International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 1 Issue 9, November- 2012

Optimization Of Spring Weight Using Genetic Algorithm

A. M. Satyanarayana**, B.** T. N. Charyulu**, C.** S. C. V. Ramanamurthy Naidu**, D.** G. Appala Naidu

1. Abstract:

Optimization is a technique through which better results are obtained under certain circumstances. The present work deals with the problem of weight minimization of Spring.

Spring problem has large number of multivariable and non-linear equations / in equalities. Hence traditional optimization techniques cannot be applied in these cases. Traditional optimization techniques have a possibility for the solutions to get trapped into local minima. Also the algorithm developed for one type of problem may not be suitable for another type of problem.

In this paper, a non traditional optimization technique, namely Genetic Algorithm is used. Optimal design of /Spring is solved using Genetic Algorithm. From the results obtained, it is observed that the optimum dimensions and weight obtained by GA are closer and they are much better than the values obtained by Consol-Opt cad

In the present study, weight minimization of a spring has been investigated. Powerful evolutionary algorithm (Genetic Algorithm) has been used to solve this problem.

A. M.Satyanarayana, Roll No.10A01D1505, NOVA College of Engg.& Tech.Jangareddigudem, W.G.Dist,A.P **Corresponding author, Email:satyamallapu@gmail.com,**
B. Assistant Professor, Department of Mechanical Engineering, NOVA College of E&T ,Jangareddigudem,W.G.Dist A.P
C. Professor, Department of Mechanical Engineering, KHIT, Guntur, A.P
D. G.AppalaNaidu,Roll No.10A01D1501 NOVA College of Engg.& Tech. W.G.Dist,A.P

Keywords: Optimization, Spring, Genetic Algorithm, Weight.

2. Introduction

Design optimization can be defined as the process of finding the maximum or minimum of some parameters which may call the objective function and it must also satisfy a certain set of specified requirements called constraints. Many methods have been developed and are in use for design optimization. All these methods use mathematical programming techniques for solutions.

In these cases it is difficult to apply traditional optimization techniques. Non-conventional techniques are applied to such cases. These are potential search and optimization techniques for complex engineering problems. Genetic algorithms are found to have a better global perspective than the traditional methods.

Dr. Shapour Azarm [1, 2] has worked on optimization of helical spring using consol-optcad and he extended his work to fly wheel using the same optimization procedure.

S.Vijayarangan, V.Alagappan [3] was applied Genetic Algorithm technique for machine component i.e. Leaf spring. By using Genetic Algorithm, the optimum dimensions of the leaf spring were found to be minimum weight with adequate strength and stiffness.

Kalyanmoy Deb [5] presented different types of optimization algorithms viz., traditional and non-traditional algorithms. Genetic and simulated annealing algorithms were explained with examples in non traditional algorithms.

Genetic Algorithms have good potential as optimization techniques for complex problems and have been successfully applied in the area of Mechanical Engineering. Popular applications include machine elements design, heat transfer, scheduling, vehicle routing, etc.

2.1. Optimal Problem Formulation

The objectives in a design problem and the associated design parameters vary from product to product. Different techniques are to be used in different problems. The purpose of the formulation procedure is to create a mathematical model of the optimal design problem, which then can be solved using an optimization algorithm. An optimization algorithm accepts an optimization problem only in a particular format. Figure 1 show the common steps involved in an optimal design formulation process. The first step is to realize the need for using optimization for a specific design problem. Then the designer needs to choose the important design variables associated with the design problem. The formulation of optimal design problems requires other considerations such as constraints, objective function, and variable bounds. Usually a hierarchy is followed in the optimal design process, although one consideration may get influenced by the other.

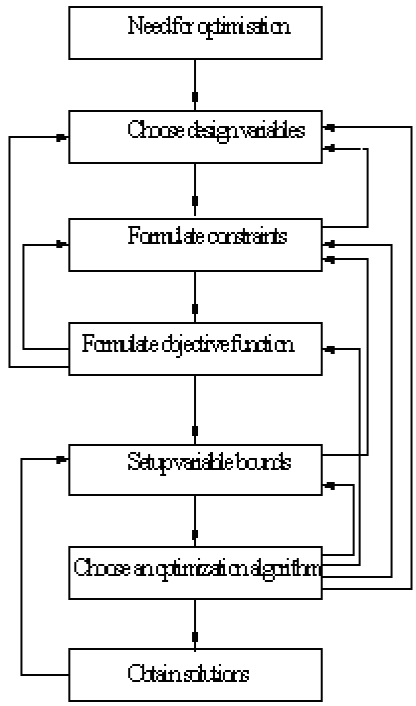

Fig.1 Flow chart for general Optimal design Procedure.

2.2. Design variables and Constraints:

The formulation of an optimization problem begins with identifying the underlying design variables, which are primarily varied during the optimization process. Other design parameters usually remain fixed or vary in relation to the design variables.

The constraints represent some-functional relationships among the design variables and other design parameters satisfying certain physical phenomenon and certain resource limitations. Some of these considerations require that the design remain in static or dynamic equilibrium. In many mechanical engineering problems, the constraints are formulated to satisfy stress and deflection limitations. Often, a component needs to be designed in such a way that it can be placed inside a fixed housing, there by restricting size of the component. The nature and number of constraints to be included in the formulation depend on the user.

There are usually two types of constraints that emerge from most considerations. Either the constraints are of an inequality type or of an equality type.

2.3. Objective function and Variable bounds:

The common engineering objectives involve minimization of overall cost of manufacturing or minimization of overall weight of a component or maximization of net profit earned or maximization of total life of a product or others. Instead the designer chooses the most important objective as the objective function of the optimization problem and the other objectives are included as constraints by restricting their values with in a certain range. The objective function can be of two types. Either the objective function is to be maximized or minimized.

The final task of the formulation procedure is to set the minimum and the maximum bounds on each design variable.

Certain Optimization algorithms do not require this information. In these problems, the constraints completely surround the feasible region. In general, all N design variables are restricted to lie with in the minimum and the maximum bounds as follows:

$X_i^{(L)} \leq X_i \leq X_i^{(U)}$ for i = 1, 2… N.

In any given problem the determination of the variables bounds $X_i^{(L)}$ and $X_i^{(U)}$ may be difficult. One way to remedy this situation is to make a guess about the optimal solution and set the minimum and maximum bounds so that the optimal solution lies within these two bounds. The chosen bound may not be correct. The chosen bound may be readjusted and the optimization algorithm may be simulated again.

3. Optimization Problem Format:

The optimization problem can be mathematically written in a special format, known as nonlinear programming format. Denoting the design variables as a column vector $X= (x_l, x_{2,\ldots\ldots\ldots}, x_N)^T$, the objective function as a scalar quantity f(X),

J, inequality constraints as $g_j(X) \geq 0$, and k equality constraints and $h_K(X)=0$;

Mathematical representation of the nonlinear programming problem:

Minimize f(X)

Subject to $g_j(X) \geq 0$, j= 1,2,………,J;

$h_K(X)=0$, k=1,2,………,K;

$X_i^{(L)} \leq X_i \leq X_i^{(U)}$, i =l,2,……….,N;

The constraints must be written in a way so that the right side of the inequality or equality sign is zero.

3.1. Optimization Algorithms.

Certain problems involve linear terms for constraints and objective function but certain other problems involve nonlinear terms for them. Some algorithms perform better on one problem, but may perform poorly on other problems. That is why the optimization literature contains a large number of algorithms, each suitable to solve a particular type of problem. The optimization algorithms involve repetitive application of certain procedures they need to be used with the help of a computer.

4. Working Principle.

When the simple Genetic Algorithms is implemented it is usually done in a manner that involves the following operators such as fitness proportionate,reproduction, crossover and mutation. The Genetic Algorithm begins with an initial population of size is equal to 10 (zeroth generation) of strings which consists of binary coding selected at random. Thereafter convert the binary coding in to decimal value and calculate the actual values of design variables with

International Journal of Engineering Research & Technology (IJERT)
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in their range by using mapping rule. Next calculates the value of objective function by substituting the design variables and thereafter violation coefficient (C) and the corresponding modified objective function is obtained.

This modified objective function is used to calculate the fitness values of each individual string and also calculate the average fitness value. First, the reproduction operator makes a match of two individual strings for mating, and then crossover site is selected at random with in the string length and position values are swapped between the same strings.

Finally the mutation is applied to the randomly selected strings. It is the random flipping of the bits or gene that is changing a zero to one and vice versa, so that the first cycle of operation is completed which is called as iteration. This iteration is termed as generation in genetic Algorithms. This new generation creates a second population (i.e. generation -1). This second population is further evaluated and tested for optimal solution which is obtained at zero violation and at the higher fitness value. Genetic algorithm is a population based search and optimization technique. It is an iterative optimization procedure. Genetic algorithm works as follows

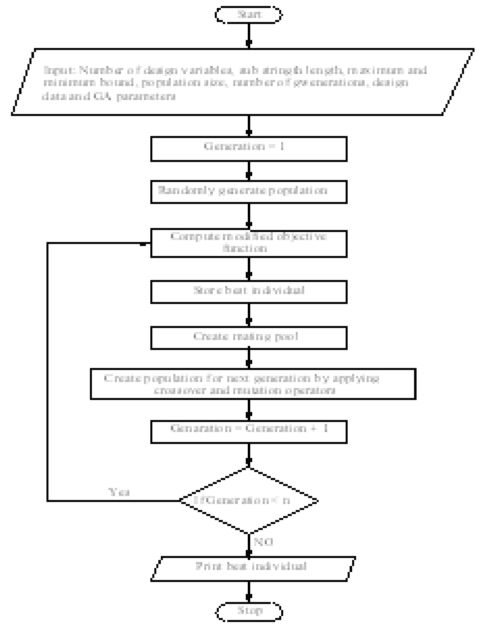

Fig.2. Flow chart of Genetic algorithm

5. Optimal Design of Spring.

5. 1 Introduction

Mechanical springs are used in machines to exert force, to provide flexibility, and to store or absorb energy. In general, springs may be classified as wire springs, flat springs or special-shaped springs and there are variations within these divisions. Wire springs include helical springs of round or square wire and are made to resist tensile, compressive or torsional loads. Cantilever and elliptical types belongs to flat springs, the wound motor or clock-type power springs, the flat spring washers are often called Belleville springs.

The main applications of the springs are as follows:

(i) To act as a reservoir energy, e.g. springs in clocks, toys or movie-cameras.

(ii) To absorb shocks and vibrations, e.g. vehicle suspension spring.

(iii) To return the mechanical part to its original position when it has been temporarily displaced, e.g. springs in valves, clutches and linkages.

(iv) To measure force, e.g. spring balance

In certain applications springs are designed with a specific objective such as minimum weight, minimum volume or maximum energy storage capacity. In such analysis only one objective is considered at a time for a given application. In this case consider the optimum design of a valve spring.

5.2 Objective Function

The objective function is to minimize the weight of the spring.

The weight of the spring is the sum of the weight of active and inactive coils.

$$\text{Minimum of } \frac{\pi^2 \rho}{4}(N+Q)Cd^3$$

N and Q are the number of active and inactive coils respectively.

Q is a constant and N depends on the spring gradient k.

Where k is defined as:

$$k = \frac{F_U - F_L}{\Delta} = \frac{Gd^2}{8D^3N}$$

So it can be written a

$$\text{Minimum of } \frac{\pi^2 \rho}{4}\left(\frac{Gdc^{-3}}{8k} + Q\right)Cd^3$$

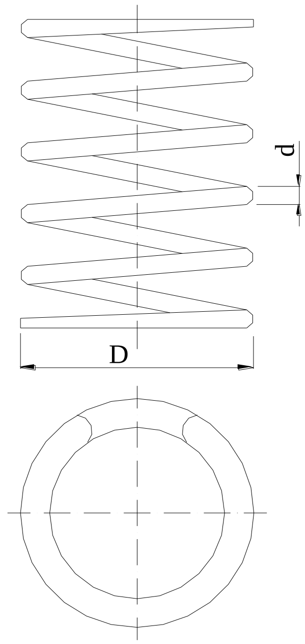

Fig.5.1 Helical compression spring

5.3 CONSTRAINTS:-

There are 11 constraints in this problem.

They are

5.3.1 Surging (g_1):-

If the spring is used in a high speed mechanism and a condition of resonance exists with the forcing function, large amplitude longitudinal vibration will result. This will appreciably affect the force exerted by the spring on the components of the mechanism also, such internal vibrations will significantly increase the maximum shear stress in the spring, possibly resulting in a premature fatigue failure. In a high speed mechanism the natural frequency of the spring is taken as 13 times the fundamental frequency of the applied force.

$f = 13\ f_{an}$

This requirement ($f_n \geq f$) is expressed as follows:

$$g_1: K_1C^{-1}d^2 \leq 1$$

Where

$$K_1 = \frac{Gf\Delta}{112800(F_U - F_L)}$$

5.3.2 Buckling (g_2):-

The critical length of spring is a function of boundary conditions and is normally presented graphically. An approximate equation to avoid buckling conservatively assuming both ends hinged is

$$L = Nd(1+A) \leq 11.5k\ \frac{d^2}{4F_u}$$

Where $N = \dfrac{Gd^4}{8D^3k}$

$g_2: K_2C^{-5} \leq 1$

Where $K_2 = \frac{GF_U(1+A)}{22.3k^2}$

5.3.3 Minimum number of coils (g_3):-

A lower limit on the number of coils must be imposed in order to obtain accuracy and control in manufacturing. A value of three is normally used as an absolute minimum but a larger value can be selected to keep the pitch angle small (Preferably 12^0-15^0). This requirement is

Where N= $\frac{Gd^4}{8D^3k}$

(5.3.3.2)

Substituting (5.3.3.2) into (5.3.3.1) and normalizing results to the constraint:

$g_3: K_3C^3 d^{-1} \leq 1$

where $K_3 = \frac{8kN_{min}}{G}$

5.3.4 Spring Index (g_4):-

The spring index (defined by C=D/d) must be bounded by a maximum number, I_U and a minimum number, I_L.

Experience indicates that extreme values are $I_L \geq 4$

$I_U \leq 20$

The corresponding constraints are:

$g_4: K_4C \leq 1$

$g_5: K_5C^{-1} \leq 1$

Where

$K_4 = \frac{1}{I_U}$

$K_5 = I_L$

5.3.5 Pocket Length (g_6):-

When space is limited, the length of a spring in its machine setting must be below an upper limit. The maximum length (L_m) at maximum force (F_u) is

$L+Qd \leq L_m$

Substituting (5.3.2.1) into (5.3.2.2) and normalizing gives

$g_6: K_6d^2C^{-3} + L_6d \leq 1$

5.3.6 Maximum Allowable Outside Diameter (g_7):-

Maximum allowable outside diameter, $\overline{OD}$

$$D+d \le \overline{OD}$$

or in normalized form

$$g_7: K_7 (Cd + d) \le 1$$

Where

$$K_7 = \frac{1}{\overline{OD}}$$

5.3.7 Minimum Allowable Inside Diameter (g_8) :-

Minimum allowable outside diameter, $\overline{ID}$

$$D-d \ge \overline{ID}$$

or in normalized form:

$$g_8 : C^{-1} + K_8 C^{-1} d^{-1} \le 1$$

Where $K_8 = \overline{ID}$

(5.3.7.3)

5.3.8 Upper and Lower on wire Diameter (g_9, g_{10}):-

The strength of the spring material is a function of the wire diameter. This relation was found for the given limits of the wire diameter for different materials.

$$g_9 : K_9 d^{-1} \le 1$$

$$g_{10} : K^{-1}_{10} d \le 1$$

5.3.9 Clash allowance (g_{11}):-

Stresses are limited by the spring solid condition. Therefore if the maximum working load approaches the spring condition, it is only necessary to provide sufficient clash allowance (i.e., the difference in spring length between maximum load and spring solid positions) to allow for any possible combinations of tolerance stack-up, differential thermal expansion and wear of parts. The usual recommendation is to provide a clash allowance of approximately 10% of the total spring deflection at the maximum work load.

$L_2 - L_s \geq 0.1\,\Delta$

$$\Delta = L_F - L_2$$

Where $\Delta = \frac{F_U - F_L}{k}$

$L_2 = [N(1+A)+Q]d$

$L_s = (N+Q)d$

$L_2 - L_s = NAd$

Constraint g_{11} in normalized form is

$g_{11} : K_{11} C^3 d^{-2} \leq 1$

Where $k_{11} = \frac{0.8(F_U - F_L)}{AG}$

The objective is to minimize the weight of spring is given by

Minimize

$$W = \frac{\Pi^2 \rho}{4} \{ \frac{G}{8K} dC^{-3} + Q \} Cd^3$$

Subjected to eleven constraints, Gi (X) ≤0,i=1,2,3…j

Where j=number of constraints =1 to 11

$G_i(X)$ can be written as

$$g_1: K_1 d^2 - C \leq 0$$

Where $K_1 = \frac{Gf\Delta}{112800(F_U - F_L)}$

G=79982 N/mm^3

f=500 Hz, Δ=6.35mm

Fu=133.4466N, Fl=80.06796 N

$g_2: K_2 - C^5 \leq 0$

Where

$K_2 = \frac{GF_U(1+A)}{22.3K^2}$,Clearance constant = 0.4

$g_3: K_3 C^3 - d \leq 0$

Where $K_3 = \frac{8KN_{min}}{G}$; $N_{min}=3$

$g_4: K_4 C \leq 1$

Where $K_4 = \frac{1}{I_U} = \frac{1}{20} = 0.05$

$g_5: K_5 C^{-1} \leq 1$

Where $K_5 = I_L = 4$

$g_6: K_6 d^2 C^{-3} + L_6 d \leq 1$

Where $K_6 = \frac{G(1+A)}{8KL_m}$

$L_6 = \frac{Q}{L_m}$ L_m= 31.75 mm .Q = 2.

$g_7 : C - K_7 d^{-1} + 1 \leq 0$

Where $K_7 = \frac{1}{OD}$

OD = 38.1 mm.

g_8: $K_8 d^{-1}$-C+10

Where K_8=ID=19.05 mm.

g_9: $K_9 d^{-1} \leq 1$

g_{10}: $(K_{10})^{-1} d \leq 1$

g_{11}: $K_{11} C^3 - d^2 \leq 0$

Where $K_{11} = \frac{0.8(F_U - F_L)}{AG}$

5.3.8. Optimal Design Model

Mathematical model for optimal design of spring is summarized as

Minimize $W = \frac{\Pi^2 \rho}{4} \{ \frac{G}{8K} dC^{-3} + Q \} Cd^3$

6. Results and Discussions

Subject to g_1: $K_1 d^2 - C \leq 0$ g_2: $K_2 - C^5 \leq 0$

g_3: $K_3 C^3 - d \leq 0$ g_4: $K_4 C \leq 1$

Method	C	d (mm)	W(N)
Consol-Optcad	9.56246	2.2248	0.09875
G A	10.032258	2.112903	0.089194

g_5: $K_5 C^{-1} \leq 1$ g_6: $K_6 d^2 C^{-3} + L_6 d \leq 1$

g_7 : $C - K_7 d^{-1} + 1 \leq 0$ g_8: $K_8 d^{-1}$-C+10

g_9: $K_9 d^{-1} \leq 1$ g_{10}: $(K_{10})^{-1} d \leq 1$

g_{11}: $K_{11} C^3 - d^2 \leq 0$

Optimal design of helical compression spring has been discussed by using Consol-Optcad and optimization capability of Genetic Algorithms (GA).

Two design variables and 11 constraints are considered in the helical compression spring problem. The results obtained for helical compression spring are shown in table A. It was observed that the optimum dimensions and minimum weight obtained by GA are better than the values obtained by the Consol-Optcad method.

Table – A:-Helical Compression Spring.

The minimum weight of Helical Compression Spring obtained by GA is reduced by 9.67 %, when compared to the weight obtained by Consol - Optcad solution**7.**

Conclusions:

Operation in Engineering Design is the past aimed at a Design problem with single objective function with single variable and with or without constraints. But here the code is used for the optimization of helical compression spring to minimize the weight. It is found that the results obtained by genetic algorithms are better, search space is wide and it aims at global optimum than that the local optimum as in a traditional method for the same input parameters.

It is found that the results obtained from genetic algorithms are less in weight as compared to consol opticad method.

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