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Optimizing Design of Spring Using Genetic Algorithm

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Abstract

This paper deals with the elaborate design optimization technique of coil spring sets with genetic algorithm. Attention is focused on reducing the weight and stresses keeping into considerations the various critical points. The spring is designed to operate with tension load, so the spring stretches as the load is applied to it. The aim of the present work is to design the extension spring for various material like steel, stainless steel, music wire (High carbon steel), oil Tempered (High carbon steel) for same loading condition, since each material has different compositions and properties. Optimization of spring helps in selecting most appropriate and cost effective material for spring. On applying the GA, the optimum parameter of spring have been obtained, which contribute towards achieving the minimum weight. A reduction of 7% weight is achieved when stainless steel spring is replaced with other spring stated here, under identical condition of design parameters and optimization. Paper also discuss about the application and problem formulation using genetic algorithm which is one of nontraditional methods.

Keywords: Spring, Genetic Algorithm (GA).

Introduction

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 [1,2].

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.

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. 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.

The spring is design to introduce controlled flexibility by deflecting under applied loads. The current design aims is to minimize weight of spring as well as reduction of stresses for various materials.

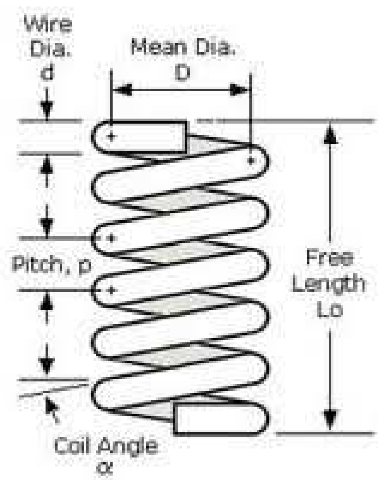

Fig a: Coil Spring

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Brief Details of GA

A Genetic Algorithm applies the principles of evolutions found in nature, to the problem of finding an optimal solution to a solver problem. In a GA the problem is encoded in a series of bit strings that are manipulated by the algorithm; also it uses the decision variables and problem functions directly. Most commercial solver problems are based on genetic algorithms [5]. A genetic algorithm for optimization is different from "classical" optimization methods in several ways:

Random Versus Deterministic Operation
Population versus Single Best Solution
Creating New Solutions through Mutation
Combining Solutions through Crossover
Selecting Solutions via "Survival of the Fittest",

GA is search algorithms that simulate Darwinian evolutionary generating a population of potential solutions to the problem and then manipulating those solutions using genetic operations. The solutions are typically represented as finite sequences drawn from a finite alphabet of characters. 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.

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

- *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. The basic formulize for design of this spring are given below.

Inner diameter is, Di=D -d
Outer diameter is, Do=D + d
Stress factor, K= ((4*D-d)/4*(D-d)) + (0.615*d/D)
Shear stress factor, Ks= (1+ (d/2*D))
Mean shear stress, tm = (ks*8*pmax*D)/ (3.14*d^3)
Variable shear stress, ta = (k*8*pm*D)/(3.14*d^3)
Endurance shear stress, ten= (2*ta)/ ((1/n)-((tm-ta)/ty)

Optimal Problem Formulation

The purpose of formulation is to create mathematical model of optimum design problem, which can be solved by optimization algorithm. Optimization problem must be formulated as per the format of the algorithm. The problem formulate for, optimal design of extension spring is proposed here. The various steps in the GA procedure are explained below:

A. Objective Function: The objective is to arrive at the minimum weight of the spring.

The objective function, *f (w)* identified for the study is given below:

$f(w) = \rho(\pi/4)\, d^2 n\pi D$

Where, ρ is the Density of material, *d* is the Diameter of coil spring; D is Mean Diameter and *n* is the Number of active coils.

B. Design Variables: The design problem usually involves many design parameters, of which, some are highly sensitive. This parameter is called design variables in optimization process. Design variables chosen for the present problem are: Load, Weight, Deflection, Coil Diameter, Material etc.

Design Load (W), Pmin, 300N & Pmax, 700 N
Maximum Deflection (∂), 30mm
Diameter of coil spring (d), 7mm
Mean diameter of coil spring (D), 43mm
Number of active coils (N), 10

C. Design Parameters: The design parameters are usually remain fixed in relation to design variable or it is independent of the design variables. The design parameters chosen for the design are, load W, material properties – (1) Density, ρ (2) Modulus of Rigidity, G (3) Maximum allowable stress, ta (4) Yield Stress, ty.

Design Constraints

The constraints represents some functional relationships amongst the design variable and other design parameters satisfying certain physical phenomenon and certain resource limitation in this problem the following are the design constraints.

Maximum endurance shear stress in a coil

$$\frac{2 * \mathrm{ta}}{(1/\mathrm{n} - ((\mathrm{tm} - \mathrm{ta})/\mathrm{ty})} \leq \mathrm{ten}$$

Outside diameter D+d <=Do
Inside diameter D-d<=di
Bounds limits
Dmin <= d<= dmax
Dmin <= D <= dmax
Nmin <= N <= Nmax
Maximum deflection allowable $\frac{8 * \mathrm{pmax\ D3N}}{\mathrm{G} * \mathrm{d}^\wedge 4}$<=0
Stress factor K= ((4*D-d)/4*(D-d)) + (0.615*d/D)
Mean shear stress tm= (Ks*8*D*pmax)/ (3.14*d^3)

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Table 1: Comparison of Stresses and Weight

Design parameters	Materials	ks	Stress (N/mm^2)	Weight (N)
D=43mm, d=7mm, ∂=30mm, P max =700 mm	Steel	1.24	275.86	5.205
	Music wire	1.24	272.41	5.205
	Oil Tempered wire	1.24	275.86	5.211
	Stainless steel	1.24	241.38	4.847

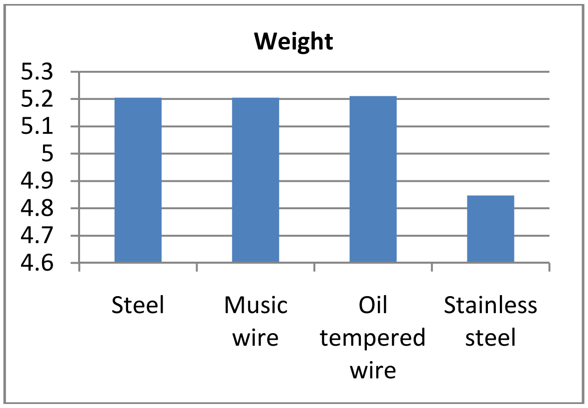

Fig b: Weight Vs Material

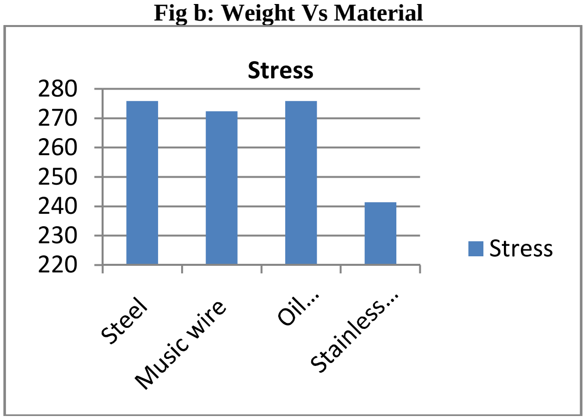

Fig c: Stress Vs Material

Conclusion

In the present work, the design parameters (Material, Weight) of Steel, Stainless steel, Music wire, oil tempered wire are optimized by making use of GA; a non-traditional optimization methods. So, it is advisable that application of GA in optimization of various design parameters can be used. When compared with other traditional method, it is observed that optimization using GA leads to time reduction as well as weight due to its search for global optimum as against the local optimum in traditional search method. These results are encouraging and suggest that GA can be used effectively and efficiently in other complex and realistic designs often encountered in engineering application.

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