International Conference on Mechanical, Industrial and Materials Engineering 2017 (ICMIME2017)
28-30 December, 2017, RUET, Rajshahi, Bangladesh.

Paper ID: IE-221

Weight Optimization of Helical Spring Using Genetic Algorithm

Shabnoor Mahmud Joty*, Md. Yasin Ali

Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, Bangladesh.
**E-mail: sm.tfs.sbn@gmail.com*

Abstract

The purpose of this paper is to design and optimize the weight of a helical spring using the genetic algorithm (GA). There are many optimization techniques used for optimization. Most of the methods consume too much computational time. Where genetic algorithm is an evolutionary algorithm that is faster than other approaches. The attention is focused on reducing the weight and stresses. On applying the genetic algorithm (GA), the optimum parameter of spring has been obtained with minimum weight. Matlab is used as the computing platform for running GA. The result shows that GA is very useful for single and multi-objective optimization of helical spring design problems. The weight can be significantly reduced by this technique in a short computational time. Helical spring is used in many applications so the requirement of minimum weight reduces the cost of the spring and fulfill the purpose of the spring without affecting the performance.

Keywords: Helical Spring, Weight Optimization, Genetic Algorithm.

1. Introduction

A spring is an elastic object used to store mechanical energy. Springs are usually made out of spring steel. Small springs can be wound form pre-hardened stock, while larger ones are made from annealed steel and hardened after fabrication. Some non-ferrous metals are also used including phosphor bronze and titanium for parts requiring corrosion resistance and beryllium copper for springs carrying electrical current (because of its low electrical resistance). When a spring is compressed or stretched, the force it exerts is proportional to its change in length. The rate or spring constant of a spring is the change in the force it exerts, divided by the change in deflection of the spring. That is, it is the gradient of the force versus deflection curve. [2] Depending on the design and required operating environment, any material can be used to construct a spring, so long as the material has the required combination of rigidity and elasticity. Both helical spring or coil spring and leaf spring are used in automobile industries. Helical spring has more versatile use. It is used as shock absorber and also rapidly used for automotive valves. Minimization of weight of helical spring will reduce the manufacturing cost as well as waste of material. Over a few years, a number of search and optimization techniques, drastically different on principle from classical methods, are getting increasing more alternation. These methods mimic a particular natural phenomenon to solve as optimization problem with the development of mathematical programming techniques for optimization and rapid advances made in computer hardware and software technologies; it is now possible to formulate engineering design problems as an optimization problem, with the objective of minimizing the cost or weight subject to satisfaction of all the conditions of design. The evolution strategies like Genetic algorithm, simulated annealing, fuzzy sets, and neural networks are major techniques of which genetic algorithms are the present topic of discussion. GA is a population based search and optimization technique. It is an interactive optimization procedure, instead of working with a single solution, in each iteration, a GA works with a number of solutions. [3]

2. Brief details of genetic algorithm

One of the most common evolutionary algorithms is the genetic algorithm(GA). Genetic algorithms are based on the mechanism of natural selection. They follow the standard iteration steps as evolutionary algorithms. They use binary or floating genes to represent design variables with fixed length. At each iteration, they use pairs of two genes with high fitness to generate new genes by crossover and mutation. The next population is selected in parent and children genes according to fitness. Through selection, crossover and mutation operations, better solutions are generated out of current population of potential solutions. This process continues until an acceptable solution is found.

GA is best applied for the problems where mathematical model is very complex and nonlinear and gradient based approach is very time consuming. [3]

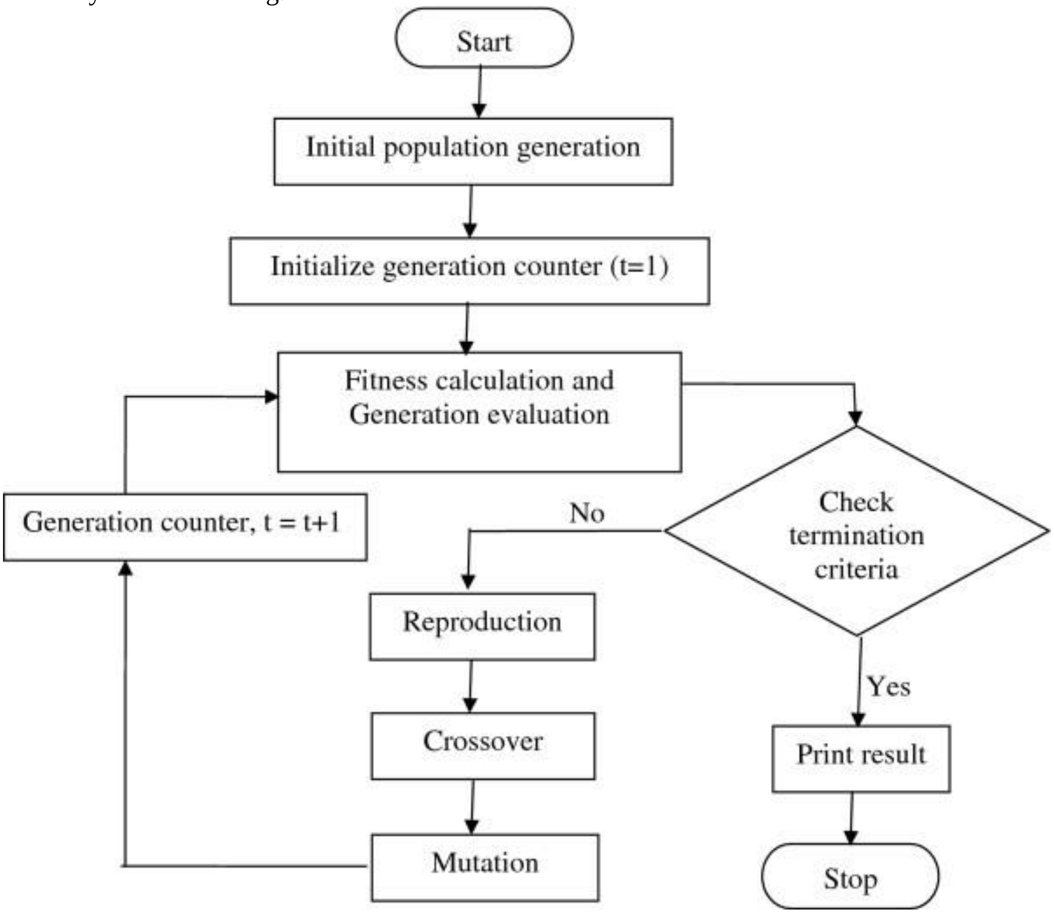

Figure 1. Flow chart of genetic algorithm [3]

3. Methodology

3.1 Design of Spring

A spring is a resilient member capable of providing large elastic deformation. A spring is basically defined as an elastic body whose function is to distort when loaded and to recover its original shape when the load is removed. Mechanical springs are used in machines and other applications mainly [1]

- To exert force,
- To provide flexibility
- To store or absorb energy.

Among the various springs helical or coil compression / extension springs are the widely used ones and hence discussions will be confined to the helical (coil) extension springs.

Formulas used for this design problem are given below [1,2],

Wahl's stress concentration factor,

$$K_w = \frac{4C+2}{4C-3} \quad (1)$$

Shear stress constant,

$$K_s = \frac{2C+1}{2C} \quad (2)$$

Shear stress,

$$\tau_a = \frac{8F_a D K_w}{\pi d^3} \quad (3)$$

Mean stress,

$$\tau_m = \frac{8F_m D K_s}{\pi d^3} \quad (4)$$

Active number of coil,

$$N = \frac{Gd^4}{8kD^3} \tag{5}$$

Stiffness,

$$k = \frac{(F_{\max} - F_{\min})}{\delta} \tag{6}$$

Minimum active working length,

$$L = Nd(1+a) \tag{7}$$

Where $F_a = \frac{(F_{\max} - F_{\min})}{2}$ and $F_m = \frac{(F_{\max} + F_{\min})}{2}$ and $C = D/d$, a = 0.4 [2]

4. The optimization problem formulation

The problem has to be formulated in a way that it can be solved by using optimization algorithms. Here GA is used so the problem formulation must follow the format of GA. In Matlab 2016b GA is a minimization algorithm. So for maximization in multi objective approach, duality principle has to be used. [4]

Three Matlab program is written. One for objective function, one for constraints and one for genetic algorithm using optimization toolbox.

The steps of GA procedure for this particular problem are given below,

4.1 Objective function

The objective of the problem is to find the minimum weight of the helical spring. The objective function $f(x)$ is defined as

$$f(x) = (\frac{\pi}{4} d^2)\rho N \pi D \tag{8}$$

Here, N is the active coil number, D is the mean diameter and d is the diameter of wire.

4.2 Design variables

There are some design variables in a machine designing problem. These parameters are sensitive and very important for designing. The basic parameters for design of this spring are given below,

Outer diameter, OD = 1.5 inch

Inner diameter, ID = 0.75 inch

Factor of safety = 1.44

Material used is ASTM A877 and the density, ρ = 0.284 lb\in^3

Operating force = 35 lb

Permanent compressive force = 5 lb

Maximum deflection, δ_{max} = 1.25 inch

Minimum number of coil, N_l = 3

Maximum weight, W_{max} = 0.18 lb

4.3 Design Constraints

The constraints are obtained from mathematical relationships of the parameters. Also there is a resource limitation for manufacturing a helical spring. [1,2] So constraints are very important.

The constraints for this problem is given below,

$$D + d \le OD \tag{9}$$

$$D - d \ge ID \tag{10}$$

$$6 \le C \le 12 \tag{11}$$

$$N \ge N_l \tag{12}$$

$$\delta \le \delta_{\max} \tag{13}$$

5. Result and discussion

All the constraints have satisfied. The minimum weight of the spring is obtained. Optimum diameters also have been found. The optimum solution is

Table 1. Optimized design parameters for helical spring

Material	ASTM A877
Density	0.284 lb\in^3
Active number of coils	3
Stiffness	120 lb/in
Mean Diameter	1.344 inch
Wire Diameter	0.157 inch
Optimized Wight	0.696 lb

6. Conclusion

In this paper, a design problem of automotive helical spring is solved. Matlab 2016b is used as a computing platform. The weight of the helical spring is minimized using genetic algorithm using Matlab optimization tool box. Helical spring design is a complex problem with nonlinear constraints. Gradient based mathematical approach is difficult for this type of problems. Genetic algorithm takes computationally less time than gradient based approach. Genetic algorithm can also be used for multi objective design optimization problems in helical spring design. In that case multi-objective genetic algorithm (MOGA) can be used to get optimized solutions for two or more objective functions.

7. References

[1] R.S. Khurmi, J. K. Gupta, (2005), “A Text Book of Machine Design”, pp. 80,824,855.

[2] Richard G. Budynas and J. Keith Nisbett, ninth edition, “Shigley’s Mechanical Engineering Design”, McGraw-Hill.

[3] Srinivas, N.; Deb, K. Muiltiobjective Optimization Using Nondominated Sorting in Genetic Algorithms. *Evolut. Comput.* 2007, *2*, 221–248

[4] P. Venkataraman, second edition “Applied Optimization with MATLAB Programming”, Wiley.