LABVIEW BASED OPTIMAL DESIGN OF A HELICAL COMPRESSION SPRING AND ANALYSIS USING ANSYS

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Abstract

In this paper, a new method is tried to optimize the design of helical compression spring using LabVIEW with two objective functions, four control variables and each including six and seven constraints respectively. This work is completed in three phases. In the first phase the optimum design values are obtained from the LabVIEW models for minimizing the mass as first objective function and then maximizing the first natural frequency as the second objective function of the spring. In the second phase the spring is modeled in AutoCAD using AutoLISP program using the optimum design values obtained from the first phase. In the last phase the modeled spring is analyzed in transient structural environment using ANSYS workbench. The results are discussed and compared with previous literature.

Keywords: Circular helical compression spring, Mass of the spring, First natural frequency, LabVIEW, AutoLISP, ANSYS

1. INTRODUCTION

The spring is an important and unavoidable key component in many mechanical systems, devices, machines and products. The two important factors considered in designing of springs are cost effectiveness and product reliability. Mass and first natural frequency are influenced in optimal design of springs. Both mass and natural frequency of spring element are mutually dependent each other and they decided the structure of the spring system; they are most focused during the design process. Helical compression spring is one type of spring used in many applications. The design parameters of a solid circular helical compression spring as shown in Figure 1. During the design process for a real time situation the selection of spring design parameters are chosen numerically using various optimization methods. Most beneficial layout in a dynamic way for a cylindrical helical spring the usage of nature stimulated metaheuristic algorithms. Nature stimulated algorithms are characterized by means of easy awareness, high precision, and speedy convergence. They are computationally green and display superiority in fixing complex troubles [5]. The MATLAB integrates computation, visualization, and programming in an smooth-to-use environment [2]. It is a high-overall performance language for technical computing. In these paintings, dynamic version of the helical spring from literature [29] is taken into consideration for obtaining choicest values of design variables and goal characteristic based on MATLAB. Optimization strategies were broadly employed in mechanical designs, [1], [2], [3] considering that a few years. Researchers had solved many spring layout issues the use of exclusive algorithms [4]. They minimized the mass, volume, and pressure distribution, movements concern to numerous geometric and mechanical parameters. Kulkarni and Balasubrahmanyam [11] minimized the mass, the free length and the volume of a helical spring. Yokota et al. [12] minimized the mass of a helical spring considering the shear strain, range of energetic coils, spring wire diameter and center coil diameter the use of genetic set of rules. Deb and Goyal [13] and Kannan and Kramer [14] as compared their consequences primarily based on genetic algorithms with outcomes of Sandregen [15] primarily based on branch and sure strategies and augmented Lagrange approach. Imaizumi et al. [16] and Hernandez [17] optimized the twine form of spring. Xiao et al. [18] optimized helical spring primarily based on Particle Swarm Optimization algorithm. Minimum mass of helical spring changed into the goal feature, geometric parameters were design variables. Shear stress, most axial deflection, important frequency, bucking, fatigue strength, condition of coils not touch, area and measurement had been constraints. Kang and Kahraman [30] investigated dynamic behaviour of a double-helical tools pair each experimentally and theoretically. Fatih Karpat et al [31] used dynamic evaluation to examine traditional spur gears with symmetric tooth and spur gears with asymmetric enamel and optimized uneven tooth layout for minimal dynamic loads. Zheng Feng Bai and Yang Zhao [32] studied dynamic behaviour of planar mechanical structures along with revolute joints with clearance the usage of computational technique. Letícia et al [33] carried out FA set of rules to locate the pressure and placement of dampers to control man made vibrations on foot bridge. The following offers a short account on dynamic optimization of helical springs: Philips and Costello [19] derived the equations of motion describing nonlinear behaviour of springs when problem to large impact of oscillations. Stokes [20] conducted analytical and experimental studies to research the spring radial displacement due to longitudinal impact. Mottershead [21] advanced a finite element for solving differential movement equations. Yilidirim [22] developed the stiffness matrix for helical spring with circular and square sections from the linear courting between attempt and pressure, considering the effect of transverse shear. The resolution of the modal equation turned into made through subspace iteration method to decide the herbal frequencies of the spring. The influence of modifications of parameters including attitude of the helix, middle coil diameter changed into studied. Forrester [23] analyzed the static and the dynamic behaviour of the spring by means of finite element and analytical techniques to determine the stiffness and herbal frequencies of the shape taking into account curvature of the spring, effects of shear and geometric effects of spring segment. These methods had been based totally on solving differential equations with boundary conditions. In the first evaluation, the spring turned into modelled via an meeting of beam factors. In the second analysis, three-dimensional stiffness matrix of a helical spring turned into determined. Taktak et al. [24] advanced a node finite element with six stages of freedom consistent with node and modelled the behaviour of a 3 dimensional isotropic helical beam. Transverse shear and torsion outcomes and all geometric parameters were taken into consideration inside the observe of the dynamic reaction of the spring for harmonic excitations. Taktak et al. [29] optimized a cylindrical helical spring with dynamic constraints using Genetic Algorithm, included in

MATLAB code. However, for most useful spring layout, these kinds of researchers had used either conventional strategies or less efficient strategies. Also, nature stimulated algorithms which can be advanced and powerful are also now not used. These algorithms are extra perfect for fixing optimization troubles in real time programs [5], [6]. Hence, on this paper, it is proposed to use nature inspired algorithms, namely, Simulated Annealing (SA), Fire fly Algorithm (FA) and Cuckoo Search (CS) to obtain dynamic gold standard layout for a helical spring. This paper is based totally on [29] and the problem is solved in MATLAB environment. This paper presents a dynamic procedure to design a circular helical compression spring optimally.

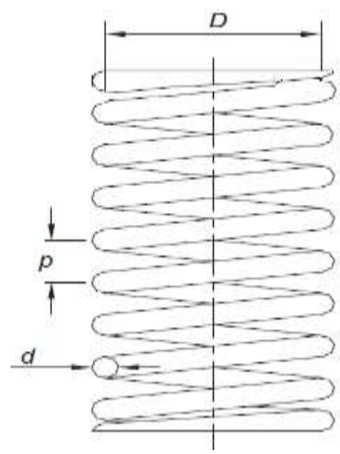

Figure 1 Design parameters of a Circular helical spring

2. DEVELOPMENT OF OPTIMAL DYNAMIC MATHEMATICAL MODEL OF HELICAL SPRING

A circular helical compression spring is considered in this work. Optimal, dynamic mathematical models are developed in LabVIEW. The model has design parameters variables ranging from minimum to maximum, objective functions, and dynamic constraints. The first objective function is to minimize the mass and the second is to maximize the first natural frequency. The LabVIEW model is developed to obtain the optimum design variables as result with the specified constraints. In first stage the ranges of the inputs are given from minimum to maximum with specified interval in LabVIEW model. The program will run till all the ranges for all the parameters are completed.

2.1 Design parameters

Designs parameters are variables are within the specified range describe the design of helical spring. The minimum and maximum values and the variation between each increase during the dynamic design process are controlled by the LabVIEW model. The objective function and constraints are expressed as function of the design parameters. In this work, four properties are taken as design parameters. They are: Circular wire diameter d, mean coil diameter D, active number of coils Na, and the pitch p. the other properties are assumed to be fixed.

Table 1 Design Parameters

Design Parameters	**Notation**	**Range**		**Units**	**Expressed in function**
		minimum	**maximum**		
Circular wire diameter	d	1	4	Mm	x_1
Mean coil diameter	D	10	30	Mm	x_2
Active number of coils	Na	5	50	-	x_3
Pitch	p	1	60	Mm	x_4

2.2 Objective function for mass

In this work, the circular helical spring is considered for the optimization of the design process. The first objective function is to minimize the mass of the spring. The mass of the helical spring can be presented as first case of study, can be expressed as function of design parameters is as follows: [29]. The design parameters are expressed in the function as shown in Table 1. The spring mass is expressed by

$$M = \rho_0 \frac{\pi d^2}{4} \sqrt{(\pi D)^2 + P^2}(n_a + 2) \quad (1)$$

$$M = \frac{\pi}{4} \rho_0 x_1^2 (x_3 + 2)\sqrt{(\pi x_2)^2 + x_4^2} \quad (2)$$

$$\min\ M(x) = 6283.185 x_1^2 (x_3 + 2)\sqrt{(\pi x_2)^2 + x_4^2} \quad (3)$$

2.3 Constraints conditions for minimize the first objective function

The following constrains are considered in this model. They are namely the conditions for shear stress, maximum axial deflection, fatigue strength, buckling, adjacent coils not touch and spring index. [29].

$$C_1(x): -R_{pg} + 4.23 F_{max} \frac{x_2^{0.84}}{x_1^{2.84}} \leq 0 \quad (4)$$

$$C_2(x): \frac{G \pi f x_1^4}{8 x_2^2 (x_3+2)\sqrt{(\pi x_2)^2 + x_4^2}} - F_{max} \leq 0 \quad (5)$$

$$C_3(x): \bar{S} - \frac{0.33 \sigma_B x_1^{2.84}}{4.23 F_{max} x_2^{0.84}} - 0.75 \frac{F_{min}}{F_{max}} \leq 0 \quad (6)$$

$$C_4(x): \frac{x_4 x_3 + 2 x_1}{x_2} - b_c \leq 0 \quad (7)$$

$$C_5(x): x_3(x_1 - x_4) + 0.33\,\frac{8F_{max}x_2^2(x_3+2)\sqrt{(\pi x_2)^2 + x_4^2}}{G\pi x_1^2} \le 0 \quad (8)$$

$$C_6(x): \frac{x_2}{x_1} - C_{min} - C_{max} \le 0 \quad (9)$$

Table 2 Mechanical and geometrical properties

Properties	**Notation**	**Value**	**Units**
Maximum amplitude of the frequency response	A_{33}	200	mm
Critical frequency	f_b	110	Hz
Maximum load	F_{max}	100	N
Minimum load	F_{min}	0	N
Maximum deflection	f_{max}	10	mm

Table 3 Constraint properties

Properties	**Notation**	**Value**	**Units**
Material	Steel		
Poisson coefficient	ν	0.3	–
Young's modulus	E	$2.1248\ 10^{11}$	N/m^2
Density	ρ	8000	kg/m^3
Shear modulus	G	83.10^9	N/m^2
Ultimate tensile strength	σ_B	2000	MPa
Allowable shear resistance	R_{pg}	6.10^8	N/m^2
Finesse ratio	b_c	3.7	–
Safety allowable factor	S	1.3	–

The mechanical and geometrical properties as shown in Table 2 and constraint properties as shown in Table 3 expressed in constraint equations they are expressed as follows. The labVIEW model is developed using the objective function from equation 2, and constraints from equation 4 to 9 explained in the next section.

$$C_1(x): -6.10^8 + 423\,\frac{x_2^{0.84}}{x_1^{2.84}} \le 0 \quad (10)$$

$$C_2(x): 32.594.10^7\,\frac{x_1^4}{x_2^2(x_3+2)\sqrt{(\pi x_2)^2 + x_4^2}} - 100 \le 0 \quad (11)$$

$$C_3(x): 1.3 - 1.56.10^6\,\frac{x_1^{2.84}}{x_2^{0.84}} \le 0 \quad (12)$$

$$C_4(x): \frac{x_4 x_3 + 2x_1}{x_2} - 3.7 \le 0 \quad (13)$$

$$C_5(x): x_3(x_1 - x_4) + 3.068.10^{-9} \frac{x_2^2(x_3+2)\sqrt{(\pi x_2)^2 + x_4^2}}{x_1^4} \leq 0 \quad (14)$$

$$C_6(x): \frac{x_2}{x_1} - 16 \leq 0 \quad - \quad (15)$$

2.4 LABVIEW Model for the Mass Optimization

The proposed methods for dynamic optimization of helical compression spring in LabVIEW environment for the first case are discussed here. The mass of the spring (M) can be minimized subject to the six constraints. In this method, the first objective function is to minimize the mass. The programme is run till all the constrained are satisfied and the corresponding design parameters are stored in an XL file. In the first phase, d starts from 0.001 and adding +0.0001 in the next iteration keeping D= 0.01, and Na = 5 and p= 0.001 constant. It goes up to 31 iterations (Range of d Minimum 0.001 to Maximum 0.004). In phase two, 61st iteration starts with d again from 0.0011 and adding +0.0001 in the next iteration keeping D= 0.01, and Na = 5 and p= 0.001 constant. It goes up to 60 iterations and so on. If all the eight constraints are satisfied the corresponding variables are stored for analysis. Likewise after completed all the iterations, iterative process will stop and solution for the problem will be displayed in the front panel. The complete algorithm runs with many phases. The total number of phases 3,554,460 and the total number of iterations per phase is 31. The number of generations required for solving the problem is a maximum of 32,258,000.

3. OPTIMIZATION OF THE FIRST NATURAL FREQUENCY USING LABVIEW MODEL

The natural frequency of the helical spring can be presented as second case of this work, by adding two more constraints along with the previous six constraints to optimize the natural frequency in the same method as in the previous optimization, by adding the two new constraints. The following constrains are considered in this model like frequency response and natural frequency. [29].

$$Max\ f_1(x): \frac{\pi}{4}\rho_0 x_1^2(x_3+2)\sqrt{(\pi x_2)^2 + x_4^2} - 0.03$$

$Max\ f_1\ (x)$ with

$$C_1(x): -R_{pg} + 4.23F_{max}\frac{x_2^{0.84}}{x_1^{2.84}} \leq 0$$

$$C_2(x): \frac{G\pi f x_1^4}{8x_2^2(x_3+2)\sqrt{(\pi x_2)^2 + x_4^2}} - F_{max} \leq 0$$

$$C_3(x): \bar{S} - \frac{0.33\sigma_B x_1^{2.84}}{4.23F_{max}x_2^{0.84}} - 0.75\frac{F_{min}}{F_{max}} \leq 0$$

$C_4(x): \frac{x_4 x_3 + 2x_1}{x_2} - \ b_c \leq 0$

$C_5(x): x_3(x_1 - x_4) + 0.33 \frac{8F_{max}x_2^2(x_3+2)\sqrt{(\pi x_2)^2 + x_4^2}}{G\pi x_1^2} \leq 0$

$C_6(x): C_{min} \leq \frac{x_2}{x_1} \leq C_{max}$

$C_7(x): A_{33} - 0.2 \leq 0$

$C_8(x) = f_b - f_i(x) \ \leq 0$

Auto LISP programe is created for the modeling of spring. The results from Lab VIEW modeling are exported in XL file. Using the selected design parameters required spring is modeled using AutoCAD with the command “springsns” created using Auto LISP program. The model is exported in ANSYS in the third stage, and the transient structural analysis is done and the results are analyzed. Exporting the solid model developed in AutoCAD imported in ANSYS. After meshing, the load is applied in various magnitudes ranging from 0 to 100 N in different time limits. The results are plotted in the form of table and graphs. The outputs are recorded and compared with the previous literature.

4. RESULTS AND DISCUSSION

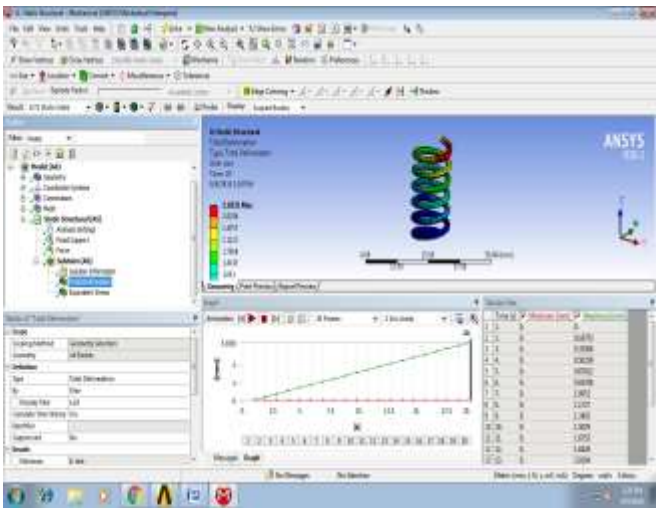

Figure 2 Deflection Plot in ANSYS

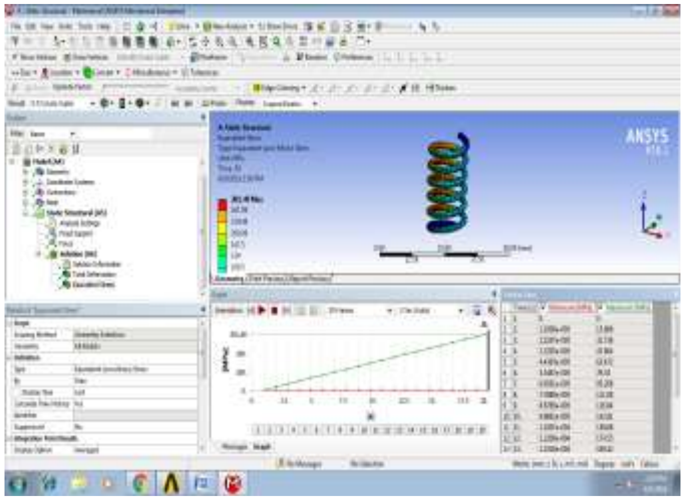

Figure 3 Stress Plot in ANSYS

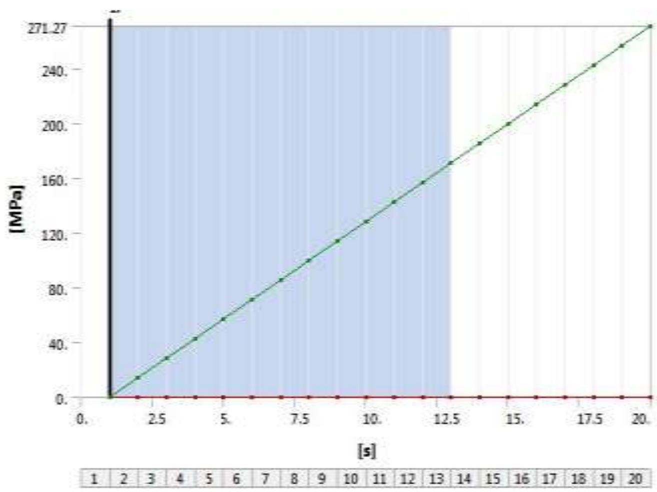

Figure 4 Stress plot

The optimized spring data are obtained from LabVIEW (circular wire diameter d, mean coil diameter D, active number of coils Na and pitch p), AutoCAD (Volume), ANSYS (deflection, stress) and the values are as given below.

Objective	d mm	D mm	Na	p mm	Volume mm^3	Deflection mm	Stress N/mm^2	Strain mm/mm
Minimization of Volume Spring1	2	13.5	5	6.4	673.74	3.1831	301.49	1.5088e-003
Maximize the first natural frequency Spring2	2.7	25.6	5.163	8.9	2391.9497	7.605	271.27	1.5379e-003

CONCLUSION

The LabVIEW is best suitable to optimize mass of the helical spring and its first natural frequency. All the possible design parameters satisfy all the constraints are displayed as well. AutoLISP is very easy to model all the possible designs and ready for analysis in ANSYS.
The following observations are noted:

- For computing most effective mass, LabVIEW model offers the best end result for computing most efficient mass and design parameters of the helical spring as follows: M=7.773 g; circular wire diameter d = 2mm, mean coil diameter D = 13.5 mm; active number of coils Na = 5 and pitch P = 6.4 mm.
- For computing most appropriate first natural frequency and corresponding design parameters, again FA offers the great result: f_1 = 53.323 Hz; circular wire diameter d = 2.7 mm; mean coil diameter D = 25.6 mm; active number of coils Na = 5.163; pitch P = 8.9 mm.
- Even right here, this method takes much less time to locate the optimized design parameters of run than other techniques found in other literature.
- Suitable for optimum design and rapid analysis for further validation.
- The proposed method is quicker and computationally more efficient than different processes of literature. Furthermore, this study can be used as reference for different comparable mechanical element ultimate designs.

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