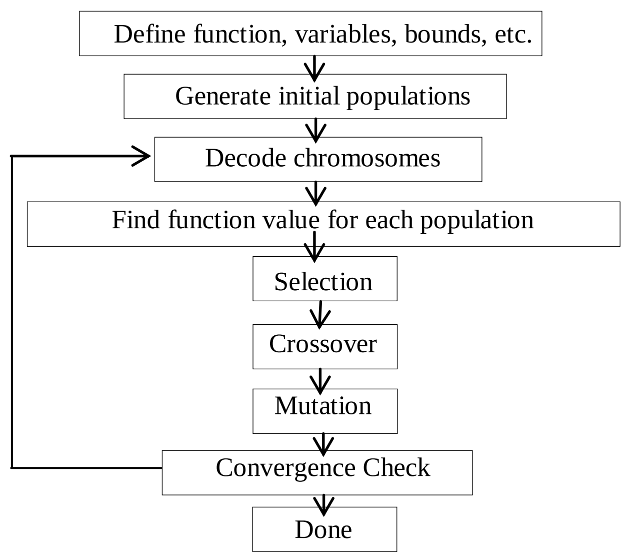

Fig. 4 Genetic Algorithm Flowchart

3. Problem Formulation

Before the use of genetic algorithm we require objective function and constraints. For helical extension spring, the objective is to reduce the weight and the variables are the wire diameter of helical spring d, coil diameter D and number of total coils in spring n_t, so the [12] function is

$$W = \rho \times N_t \times (\pi \times D) \times (\frac{\pi}{4} \times d^2)$$

Here ρ is the density of thematerial.

In spring design factor of safety should be more than 1.5 so

$$\frac{\tau_{allowable}}{\tau_{max}} > fos$$

$$or \quad \frac{\tau_{allowable}}{\tau_{max}} - fos > 0 \qquad \dots (1)$$

$\tau_{max} = \frac{8KF_{max}D}{\pi d^3}$,Wherek is Wahl correction factor.

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$$

Extension spring should have constant stiffness because it's used for maintaining constant force or measurement load so

$$k_{desire} = \frac{Gd^4}{8D^3 n} \qquad \dots (2)$$

k_{desire} - Desired stiffness, G is modulus of rigidity

Spring index $\left(C = \frac{D}{d}\right)$ also have some limitations so $C_{min} < C < C_{max}$and constraints are

$$C_{min} - \frac{D}{d} < 0 \dots (3)$$

$$\frac{D}{d} - C_{max} < 0 \qquad \dots (4)$$

Numerical Example:[13]

A helical tension spring is used in the spring balance to measure weights. One end of spring to rigid support while the other end is free carries the weight to measure. The maximum weight attached to spring is 1500 N and length of spring should be approximately 100mm.the spring index should be 6 to 8. The spring the spring is made of oil hardened and tempered steel wire with ultimate tensile strength of $1360\, N/mm^2$ and modules of rigidity is, $81370\ N/mm^2$. The permissible shear stress in the spring wire should be taken as 50% of the ultimate tensile strength. Design the spring. Density of material is $7.861 \times 10^{-6}\, kg/mm^3$, diameter of coil should be 35 to 50mm, and number of turns should be 15to 25.

If we use $d = x_1$, $D = x_2$, $n = x_3$, $N_t = n + 1$

$$f(x) = 19.39 \times 10^{-6}(x_3 + 1)x_2 x_1^2 \dots (5)$$

Factor of safety in problem is 2, so

$$g_{1(x)} = 0.356\frac{x_1^3}{x_2} \times \frac{1}{\left(\frac{4x_2 - x_1}{4x_2 - 4x_1} + \frac{0.615x_1}{x_2}\right)} - 2 \dots (6)$$

Spring index should be in 6 to 8, than constraints

$$g_{2(x)} = \frac{x_2}{x_1} - 6 \quad \dots (7)$$

$$g_{3(x)} = 8 - \frac{x_2}{x_1} \dots (8)$$

Stiffness should be 15 for accuracy in measurement

$$\frac{10171.25x_1^4}{x_2^3 x_3} = 15 \dots (9)$$

Maximum deflection should be about 100.

$$\frac{0.1474x_2^3 x_3}{x_1^4} = 100 \dots (10)$$

4. Results and Discussion

Table 1 Represents Data Selected For Genetic Algorithm

Selection type	Cross-over	Mutation Probability	d	D	n
Rolette Wheel	Single point	6%	6-8	35-50	15-25

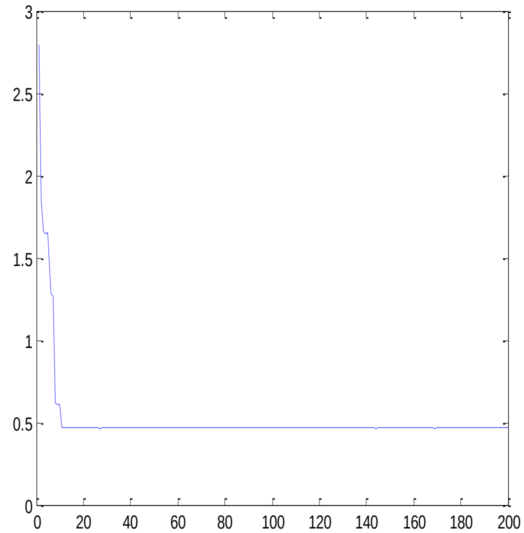

Fig. 5 Wight variation with iteration

Figure 5 represents the reduction in the weight of the spring with the increase in the number of iterations. The weight of the spring decreases as the number of iterations, of genetic algorithm optimization technique, increases i.e. up to around 16 but after that this value becomes stable. The minimum value that can be obtained is$0.4651 kg$.

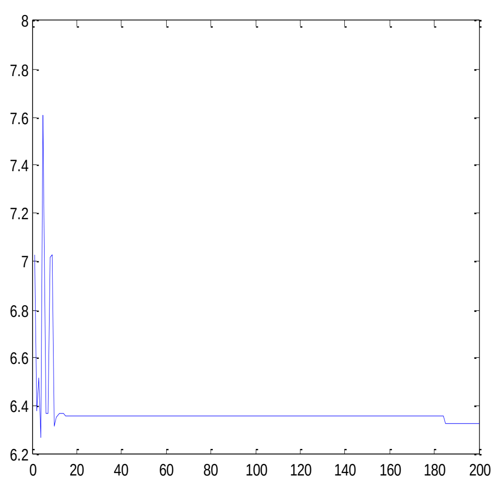

Fig.6 Diameter variation with iteration

Figure 6 shows the variation in the wire diameter of the spring with the increase in the number of iterations. The wire diameter of the spring varies as the number of iterations, of genetic algorithm optimization technique, increases but after 16 iterations this reduction becomes negligible. The optimum value that can be obtained is6.328 mm.

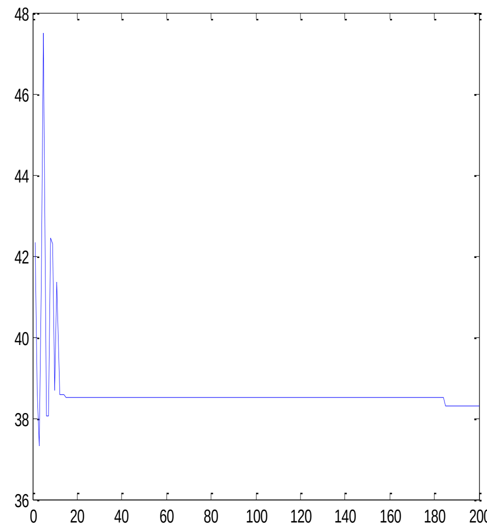

Fig.7 Mean coil diameter variation with iteration

Figure 7 represents the variation in the mean coil diameter of the spring with the iterations. The mean coil diameter of the spring varies as the number of iterations, of genetic algorithm optimization technique, increases i.e. upto around 16 but after that this value stabilizes to$38.2845\ mm$.

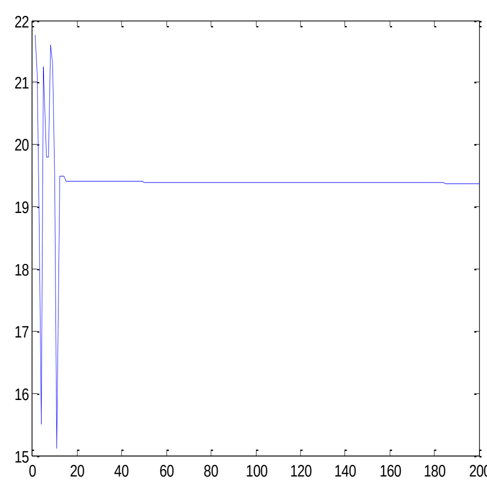

Fig.8 No. of turns variation with iteration

Figure 8 represents the variation in the number of turns of the spring with the increase in the number of iterations. The number of turns of the spring varies as the number of iterations, of genetic algorithm optimization technique, increases i.e. up to around 16 but after that this value becomes stable. The optimum value that can be achieved is19.3793.

Table 1 presents the comparison of the results obtained by the mathematical calculation, i.e. without GA, and those obtained by the optimization technique, with GA.

Table 2 Comparison of Results

	$d(mm)$	$D(mm)$	n	$weight(kg$
$Without$ GA	7	42	22	0.926
$With$ GA	6.328	38.2845	19.3793	0.4651

It can easily be noticed from the table a great reduction in the weight of the spring can be obtained, which is as high as 49.77%.

5. Conclusion

The objective of this paper is to minimize the weight of the extension helical spring. The design of the helical spring is optimized by using Genetic Algorithm optimization technique. The results obtained here show that, in comparison to mathematically obtained results, a very high reduction in the weight of the spring can be achieved using GA for the same performance characteristics.

So it can be concluded that by using genetic algorithm an optimum design of helical spring can be done.

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